THE UNIVERSITY OF HULL

Implicit Social Cognition in Autism Spectrum Disorder

Thesis submitted for the Degree of Doctor of Philosophy
in Psychology at the University of Hull

Sylwia Teresa Macinska, BSc

March 2019

Abstract

Implicit learning about people's states of mind relies inherently on associated emotions and affective valences, with abstract concepts such as disposition, attitude and intention being an intrinsic part of what is learned. Yet, similarly to studies aiming at the typically developed population, nearly all implicit learning studies on individuals with Autism Spectrum Disorder (ASD), are limited to the non-social domain, neglecting the possibility of domain-specific implicit learning impairments. Human behaviour is variable and complex and therefore detecting regularities in social interactions may be more challenging than in the physical world, which is largely governed by predictable laws.

This project employed a novel implicit learning paradigm to evaluate implicit learning abilities in the social and non-social domains in typically-developed individuals with varying levels of ASD traits and individuals with a clinical diagnosis of ASD.

The results revealed that impairments in implicit learning in ASD individuals emerge with respect to implicit social learning, with intact implicit learning abilities in the non-social domain. Deficits in implicit social learning were observed despite the participants' ability to correctly identify facial expressions, gaze direction and identities of the characters used in the studies. These findings extrapolated to typically-developed individuals high in ASD traits, suggesting a gradient of social implicit learning ability that runs throughout the population.

The relative contributions of three potential mechanisms underpinning implicit social learning were examined: (i) contingency learning *per se*, (ii) contribution of other cognitive processes such as memory for facial expressions and social attention, (iii) implicit affective tagging. The evidence suggests that individuals with ASD may be impaired in their ability to implicitly incorporate affective values into cognitive processing, supporting the implicit affective tagging hypothesis. I argue that ASD individuals use alternative strategies to comprehend others' minds, relying more on physical characteristics, rather than socio-emotional meaning.

Acknowledgements

First and foremost, I would like to thank my advisor Dr Tjeerd Jellema for his constant encouragement and insight. This work would not have been possible without your skilful guidance and support that allow me to develop as an independent researcher.

Special thanks go Dr Shane Lindsay for teaching me how to conduct eye-tracking experiments and analyse the data. To all members of the Psychology Department at the University of Hull, thank you for making my time at the university more enjoyable.

Thanks to all PhD students for a fun and productive atmosphere. My particular thanks go Manon Krol for all the help with recruitment of ASD individuals – it has been a great pleasure to work with you. I hope we will get to collaborate in the future. Thank you for your company and support. Thanks to Katie Oxtoby the ability to commiserate during those gruelling writing days and motivating talks.

And last but not least, I am grateful to my partner, Kuba Maruszczyk - your contagious enthusiasm, curiosity and encouragement brought much joy into this research process. Thank you for fruitful discussions that contributed to this work and your help in the creation of the musical stimuli. But most of all, for your unconditional love and support.

Figure 1 Word cloud of words most frequently occurring in this thesis.

Declaration

This thesis contains original work completed by myself under the supervision of Dr Tjeerd Jellema. The data presented in various parts of this thesis have been published or presented at conferences as follows:

Macinska, S.T., Krol, M. & Jellema, T. (2015). The capacity for implicit social learning in relation to autistic traits. In *EAPCogSci Proceedings.*

Macinska, S. T., & Jellema, T. (2016) 'Implicit Learning of Social and Non-social Information' *Fifth Implicit Learning Seminar*, Lancaster, UK.

Macinska, S. T., & Jellema, T. (2016). 'Automatic Processing of Affective Social Cues in individuals with and without Autism Spectrum Disorder' *BPS Cognitive Section Annual Conference*, Barcelona, Spain.

Macinska, S. T., & Jellema, T. (2017). 'Direct Gaze Advantage and the Role of Repeated Encounters in Memory for Facial Expressions' *20th Conference, European Society of Cognitive Psychology,* Potsdam, Germany.

Palumbo, L., **Macinska, S. T.**, & Jellema, T. (2018). The Role of Pattern Extrapolation in the Perception of Dynamic Facial Expressions in Autism Spectrum Disorder. *Frontiers in psychology*, *9*.

Contents

Chapter 1: Literature Review

As social species, humans routinely engage in a variety of social interactions by sharing intentions, interests, beliefs and feelings with one another. Through social exchanges individuals design systems of social rules and institutions within which they seek to operate and achieve a diverse set of social goals such as acquiring information, influencing others behaviour and maintaining emotional relationships. Integral to an individual's efficacy in navigating the social world is the ability to reason about the motivations, beliefs and affective states to predict the behaviour of others. This cognitive ability is often referred to as a *theory of mind* (ToM) or *mentalising* (Baron-Cohen, Leslie, & Frith, 1985; Premack & Woodruff, 1978). Individuals who lack the ability to comprehend others' mental states, as it is proposed to be the case in ASD, find it more effortful and distressing to navigate social interactions and adjust their behaviour accordingly to the demands of social situations (Baron-Cohen, 1995).

The processes through which humans achieve the understanding of others' minds are still highly debated in different disciplines, including psychology, social cognitive neuroscience and philosophy of mind. In particular, the contribution of automatic, implicit processes in making sense of social information in contrast to more deliberate, controlled and reflective mechanisms has been a recurring theme in the study of social interactions (Adolphs, 2009; Frith & Frith, 2008; Lieberman, 2007; Satpute & Lieberman, 2006).

This chapter provides an overview of the current theories on how social understanding is acquired, with a focus on the distinction between implicit and explicit mentalising activities. The special case of social understanding is considered in relation to ASD, with a discussion of how each of the proposed theories attempts to address impairments in social functioning observed in this population. The pivotal role of learning processes in the development of social cognition is then discussed. The final section of this chapter outlines the overall structure of the thesis and the research aims.

1.1 ToM: definition and function

ToM is the ability to infer the beliefs, motivations and affective states of others to anticipate behavioural responses (Baron-Cohen et al., 1985; Premack & Woodruff, 1978). ToM allows one to attach a meaning to the actions of others, providing explanations of observed behaviours. Without ToM, the actions of others would appear purposeless and chaotic, therefore the ability to reason about others' mental states creates structure in social interactions by attaching meaning to the behaviours of others. The outcome of ToM processing may not always be correct; however, it allows one to infer the approximate explanation for others' actions as well as to predict the most likely chain of events within a social encounter, reducing uncertainty and complexity inherent to social interactions. The prediction outputted by the ToM reasoning can be used to influence others' behaviour by managing information to be shared or adjusting own's reactions. However, this can only be achieved when one perceives the other's goals, desires and beliefs through the ToM ability.

The ToM ability develops continuously from infancy into adulthood. Wellman and Liu (2004) proposed that there are five key aspects of ToM, which develop sequentially between the ages of three to five. Firstly, children develop the understanding that others have (diverse) desires and beliefs, this is followed by the realisation that others have access to a different knowledge base than the observer, then the understanding that others can hold beliefs that are false and finally, that individuals are capable of hiding their emotions (Wellman & Liu, 2004).

ToM qualifies as a theory in the sense that the representations of mental states of others are not directly accessible, rather they have to be inferred. Byom and Multu (2013) distinguished three components of social interaction, which serve as informative clues to understanding others' minds: (1) perception of social cues, (2) knowledge of the shared context and (3) interpretations of actions (Byom & Mutlu, 2013). These components will be now reviewed along with the ToM tasks employed to investigate how they facilitate ToM operations.

Perception of social cues

One of the ways to understand others' minds is through the perception of social cues. Humans have been endowed with a sophisticated repertoire of expressive behaviours, such as dynamic facial cues and bodily gestures, which may trigger the attribution of others' mental states (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995; Bayliss, Griffiths, & Tipper, 2009; Bayliss & Tipper, 2006; De Sonneville et al., 2002; Hudson & Jellema, 2011; Hudson, Jellema, & Liu, 2009; Hudson, Nijboer, & Jellema, 2012). The causal relationships between specific cues serve as an input for the mental state attribution process.

The influence of gaze cues on inferring mental states of others has been studied extensively. Individuals automatically follow the gaze of others' (Bayliss & Tipper, 2006; Sato, Okada, & Toichi, 2007). Gaze cues signal one's attentional focus, be it oneself or another object/individual (Frischen, Bayliss, & Tipper, 2007), and by following the gaze of another person, an individual is able to infer their intentions and anticipate future actions (Baron-Cohen et al., 1995). Gaze cues seem to outweigh deceptive verbal cues (Freire, Eskritt, & Lee, 2004). While the attention of others can be to some extent discerned from the head orientation, the eyes are found to offer the most meaningful social cue, which is reflected in the preferential allocation of attention afforded to the eyes over other facial features (Bindemann, Scheepers, & Burton, 2009). The attention to the eyes has been proposed to facilitate the processing of face identity and the development of face expertise. However, the eyes are not only important for identity recognition but also for recognition of emotional expressions (Gliga & Csibra, 2007).

Facial expressions are a vital component in an observer's ability to understand the behaviour of others and together with gaze direction share a common social function in the information they convey. Facial expressions are displayed through the movement of the facial musculature into distinctive configurations, which provide information about emotional states of others (Burrows, 2008; M. Smith, Cottrell, Gosselin, & Schyns, 2005). Expressions are thought not to be a simple manifestation of an individual's internal state but serve to intentionally communicate specific information to others. The emotions conveyed through facial expressions inform about the stimulus that elicited the response, the expresser's internal mental state and anticipated action, and the expected response of the observer to the sight of the expression (Ekman, 1997).

Facial expressions can be identified easily from still images of others' faces (Baron-Cohen et al., 1995; De Sonneville et al., 2002; Ekman, Friesen, & Ancoli, 1980), even if the expressions are displayed subtlety (Thomas, De Bellis, Graham, & LaBar, 2007). One of the most popular tasks linking ToM abilities and face perception is The Reading the Mind in the Eyes task, which involves inferring a person's state of mind from a photograph of their eyes (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). Studies employing this task showed that even relatively complex emotional states can be inferred on the basis of others' eyes, implicating their importance in ToM operations. Typically, the ability to discriminate and perceive changes in facial expressions develops in infancy but the speed and accuracy with which children identify and match facial emotions continues to mature into adulthood (Barrera & Maurer, 1981; McClure, 2000).

Social cues are extremely informative with regards to inferring mental states of others. However, they are rarely judged in isolation. Rather, dynamic facial cues and bodily gestures are embedded in the context of social encounters.

Knowledge of shared context

The second component of social interaction, the knowledge of the shared context, refers to the appreciation of the context, in which mentalising activities take place. On-line understanding of another individual's mental state requires integration of the social cues expressed by the interaction partner with contextual information, such as prior knowledge about the individuals, goal of the interaction and the interaction setting. A common task designed to assess an ability to reason about mental states through the integration of shared world knowledge is the Strange Stories Task, in which participants are presented with short social scenarios, which describe a situation in which a person makes a statement that is not meant literally. For example, someone may be described as having a frog in the throat and the task is to figure out whether the statement is true and infer reasons for the use of the statement (Happé, 1994). The Strange Stories Task tests showed that individuals use contextual cues and prior knowledge of social interactions in order to understand several communication acts embedded in story situations, including faux pas, persuasion, pretending, and deception, and to accurately select the intended story interpretation.

<u>Interpretations of actions</u>

Another cue to understanding mental states are actions of others, other than facial expressions. Humans can infer the intentions of others through observation of their actions (Frith & Frith, 1999; Gallese & Goldman, 1998; Grafton & Hamilton, 2007), where action comprises a sequence of movements toward achieving a specific goal. Children as young as six months of age have been found to form expectations about human actions aimed to interact with other individuals as well as inanimate objects (Legerstee, Barna, & DiAdamo, 2000). Humans assume that actions of others tend to be consistent with their goals and beliefs (Ajzen, 1991; Heider & Simmel, 1944). As such, even passively observing others can offer clues needed to infer their intentions or beliefs.

A variety of tasks have been created to evaluate individual's abilities to interpret mental states from others' behaviour (Baron-Cohen et al., 1985; Luo, 2011; Scott, He, Baillargeon, & Cummins, 2012). One example of such a task is a false-belief task (Wimmer & Perner, 1983). In a standard false-belief task, participants view character (Sally) as she places a marble in a container and then leaves the room. Another character (Ann) then moves the marble to another container, before Sally returns. The question is where will Sally look for her marble? Through this simple manipulation, researchers examined a part of ToM ability that allows one to understand that the representations generated in the mind may not always be accurate and reflect the reality. Evidence suggests that children are able to pass the false belief task around the age of four, indicating that they are able to figure out a character's belief by simply observing their actions.

Social interactions provide valuable clues to understanding others' minds such as social, behavioural and contextual cues, which interact with one another to provide a rich input for mentalising activities. However, ToM reasoning tasks described in this section focus on measuring an explicit aspect of ToM, which involve deliberate consideration of others' mental states, with individuals constantly analysing the impressions of others and constructing theories based on their experience. More recent accounts of ToM postulate that there are two ToM systems: explicit and implicit (Apperly & Butterfill, 2009; Baillargeon, Scott, & He, 2010; Heyes & Frith, 2014; Low & Perner, 2012; Schneider, Slaughter, & Dux, 2017; Schuwerk, Vuori, & Sodian, 2015). A slow, cognitively demanding and deliberate ToM system has been contrasted with its fast, effortless, automatic counterpart, which develops early in life.

1.2 Explicit and implicit ToM

Explicit ToM refers to the ability to deliberate about mental states of others and reason about the origin of their behaviour. As in the case of false belief task, one can explain that Sally will look for the marble in the old location, because she did not witness Ann moving the object, and therefore, falsely believes it is still there. The explicit form of ToM can be flexibly employed in a variety of situations in a conscious manner, but it is cognitively demanding, therefore, its development coincides with the development of other cognitive functions. The explicit form of mentalizing is linked to the development of metacognition and language, which develop typically by the age of four to six years (Frith & Frith, 2012). Executive functioning such as working memory and inhibitory control have also been implicated in the ToM ability. The correlations between ToM and executive functioning typically persist when age, verbal ability, and other factors are controlled (for a recent meta-analysis see Devine & Hughes, 2014). Despite a seemingly close association between executive functioning and ToM, some components of ToM develop together with executive functioning (Carlson, Mandell, & Williams, 2004), whereas others develop independently (Qureshi, Apperly, & Samson, 2010). Development of executive functioning is not itself sufficient to produce improvements in ToM abilities, however, it seems necessary at least for the expression of more explicit forms of ToM (Korkmaz, 2011).

Whereas the heavily controlled ToM system may drive behaviour for complex mentalising activities, people may rely on implicit ToM system for simpler tasks. An implicit aspect of ToM processes operates fast, largely in an automatic manner, without the need for deliberate consideration of others' mental states and appears to developmentally precede an explicit ToM (Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010). Researchers used infants' looking time as a proxy for expectancy-violation (Luo & Johnson, 2008; Onishi & Baillargeon, 2005) and eye-tracking studies (Senju, Southgate, White, & Frith, 2009; Southgate, Senju, & Csibra, 2007) to evaluate mentalising abilities in early development. While infant and children under the age of four typically fail explicit ToM tasks, they show spontaneous sensitivity to others' goals, perceptions, and even false beliefs when tested in implicit ToM, with the implicit form of mentalizing is observed in infants by 7 to 15 months of age (Sodian, 2011).

Some of the evidence for implicit ToM comes from a modified version of the Sally-Ann false-believe task, in which no instructions are given to process the mental states of the characters, rather anticipatory looking behaviour is recorded using eye-tracking methodology (Southgate et al., 2007). Studies found that children and adults spontaneously look to the location of the target anticipated by the character holding a false belief, even without explicit instructions to do so (Schneider, Slaughter, Becker, & Dux, 2014; Schuwerk et al., 2015; Senju et al., 2009). Automatic tracking of belief of others has also been observed even when participants engaged in the primary, unrelated task and were unaware of ToM manipulations (Schneider, Bayliss, Becker, & Dux, 2012). In one study, participants had to indicate the location of the object on the computer screen with a mouse, whilst the character was holding either a true or false belief (van der Wel, Sebanz, & Knoblich, 2014). While one group of participants was explicitly required to concurrently track the belief of the character, the other group was not given any instructions with regards to the character's belief. Yet, results showed that the mouse movement parameters were influenced by the character's false belief, even in the implicit group.

Similar findings emerged in visual perspective-taking studies, in which participants simply have to judge the number of coloured dots displayed on a wall in the presence of another character (Furlanetto, Becchio, Samson, & Apperly, 2016; Qureshi et al., 2010; Samson et al., 2010). Importantly, participants are slower to report the number of dots, on the trials when the character sees a different number of dots, as compared to the trials when both participant and character see the same number of dots (altercentric inference effect). This suggests that the perspectives of others are processed automatically, regardless of whether there is an explicit objective reason to do so.

Although there is some evidence that implicit ToM can be modulated by top-down influences in some circumstances (Furlanetto et al., 2016; Palumbo, Burnett, & Jellema, 2015; Teufel et al., 2009), collectively the studies reviewed above provide evidence of implicit ToM processing, which operates in an unconscious and unintentional manner. It has been argued that it is the implicit aspect of ToM which is specifically impaired in autism spectrum disorders (ASD; Hudson et al., 2012; Jellema et al., 2009; Schuwerk et al., 2015; Senju, 2013; Senju et al., 2009).

.

1.3 ToM abilities in ASD

Features of ASD

Autism spectrum disorder (ASD) is a pervasive neurodevelopmental disorder of variable severity and heterogeneous phenotypes, which are characterized by qualitative impairments in social interaction and communication and restricted and repetitive patterns of behaviours and interests (DSM-V; American Psychiatric Association, 2013). Difficulties in social interaction are underpinned by impairments in recognising and understanding other people feelings and intentions, resulting in problems with forming relationships. ASD-individuals struggle with non-verbal communication, showing difficulties with using and understanding facial expressions, eye gaze and gestures. The features of

ASD are present throughout the lifespan. However, they may become less pronounced in adulthood due to the development of coping strategies, especially in those ASD-individuals with normal intelligence.

The spectrum ranges from very severe forms to milder manifestations of autism. Those on the lower end of the spectrum require a high level of support in their daily activities. This form of autism is typically referred to as low-functioning autism, which is associated with the absence of verbal language and with low intelligence. The autism spectrum diagnostic criteria have recently been expanded to include Asperger's syndrome (AS) - a milder manifestation of autism, which lacks general retardation in language and intellectual disability. However, individuals with AS still show deficits in social interaction and non-verbal communication along with repetitive and restricted patterns of behaviour.

There is some confusion in the use of the terms AS and high-functioning autism. High-functioning autism is an informal term often used to describe those on the milder end of the spectrum, whose expression of symptoms is less intense than in more severe form of autism and it is not marked by intellectual disability but still show motor impairments and a significant delay in the development of early speech and language skills, before the age of three years, which are absent in Asperger's syndrome. As such, individuals with AS manifest less severe symptoms, especially in early development, milder developmental course and a better prognosis.

<u>Do individuals with ASD have a theory of mind?</u>

Individuals with ASD may lack theory of mind (ToM) abilities, i.e. the ability to put oneself into someone else's shoes, to attribute epistemic mental states, such as beliefs, knowledge, thoughts, desires and intentions to oneself and others (Baron-Cohen et al., 1985, 1995). As a consequence, they may find the behaviour of others' confusing and unpredictable, as the deficits in ToM leave them with a degree of 'mindblindness', without the ability to infer emotional and mental states of mind and understand the communicative intention of other people (Baron-Cohen et al., 1999).

Experimental studies supported the notion of impaired ToM in ASD, with ASD individuals having trouble passing the false belief tasks (Baron-Cohen et al., 1985; Baron-Cohen, Leslie, & Frith, 1986; Leekam & Perner, 1991; Perner, Frith, Leslie, & Leekam, 1989; Swettenham, 1996), solving the strange stories test using mentalistic explanations (Happé, 1994; White, Hill, Happé, & Frith, 2009) and identifying mental states based on facial expressions (Baron-Cohen et al., 2001; Havet-Thomassin, Allain, Etcharry-Bouyx, & Le Gall, 2006; Turkstra, 2008), as compared to typically developed control individuals. However, developmental improvements in some of these tasks were observed, especially in those ASD individuals with higher verbal ability, who were able to pass explicit ToM tasks (Bowler, 1992; Happé, 1995; Joseph & Tager-Flusberg, 2004; Schuwerk et al., 2015; Senju et al., 2009). It has been argued that this could be due to compensatory learning strategies, which may to some extent alleviate explicit ToM deficit in ASD (Frith & Frith, 2012; Senju, 2013). Experience of social interactions potentially resulted in the development of non-mentalistic methods for figuring out others' minds.

In contrast, implicit measures suggest a persisting deficit in spontaneous and implicit ToM reasoning in ASD (Callenmark, Kjellin, Rönnqvist, & Bölte, 2014; Schneider, Slaughter, Bayliss, & Dux, 2013; Senju et al., 2009). In a classic Sally-Ann false-belief task typically-developed individuals more often look at the location without the object when Sally falsely believed it is there, compared when she correctly believed it was not there, while the ASD-individuals fail to show spontaneous looking in line with the anticipation of the false-belief congruent behaviour, even though their performance on explicit ToM was similar to that of control participants (Schneider et al., 2013; Schuwerk et al., 2015; Senju et al., 2009; Sodian, Schuwerk, & Kristen, 2015).

Further to this, studies showed that the lack in automatic belief tracking in ASD was persistent over the repetition of test trials (Schneider et al., 2013) unless a belief-corresponding action (perception-action contingency) is explicitly demonstrated (Schuwerk et al., 2015). The change in anticipatory looking behaviour was observed only when ASD individuals witnessed Sally actually searching for the object in the incorrect location. Therefore, the explicit knowledge about the sequence of events may have led to the improvement in anticipation of the false belief–congruent action. Such learning can occur without awareness of Sally's belief but on the basis of behavioural cues. However, it is important to note that any learning form the sequence of events would mean that association between the character's looking behaviour and subsequent action was formed. This further supports the notion that ASD individuals are sensitive to behavioural cues relevant for action prediction if they are presented explicitly.

A stark dissociation between explicit and implicit ToM abilities in ASD was also reported by Callenmark and colleagues (Callenmark et al., 2013). In this study, participants responded to the 'social-norm violation' rating questionnaire, which was administered either in a multiple-choice format (explicit task) or as an unstructured interview (implicit task). The results revealed similar performance on the multiple-choice questionnaire between typical and ASD-individuals, however, ASD-individuals performed more poorly on the implicit task, as compared to controls. These studies suggest that explicit reasoning about others' mental states can be achieved despite marked impairments in implicit ToM ability necessary for a spontaneous appreciation of others' minds. However, such effortful cognitive computations could have an adverse impact on the efficiency and effectiveness of ToM operations.

There is no doubt that navigating complexities of the social world would be challenging without an effective ToM. However, there are various explanations for how exactly the mentalising abilities are acquired. The most influential theories of ToM development are the Theory-Theory (Gopnik & Wellman, 1994; Wellman, Cross, & Watson, 2001) and Simulation Theory (Gallese & Goldman, 1998; R. M. Gordon, 1986).

1.4 How is ToM acquired?

Debate has focused on whether the ToM development is analogous to constructing a scientific theory as per the theory-theory account of ToM, which is closely related to cognitive aspects of mentalising, or whether ToM involves more intuitive ways of simulating what is taking place in another person's mind, i.e. the simulation ToM, which is linked to the direct, experiential, understanding of others' nonverbal behaviour, empathy and affective ToM. This distinction is thought to be reflected in distinct brain networks revealed in neuroimaging studies (the mentalising network versus the mirror neuron system, respectively).

Theory-theory (TT)

According to the TT account (Gopnik, 2003; Gopnik & Wellman, 1994, 2012), individuals collect evidence about the relationships between mental states, behaviour and environment, in the same way as scientists collect data to inform theory. On the basis of such data, attributions of others mental states can be made with the use of domain-general reasoning mechanisms. To the extent the observed evidence is inconsistent with one's current theory of mind, conceptual change will eventually occur. This indicates that relatively abstract theorising about third-person mental state attribution is purely inferential. Theories acquired through the interactions with the social world form a system of mental concepts, which are then used to infer mental states. The relationships between mental concepts and behaviour are constantly being updated, accounting for new evidence gained from social encounters, much as scientist refine their theories based on new data. Theory-theory account implicates a crucial role of experience in the development of ToM.

An alternative version of theory-theory account are modularity theories (Baron-Cohen et al., 1995; Leslie, Friedman, & German, 2004; Scholl & Leslie, 1999), which argue that development of ToM is determined by an innate neural mechanism specifically dedicated to mental state reasoning, which matures at pre-programmed stages (Leslie et al., 2004; Scholl & Leslie, 1999, 2001). According to this account, individuals are born with an initial level of mentalising knowledge that is part of their genetic endowment, rather than acquired through learning, and becomes triggered by appropriate environmental factors (Scholl & Leslie, 2001). ToM mechanisms rely on innate mental state concepts, which serve as examples of the equivalent mental states observed in humans and combined with a predisposition to attend to the properties of believing, desiring and pretending, allow children learn about mental states of others (Leslie et al., 2004; Scholl & Leslie, 1999, 2001).

Neural correlates of the mentalising framework

A plethora of neuroimaging studies aimed to isolate the underlying neural substrates of ToM. The core brain regions implicated in ToM seem to include medial prefrontal cortex (mPFC), precuneus/posterior cingulate cortex (PCC) and bilateral temporoparietal junction (TPJ), with the additional activation in other brain regions being more task-specific (Frith & Frith, 2006; Molenberghs, Johnson, Henry, & Mattingley, 2016; Van Overwalle & Baetens, 2009)

In particular, a recent analysis of 144 datasets revealed differences in implicit and explicit ToM tasks, which reliably activated unique brain areas (Molenberghs et al., 2016). While both implicit and explicit mentalising overlapped considerably in engaging core mentalising neural network, implicit tasks seem to impose greater demands on the right orbitofrontal cortex (OFC), supporting its role in automatic aspects of social cognition and possibly implicit reinforcement learning (Berridge & Kringelbach, 2013). On the contrary, greater activation was observed in TPJ for explicit inferential components of social understanding (Van Overwalle & Baetens, 2009).

Interestingly, the OFC was also consistently activated in relation to affective aspects of ToM; that is those that required an understanding of emotional mental states, so-called "hot" ToM. This was in direct contrast to cognitive aspects of ToM, "cold" ToM, which seem to correspond more to an explicit understanding of others mental states (Amodio & Frith, 2006; Saxe, 2006; Saxe & Wexler, 2005). These results indicate that implicit processes may be more relevant to affective ToM components, whereas more cognitive tasks rely on explicit processes (Molenberghs et al., 2016). Of course, implicit processes can contribute to the cognitive aspects of ToM, as it is the case in implicit visual perspective-taking. However, affective mentalising is more likely to involve implicit components.

Predictive Coding of Mental States

The theory-theory account of mentalising seems closely linked to the predictive coding framework, which was argued to be the basis for ToM processes (Frith & Frith, 2003). According to the Bayesian inference theories (Haker, Schneebeli, & Stephan, 2016; Musser, 2018; Otten, Seth, & Pinto, 2017; Pellicano & Burr, 2012; van Boxtel & Lu, 2013), which operate under the predictive coding framework, beliefs are the probabilistic representation of the particular state of the world, which are updated in the light of experience. In other words, children learn the properties of the environment through continuous interaction, implicitly building a model of the world based on their experience. New experiences can alter existing beliefs; the new observed data changes prior belief into posterior belief, i.e. the inference about the most likely cause behind the observed data, given previous knowledge. The posterior belief then becomes a new belief on which the future predictions are based. The difference between actual and predicted sensory input is referred to as prediction error and constitutes an approximation of surprise (Friston, 2010). The goal is to avoid prediction errors and minimise surprise to make one's environment more predictable (Friston, 2010). The probabilistic representation of the world cannot be, however, updated based on every single experience. Changes in belief are proportional to prediction error but are weighted by the ratio of the confidence in sensory input and prior belief (Haker et al., 2016). For example, if the confidence in sensory output (bottom-up information) is higher than confidence in current belief (top-down information), the higher the ratio of the confidence in sensory input and prior belief will be and therefore, the more pronounced change in belief will occur.

The Bayesian inference theories fit with recent accounts of the bi-directional relationship between sensory processing and ToM (Otten et al., 2017; Teufel, Fletcher, & Davis, 2010). The predictive processing framework suggests that existing social knowledge constrains predictions about the causes of current sensory inputs in the form of facial expressions, gaze or bodily gestures, etc. By combining prior believes with the actual sensory input, perceptual content is specified. Within such a framework, desires, goals, emotional states and individual social knowledge about others all have a potential to contribute to the perceptual predictions that are generated through the Bayesian inference (Otten et al., 2017). It is through these predictions that high-level social factors may directly shape perception. Such integration of bottom-up information provided by the sensory input and top-down influences of various contextual variables channelled by ToM has been termed ‘perceptual mentalising’ (Teufel et al., 2010). Research has shown that bottom-up perception of social stimuli can be modulated by both explicit (Furlanetto et al., 2016; Teufel et al., 2009) and implicit mental state attributions (Hudson, Liu, & Jellema, 2009; Palumbo et al., 2015).

The precision of Prior Beliefs in ASD

Recent Bayesian inference theories propose that ASD is characterised by an aberrant updating of the perceptual predictions about the world. Specifically, it has been argued that individuals with ASD tend to overly rely on bottom-up sensory information at the expense of top-down prior believes (Haker et al., 2016; Musser, 2018; Pellicano & Burr, 2012; van Boxtel & Lu, 2013). With decreased high-level processing in ASD, predictions about the world are presumably less precise than in typically-developed individuals (i.e., hypo-priors; Pellicano & Burr, 2012). This may potentially lead to a perceptual processing style dominated by detailed sensory aspects of the environment, with difficulties extracting the meaning (Haker et al., 2016). This explanation ties neatly with the weak central coherence theory of ASD, which postulates the processing of details at the expense of the global integration of information in ASD (Happé & Frith, 2006).

The disbalance between prior believes and sensory input in ASD may lead to an overfitted model of the world, which is dominated by sensory details but has low generalisability (Haker et al., 2016). As a result, a number of prediction errors (surprises) will be high in ASD, with even relatively predictable stimuli continuously perceived as surprising (Haker et al., 2016; van Boxtel & Lu, 2013). However, the problems are likely to be amplified in highly unpredictable environments, such as social interactions, which are governed by complex dynamic processes and irrelevant random features (Haker et al., 2016; Musser, 2018). Under the predictive coding framework, social inferences about others' emotions and intentions are just another type of inferences but made on the basis of facial expressions, gaze and bodily gestures (Hohwy & Palmer, 2014; Palmer, Seth, & Hohwy, 2015), in the context-bound social interactions. As such, the predictive coding framework provides a general account of ToM deficits in ASD, but also other perceptual peculiarities, such as detail-oriented processing or repetitive activities (van Boxtel & Lu, 2013). A lack of predictability can lead to anxiety problems, which are common in individuals on the spectrum. Many features of ASD, such as a preference for routine, can be seen as coping mechanisms; an attempt to make their environment more predictable and safer.

Although promising, predictive coding approach comes with several limitations (Musser, 2018). Firstly, it is not clear what aspect of Bayesian inference process is dysfunctional: inaccurate predictions, differences in sensory input, generation of the prediction error based on the two or failure to update the prior belief/too frequent updating of the belief. Additionally, if it were the predictions about the world that are inaccurate in ASD as some argue, the cause of this would need to be further explained. Secondly, individuals with ASD are capable of making inferences in some contexts, which may suggest that only some types of inferences are affected in ASD. Thirdly, issues with predictive coding may be a result, rather than a cause of social difficulties seen in ASD, as it has been argued that much predictive coding capabilities are developed through social interactions.

Simulation of others' minds

Simulation approach implies imagining oneself in another's person position as if directly experienced. ST suggests understanding others is not achieved through conscious theorising about others' mental states. Rather, an individual's own mental and/or motor apparatus is used to form explanations of someone's behaviour by putting themselves in their position and simulating them. While many varieties of ST exist, what they all have in common is that simulation acts as a very effective device for reasoning others' mental states.

ST explains the extended developmental trajectory of ToM abilities from the early understanding of simple social cues to later success on more complex ToM abilities. Goldman (2006) proposed a distinction between low-level and high-level mindreading. The latter is an imagination-driven simulation, related closely to the attributions of propositional attitudes, such as desires and beliefs (Goldman, 2009; Goldman, 2006). The low-level simulation, on the other hand, focuses on explaining simpler mental states such as attribution of face-based emotion or motor intention. The low-level simulation is supported by an automatic and unconscious simulation, which can be viewed as an elaboration of a primitive automatic mental/motor mimicry, therefore, it is thought to develop early in life (Goldman, 2009).

Low-level mindreading is closely related to embodied simulation account (Gallese, 2001, 2007), which follows theories of embodied cognition emphasising the way cognition is shaped by the sensorimotor interaction of the body with the social environment (A. Clark, 1998). According to Gallese (2007), humans are equipped with an automatic mechanism enabling understanding of others' minds in a direct, immediate way, without explicit consideration. By means of embodied simulation, neural mechanisms used in the production of own behaviour are activated when an action, emotion or sensation is observed. As such, ToM is achieved through 'experiential understanding' in the process of activation of neural circuitry present in perception, emotion and action. The aforementioned neural mechanism responsible for the direct understanding of others' mental states has been termed the Mirror Neuron System (MNS; Rizzolatti & Craighero, 2004).

Mirror Neuron System

The *mirror neuron system* (MNS) comprises of a special class of motor neurons, first discovered in macaque monkeys, which were found to discharge not only when an action is executed but also when the observer perceives the identical (or similar) action (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). Results from later studies suggested the existence of the MNS in humans (Buccino et al., 2001; Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Grafton, Arbib, Fadiga, & Rizzolatti, 1996; Kilner, Neal, Weiskopf, Friston, & Frith, 2009). The discovery of mirror neurons led to a proposition that they allow one to understand the mental states of others through automatic simulation of their actions/emotions. That is, individuals are capable to infer the goals and intentions of others through the internal matching of action representations of others' actions ('mirroring') with action representations in their own action repertoire (Rizzolatti & Sinigaglia, 2010). The mirror neurons support simulating others' mental states by facilitating direct mapping between actions and emotions of others to oneself (direct mapping hypothesis). The observed action (or emotion) is simulated in the mirror neurons without the need to interpret the action. The observer achieves the understanding of the goal or intention of the action by attributing to another his 'experienced' goal or intention as if he would be performing the action himself (Rizzolatti & Fabbri-Destro, 2008). Importantly, in macaque monkeys, mirror neurons were found to respond exclusively to goal-directed actions, and not to the observation of simple movements, which fails to activate the MNS. However, in humans, pantomimed action activates the MNS as well.

Neuroimaging studies revealed the existence of two main networks with mirror properties: parietofrontal mirror system and limbic mirror system (Cattaneo & Rizzolatti, 2009). Parietofrontal mirror system resides in the parietal lobe, the premotor cortex and the caudal part of the inferior frontal gyrus. Parietofrontal mirror system is engaged when performing and observing goal-directed actions, enabling the automatic understanding of actions based on sensory information alone (Coricelli, 2005; Iacoboni et al., 2005; Keysers & Gazzola, 2007; Rizzolatti & Craighero, 2004). The limbic mirror system is formed by the insula and the anterior mesial frontal cortex and it is involved in recognition of emotions, activating when emotions are both experienced and observed. Such 'emotional sharing' of others' emotions has been argued to act as a prerequisite for empathy (Frith & Frith, 2012).

The existence of MNS is rarely contested, however, its involvement in ToM processes is questioned. For example, according to the action-reconstruction hypothesis others' actions are anticipated by the MNS through top-down processes and MNS does not merely act in response to bottom-up visual input (Csibra, 2008). This would suggest that MNS is engaged as a consequence of mentalising activities and not as the source. The latest research on the topic found that the onset of the MNS activity was indeed observed prior to the onset of observed actions but only those that were predictable, and not to those actions that were unpredictable, suggesting top-down modulation of MNS activity by conceptual knowledge (Krol, Schutter, & Jellema, 2018).

Role of Simulation in Emotion Perception

The sensorimotor simulation discussed above was particularly implicated in perception and recognition of emotional states of others. Numerous studies show that perception of another person's emotional state leads to a sensorimotor simulation, in which individuals recreate the motor production of the perceived facial expression in themselves (Korb, Grandjean, & Scherer, 2010; Krumhuber, Likowski, & Weyers, 2014; Pawling, Kirkham, Hayes, & Tipper, 2017; Sato, Kochiyama, & Uono, 2015; Schilbach, Eickhoff, Mojzisch, & Vogeley, 2008). This unconscious activity is then argued to trigger other neural systems involved in experiencing the corresponding emotion, from which the expresser's internal state is inferred (Niedenthal, Mermillod, Maringer, & Hess, 2010; Wood, Rychlowska, Korb, & Niedenthal, 2016). Studies showed that mimicry of facial expressions can modulate emotion experience in the observer (Price & Harmon-Jones, 2015). Amplification of feedback from facial muscles can enhance the emotional experience (Lee et al., 2013), while inhibition of facial movement can reduce its intensity (Davis, Senghas, Brandt, & Ochsner, 2010). Further to this, it has been found that muscle mimicry of prior emotional states can be triggered when individuals are encountered at a later time, even if the emotional state is no longer expressed (Pawling et al., 2017).

The activation of the perceived emotional state in the observer was postulated to serve as a mechanism for accurate facial expression recognition (Niedenthal et al., 2010), a notion supported by a number of studies (Ipser & Cook, 2016; Oberman, Winkielman, & Ramachandran, 2007; Ponari, Conson, D'amico, Grossi, & Trojano, 2012; Rychlowska et al., 2014). The tendency to imitate perceived emotional expressions may facilitate social understanding and allow one to vicariously learn, which stimuli and behaviours are desirable and which are threatening (Niedenthal & Brauer, 2012). It has been argued that sensorimotor simulation may not only support recognition of current emotional states of others but also formulate expectations of future actions and emotions of others (Hudson, Nicholson, Simpson, Ellis, & Bach, 2016; J. Kaufman & Johnston, 2014; Palumbo & Jellema, 2013).

'Broken Mirror' Hypothesis of ASD

It has been argued that ASD individuals suffer from impairments in the MNS (Dapretto et al., 2005; Oberman et al., 2005; Rizzolatti, Fabbri-Destro, & Cattaneo, 2009), a hypothesis termed as the 'broken mirror' hypothesis (Ramachandran & Oberman, 2006). According to this theory, the dysfunction of the MNS constitutes a primary reason for atypical social skills in ASD.

Numerous behavioural studies investigated imitation abilities in ASD in an effort to measure MNS function, with mixed results. Researchers found abnormal imitation behaviour in individuals with ASD, reporting less frequent spontaneous imitation (Charman et al., 1997; Ingersoll & Gergans, 2007) and reduced imitation accuracy (S. J. Rogers, Bennetto, McEvoy, & Pennington, 1996; Vivanti, Nadig, Ozonoff, & Rogers, 2008) but sometimes also increased imitation as in echolalia (meaningless repetition of another person's spoken words). At the same time, several studies revealed intact imitation and understanding of action goals ASD (Aldridge, Stone, Sweeney, & Bower, 2000; Bird, Leighton, Press, & Heyes, 2007; Carpenter, Pennington, & Rogers, 2001; Hamilton, Brindley, & Frith, 2007). There is some evidence that individuals with ASD show reduced spontaneous imitation as opposed to that guided by instruction (Ingersoll & Gergans, 2007). Hamilton (2013) argued that poor imitation skills in ASD may not necessarily reflect dysfunction in MNS, rather they may relate to problems with visual processing, control of responding or motor performance and it is difficult to discern between those competing explanations (Hamilton, 2013).

Similarly, neurophysiological data fail to clarify whether MNS responses are intact in ASD. Abnormal MNS responses to emotional stimuli have been found in

ASD (Dapretto et al., 2005; Grèzes, Wicker, Berthoz, & De Gelder, 2009; Perkins, Stokes, McGillivray, & Bittar, 2010), including atypical spontaneous facial mimicry of emotional expressions (Beall, Moody, McIntosh, Hepburn, & Reed, 2008; McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006; Oberman et al., 2005; Yoshimura, Sato, Uono, & Toichi, 2015). On the contrary, the ASD mirroring mechanisms seems to be functional for goal-directed actions (Dinstein et al., 2010; Grèzes et al., 2009; L. E. Marsh & Hamilton, 2011). These results suggest that MNS functioning specifically in relation to emotion-triggered imitation may be impaired in ASD.

It has been argued that abnormal activity in MNS in ASD during emotional tasks (Dapretto et al., 2006; Grèzes et al., 2009) can be a consequence of the failure of emotional cues to modulate the MNS (Hamilton, 2013; Wang & Hamilton, 2012). There is some evidence that it may be the failure to modulate mimicry/imitation rather than dysfunction in MNS per se that is the root of social difficulties in ASD (Cook & Bird, 2012; Grecucci et al., 2013). For example, individuals in ASD failed to adjust their imitation behaviour following the priming with prosocial sentences, which was evident in the typically developed group (Cook & Bird, 2012).

In summary, the 'broken mirror' hypothesis is unlikely to provide a fundamental explanation of social cognition in ASD. However, further research is required to verify if ASD individuals indeed fail to modulate imitation, especially in relation to affectively valenced stimuli.

The interplay between simulation and theory-driven ToM

Evidence in support of the different explanations of how ToM is acquired led to the proposition that social understanding is derived through the interplay between simulation and theory-driven ToM, with each serving somewhat different function (Apperly, 2008; Keysers & Gazzola, 2007; Mitchell, 2005; Thioux, Gazzola, & Keysers, 2008). Simulation processes may facilitate the automatic and implicit attribution of others' intentions or emotions, forming primary representations of others' mental states, through which one can understand *how* and *what* others' do.

The subsequent theory-driven processes may then use these simulated representations, which can later be interrogated by more deliberate mentalizing systems to reflect on *why* the action was undertaken (Keysers & Gazzola, 2007). According to this account, simulation acts as an input for the theorising processes. A similar idea was proposed by Lieberman, who argued that there exist two systems, which operate in tandem to reach understanding of others' mental states: a reflexive X system, which is supported by simulation processes and a reflective C system, which is supported by mentalising activities (Lieberman, 2003, 2007). The X system operates pre-attentively generating expectations on the basis of the sensory input. Consciously controlled C system can then mediate or even supersede such expectations if deemed appropriate. With experience, the situations that require reflective system C, may become more automatic and eventually processed by the X system (Satpute & Lieberman, 2006). This dual system description of ToM is corroborated by the neuroimaging evidence showing that the MNS is implicated in automatic social cognition and the conscious mentalising system is engaged during controlled social causal attribution (Spunt & Lieberman, 2013).

However, the two systems do not operate in isolation; simulation can be modulated by the top-down processes and engaged in a conscious manner (Coricelli, 2005). At the same time, reasoning about others' mental state makes use of the same mechanisms as when deliberating own mental state (Uddin, Iacoboni, Lange, & Keenan, 2007). It is likely that individuals use a mix of strategies to figure out other people's minds (Apperly, 2012). Rather than continuing the debate between simulation or theory-based mentalising as a means to understand mental states, a more fruitful approach is to determine in which context one is employed over another and why (Mitchell, 2005). Current evidence suggests that simulation-based judgements may be more relevant for implicit and affective components of ToM processing, which are heavily influenced by the salience of the individual's own beliefs, are less flexible but cognitively efficient and appear earlier than the rule-based mentalising judgments, related to the theory-driven ToM (Mitchell, Currie, & Ziegler, 2009).

1.5 Learning processes in social cognition

ToM activities implicate the involvement of learning processes. In order to be able to reason about others' mental states, one needs to make active use of a 'social knowledge base' acquired through learning experiences. Mentalising implies the use of prior knowledge. For example, according to the predictive coding account, the events are evaluated by calculating the balance between prior beliefs and sensory input. Consequently, one's beliefs need to be acquired through the experience of their environment, which necessitates intact learning mechanisms. Similarly, simulation of others is argued to lead to the activation of associated concepts within one's own mental repertoire, which allows one to grasps another's mental state, which again points to the importance of learning mechanisms.

Social learning

Individuals learn through observing others' behaviour and outcomes of those behaviours (Bandura, 1977). It has been argued that general learning mechanisms enable social processes. According to Vygotsky however, social interaction plays a principal role in the development of cognition (Vygotsky, 1980). Infants learn by observing others, they see the consequences of their behaviours, learn about the world through their experiences (Barr & Hayne, 1999; Elsner, 2007; Forman, Aksan, & Kochanska, 2004; Hauf & Aschersleben, 2008; Verschoor, Weidema, Biro, & Hommel, 2010). Therefore, implicit learning processes seem to precede the development of conscious reasoning about others' mental states (Paulus, Hunnius, & Bekkering, 2012; Sommerville & Woodward, 2005). Vivanti and Rogers (2014) argued that: *"Infants make sense of, imitate and learn from the actions of others using implicit learning processes long before they have the cognitive and linguistic capacities for declarative learning involving explicit reasoning, verbal mediation and inferential understanding of others' behaviour. Cognitive development is therefore built up from a pre-linguistic, implicit understanding of others' behaviour, and early engagement with others and the social learning opportunities that occur during typical social exchanges between infants and others are the starting point, rather than the outcome, of the explicit* *representation/understanding of others' minds."* (Vivanti & Rogers, 2014, p. 2). Implicit social learning, therefore, plays a crucial role in the development of skills in social interaction, which starts before one's ability to make explicit inferences about others' states of mind. Deliberate mentalising about motivations, beliefs and desires of others comes later in the development, once the cognitive apparatus matures.

Implicitly learnt sequences of nonverbal cues, such as facial expressions, body postures or gestures linked to specific identities giving raise to social intuition (Lieberman, 2000). The source of social intuition seems to be the knowledge of cue-outcome relationships acquired through implicit learning experiences, which built up the representative social knowledge base (Lieberman, 2000, 2003). Given the abundance of social information, it is important to differentiate between meaningful cues and behavioural noise that does not bring any value to the interaction. Implicit learning can strengthen associations between predictive cues and outcomes, and weaken the link between non-descriptive cues and outcomes. Predicting others' behaviour based on previous nonverbal social communication, and adjusting one's own behaviour based on these predictions, greatly facilitates normal social functioning (Heerey & Velani, 2010; Janacsek & Nemeth, 2012; Lieberman, 2000).

<u>ASD as a socio-emotional implicit learning impairment</u>

Contrary to traditional explanations, the ability to use explicit reasoning about social phenomena is preserved in ASD, in particular in those individuals without intellectual disability. What seems to be impaired are the implicit processes that contribute to successful participation in social exchanges and enable individuals to automatically orient toward and integrate relevant social and emotional cues (Becchio, Pierno, Mari, Lusher, & Castiello, 2007; Jellema et al., 2009; Senju, 2013). High-functioning ASD individuals seem to compensate for the deficit in the automatic processing of social cues through the use of explicit social cognition, consciously reminding themselves to think about mental states of others. Studies reported that ASD individuals are capable to perform well on socio-emotional tasks, which are based on explicit knowledge, verbal mediation and inferential reasoning (e.g. labelling or imitating emotional expressions on demand) but show abnormalities in performance of socio-emotional tasks that require the implicit processing of others' actions and emotions (Cattaneo et al., 2007; Klin, Jones, Schultz, & Volkmar, 2003; Nuske, Vivanti, & Dissanayake, 2013; Vivanti, Trembath, & Dissanayake, 2014).

However, a recent meta-analysis of studies exploring implicit learning abilities in the non-social domain in ASD failed to find evidence of dysfunctional implicit learning in ASD (Foti, Crescenzo, Vivanti, Menghini, & Vicari, 2014). Given that human behaviour is dynamic, variable and complex, detecting regularities in social interactions may be more difficult than detecting regularities in the physical environment. Individuals with ASD may, therefore, show domain-specific implicit learning deficits, in particular when social learning is involved. Further to this, implicit learning in the social domain relies inherently on associated emotions and affective valences, with abstract concepts such as disposition, attitude and intention being an intrinsic part of what is learned. Surprisingly, empirical studies on this form of implicit learning in ASD are not available.

One possibility for why social implicit learning may be impaired in ASD is a failure in implicitly attributing emotional value to the representation of social stimuli. As a result, affective states cannot assist in guiding the response or attitude towards the stimuli. There is fMRI evidence supporting this view: reduced levels of brain activation in individuals with ASD during implicit emotion processing were found in the medial prefrontal cortex and superior temporal gyrus, while activations during explicit emotion processing did not differ from controls (Kana, Patriquin, Black, Channell, & Wicker, 2016). This suggests, that the emotional value of the stimuli is processed in typically-developed subjects, even when it is not explicitly required; in contrast individuals with ASD may not automatically engage brain structures playing a role in detecting emotional information perceived incidentally. Further to this, the same study found reduced functional connectivity between the medial prefrontal cortex and the amygdala in ASD only for emotional processing that is automatic or implicit.

These findings suggest that neural mechanisms underlying implicit, but not explicit, emotion processing may be altered at multiple levels in individuals with ASD. This is further supported by studies exploring automatic mimicry of facial expressions, which found deficits in imitation of emotional expressions in ASD. If the role of the mirror mechanisms is to provide direct experiences of others' mental states to aid learning from observation, lack of modulation by the affective value of the stimuli may have far-reaching consequences for individuals with ASD. While explicit instruction can help people with ASD navigate the social and emotional world more effectively over time, a failure to use implicit emotions could significantly affect the quality of social interaction in individuals with ASD.

1.6 Aims of the thesis

The current collection of studies aimed to contribute to the discussion about the role of implicit learning processes in the understanding of others' mental states and the development of social intuition. Although numerous studies have investigated domain-general implicit learning abilities in typical and ASD individuals, little is known about the extent to which the distinction between the social and non-social domain is crucial for implicit learning processes, in particular in relation to ASD.

Building on the work by Hudson et al. (2012), a novel implicit learning paradigm was developed to allow for direct comparison of social and non-social implicit learning abilities. The paradigm consists of comparable versions of implicit learning task in the social and non-social domain that are very much alike in terms of internal structure and difficulty. Experiments 1 and 2 aimed to evaluate whether social learning of others' mental states can occur implicitly in typically developed individuals on the basis of social cue contingencies and to what extent such learning may rely on general perceptual learning processes. Experiment 3 involved a matched non-social learning task.

After establishing that the implicit social learning was consistently observed in the typical population, the aim of Experiments 4-6 was to replicate the experiments with ASD individuals. The remaining experiments were devoted to understanding the mechanism underpinning implicit social learning and investigating potential contributions of other factors to the observed results, such as memory for social information (Experiments 7 and 8), social attention (Experiments 9 and 10) and automatic influence of emotion on cognitive processing (Experiments 11 through to Experiment 14). The latter experiments aimed to aid the interpretation of the learning effects obtained in experiments 1-6.

The main research questions were as follows:

(1) Can typically developed individuals implicitly learn about others' dispositions and attitudes on the basis of combinations of social cues? What is the contribution of general perceptual learning mechanisms to implicit social learning processes?

(2) Will implicit social learning be observed in ASD individuals? If implicit learning is impaired specifically for social information in ASD, deficits on implicit social learning task should be observed despite intact general implicit learning abilities.

(3) What is the potential contribution of other cognitive processes to the ability to learn implicitly, especially in the context of social information:

    a. Are certain combinations of social cues more memorable than others? Could these potential differences in memory for social information influence learning processes in typical development and ASD?

    b. The role of attention in implicit learning processes is currently debated and it is not clear to what extent attention is required for implicit learning processes to occur. Can aberrant social attention reported in ASD therefore, have negative implications for implicit learning processes? To what extent does this attention differ from typical development?

    c. An essential difference between the social and non-social version of the implicit learning paradigm is that in the social learning task the cue combinations convey the individual's affective (positive or negative) disposition toward the observer, whereas no such affective meaning (or any meaning for that matter) is associated with the non-social stimuli. Do affective valences play a crucial role in implicit learning and in bringing about learning differences between the TD and ASD groups?

Chapter 2: Participants' Selection

Study samples selected for the research studies presented in this thesis consisted of adult participants from the general population and those diagnosed with ASD. A number of participants' characteristics was measured to control for the influence of age and IQ to ensure appropriate matching of the comparison groups. This chapter highlights the participant selection and justification with regards to participant characteristics and test measures used, including diagnosis verification tools.

2.1 Use of adult participants

ASD is a pervasive neurodevelopmental disorder of variable severity and heterogeneous phenotypes. However, the traits considered autistic are distributed to a higher or lesser degree in typically-developed individuals throughout the population (Constantino & Todd, 2003). In this work, implicit learning abilities in the context of social and non-social information are explored with respect to typically developed individuals with varying levels of autistic traits (also referred to as ASD-traits or autism spectrum traits) and those with clinical ASD diagnosis as compared to matched control groups.

The experimental work presented in this thesis comprised of mostly young adults. Traditionally, the majority of research on ASD focused on infants or children either at risk of ASD or with the disorder to support identifying and making a prompt intervention to those affected (Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009). However, there is increasing recognition that ASD is a lifelong neurodevelopmental disorder that often negatively affects everyday functioning (Murphy et al., 2016). The studies show that difficulties experienced by children with ASD, often persist into the adulthood (Howlin, Goode, Hutton, & Rutter, 2004; Murphy et al., 2016; Seltzer, Shattuck, Abbeduto, & Greenberg, 2004), with outcomes in the social domain affected the most (Magiati, Tay, & Howlin, 2014).

Further to this, there is an increasing number of adults being diagnosed with ASD and the ageing population in Western countries makes this number likely to increase even more, highlighting the need to further investigate the challenges that this somewhat neglected group can face (Murphy et al., 2016; Piven, Rabins, & Group, 2011; Wright, Brooks, D'Astous, & Grandin, 2013).

The relative scarcity of research in adults with ASD is demonstrated by discrepancies in research between children and adult ASD participants prominent in literature on social attention (Guillon, Hadjikhani, Baduel, & Rogé, 2014) and emotion recognition (Harms, Martin, & Wallace, 2010), where majority of studies are conducted with child samples, inviting further investigations with adult subjects.

2.2 Measuring autism spectrum traits

Several studies presented in thesis examined implicit social cognition in typically-developed individuals in relation to autistic traits, in line with the proposition that traits consistent with ASD extend below the clinical cut-off. If individuals high in autistic traits show atypicalities in implicit social cognition analogues to those observed in ASD, but to a lesser degree, this would provide evidence that the characteristics related to ASD lie on a spectrum of behavioural traits.

In the current thesis, the autism spectrum traits were measured with the Autism Quotient (AQ) questionnaire (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) due to its efficacy in assessing autistic traits in general populations and those with the diagnosis of ASD.

The AQ is a self-report tool, consisting of 50 statements, with participants required to indicate to what extent they agree or disagree with each. The available responses are "definitely agree", "slightly agree", "slightly disagree" or "definitely disagree". The AQ comprises five subscales of social skill associated with autism spectrum: social skills, communication skills, attention to detail, attention switching and imagination. In the initial trials, the AQ was found to discriminate well between typical and autistic individuals, with a score above 32 indicating clinically significant levels of autistic traits, as 80% of individuals with ASD diagnosis exceeded this cut off compared to only 2% of the control group. Further research indicated that the AQ could a useful screening tool, with scores less than 26 indicating that the diagnosis can effectively be ruled out (Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005). Since its inception, the AQ has been widely validated and found to have a good internal consistency, test-retest reliability, and discriminant validity (Armstrong & Iarocci, 2013; Austin, 2005; Hoekstra, Bartels, Cath, & Boomsma, 2008; Woodbury-Smith et al., 2005). Further to this, the AQ is often used in general population to investigate the continuum hypothesis of autistic traits and was previously successfully applied to the study of social cognition in typically developed subjects (Bayliss & Tipper, 2006; F. S. Chen & Yoon, 2011; Freeth, Foulsham, & Kingstone, 2013; Haffey, Press, O'Connell, & Chakrabarti, 2013; Hudson, Nijboer, et al., 2012).

2.3 Creating low and high autism traits groups

A median split procedure was used to split typically-developed participants into groups based on their AQ score. This method allows to classify participants into two groups, whether their score on a measure in question falls below or above the sample median, with approximately equal numbers in each group. Participants whose level of autism traits, falls above the median AQ score are classified as high AQ group, and those scoring below the median as low AQ group. The median split is a common method in studies investigating how autism traits relate to various phenomena (F. S. Chen & Yoon, 2011; Cox et al., 2015; Hudson, Nijboer, et al., 2012; Skewes, Jegindø, & Gebauer, 2014; van Boxtel & Lu, 2013).

The use of median split has been criticised as it may result in a loss of power and therefore, give rise to Type II errors, as it dichotomises continuous variable, treating all participants scoring above (or below) the median as equal, regardless of individual variability (L. G. Humphreys, 1978; Neelamegham, 2001). Further to this, it has been argued that in some cases median split also increase the probability of the false conclusion of an effect - Type I error (Maxwell & Delaney, 1993). However, recently conducted simulation studies suggest that such effects are often negligible and choice of working with median split variable or continuous variable tends to be statistically equivalent (Iacobucci, Posavac, Kardes, Schneider, & Popovich, 2015).

Most importantly, performing a median split allows for the use of the analysis of variance (ANOVA) model, which is typically the analytical tool of choice for experimental designs, as it facilitates analytic ease and communication clarity (DeCoster, Iselin, & Gallucci, 2009). While using regression analysis would allow for avoiding the median split, it was not considered appropriate for repeated measures design employed in all of the studies of the present thesis.

2.4 Participant recruitment

Participants were recruited from the population of undergraduate students from the University of Hull. Individuals with an ASD diagnosis have been contacted through the university's disability services, who would have verified students' diagnoses in order to provide support services. This was done to ensure that all participants received a diagnosis by experienced clinicians at some point in their life. The final sample of ASD participants consisted of twenty-seven students, who completed the studies as paid volunteers. Not all participants completed all studies comprising this thesis due to a variety of reasons, with the sample sizes varying between the studies (for details see individuals method sections of each experiment).

The samples for studies investigating ASD-traits and the ASD control groups were recruited from the undergraduate student community at the University of Hull. The ASD control groups were matched with the ASD participants on chronological age, sex and IQ, as each variable can influence the performance on experimental tasks used in the studies presented in this thesis. Participants were required to have normal or corrected to normal vision and no current psychological and developmental diagnosis. Unlike ASD samples, which were drawn from the same twenty-seven ASD individuals, typically developed subjects differed from study to study.

ASD diagnosis verification

The diagnosis of ASD participants was verified with the administration of the Autism Diagnostic Observation Schedule (ADOS-2; Lord, Rutter, DiLavore, & Risi, 2008). The ADOS recommended as a standardised diagnostic tool and one with the most empirical support (Wilkinson, 2016). The assessment consists of structured and semi-structured activities that involve social interaction between the clinician (or researcher) and the individuals undertaking the assessment to evaluate whether behaviours consistent with ASD are present. ADOS-2 offers five different assessment modules, which are selected based on age and verbal abilities of a person. Module 4 of the ADOS-2 was used for the purpose of the studies presented in this thesis, as all participants were verbally fluent adults. This module consists of developmentally appropriate activities and interview questions to offer different prompts for assessing four types of behaviours: communication, reciprocal social interaction, imagination and stereotypical behaviours. Behaviours within each category are coded to produce four scoring scales. These are then subsequently combined with the use of standardised algorithms to determine a final ADOS score. An ADOS score of seven or higher is indicative of clinical levels of autism spectrum and a score of 10 or higher is indicative of autism. Studies examining the reliability and validity of the ADOS reported good reliability and discriminant validity (Hus & Lord, 2014; Oosterling et al., 2010; Pugliese et al., 2015).

Of the 27 ASD participants, who took part in the studies presented in this thesis, eleven scored above 10 and one below 7 (one score of 6). Since the ADOS is not used as a standalone diagnostic tool and all participants previously received an official diagnosis of ASD, one participant who's ADOS score of 6 was below the clinical cut-off score of 7 was not removed from the analyses.

All ASD participants have also completed the AQ questionnaire. The scores ranged from 12 to 46, with an average score of 32.11 (SD = 8.89), with 16 scoring above the clinical cut-off. As the AQ questionnaire is a screenings instrument rather than a diagnostic instrument, the participants were not removed from the analysis based on AQ.

Psychiatric comorbidities are prevalent in ASD, with studies typically reporting around 70% of participants have at least one other current psychiatric disorder (Belardinelli, Raza, & Taneli, 2016). Four recruited ASD participants disclosed comorbid diagnoses, including one with Attention Deficit and Hyperactivity Disorder, two with anxiety and one with depression. The decision was made not to exclude these participants from the analyses, which was justified by the comparison of results obtained, which were not found to differ with and without the inclusion of these subjects.

Intellectual functioning

A short version of the Wechsler Adult Intelligence Scale – fourth edition (WAIS-IV; Wechsler, 2008) was administered to evaluate participants' intellectual abilities and to allow matching with control participants. This is the most common test used to assess intellectual abilities in clinical and research settings. The reliability and validity of WAIS have been established for a wide range of cognitive abilities to measure general intelligence (Wechsler, 2008). The fourth edition of WAIS includes 15 subtests, which result in four-factor index scores; verbal comprehension, perceptual reasoning, working memory, and processing speed, which are used to calculate an overall Intelligence Quotient (IQ).

For the purpose of this thesis, the short form of the test was administrated, with the following subtests: block design, similarities, digit span, arithmetic, information, coding, and picture completion (Meyers, Zellinger, Kockler, Wagner, & Miller, 2013; Ward, 1990). The short version of the test is more efficient to administer and the scores obtained from this version correlate highly with full-scale WAIS-IV (Meyers et al., 2013).

The present research involved ASD-individuals with the inclusion criteria of the IQ above 70. The mean IQ score in the present ASD sample was 115.59 (SD = 8.90), which is an above-average score, typical in the undergraduate student population. Individuals with a diagnosis of autism and an IQ above 70 (i.e. without intellectual disability) have informally been described as high functioning autism (Ghaziuddin & Mountain-Kimchi, 2004). Unlike explicit learning, implicit learning abilities tend to be independent of intellectual abilities (A. S. Reber, Walkenfeld, & Hernstadt, 1991). Therefore, findings from the high-functioning samples included in the present thesis are likely to translate to those with more severe autism to some extent. Furthermore, the specific tasks used required good motor skills and focused attention, with HFA individuals better suited to complete such tasks than those with severe autism (B. T. Williams & Gray, 2013).

Familiarisation with the research setting

All ASD participants were invited to a separate session before taking part in any of the experimental studies. During this session, participants had an opportunity to meet the researcher and familiarise themselves with the Social Brain Laboratory, in which all testing took place. This session was also used for conducting all the necessary assessments, in the following order: ADOS-2, WAIS-IV and AQ questionnaire (all administered by SM). Module 4 of the ADOS-2 was the first test administered, as it should be completed during the initial contact between the assessor and participant for an accurate evaluation. This was followed by cognitively demanding WAIS-IV. At the end of the session, participants completed an online version of AQ questionnaire. Participants received sufficient breaks to rest between each assessment. Individual characteristics of each participant in the clinical group are presented in Table 1.

Table 1 The characteristics of the clinical group.

Participant	Age	Sex	IQ - Total	AQ	ADOS
1	21	man	110	34	13
2	20	man	126.5	34	15
3	20	woman	121.5	34	7
4	19	woman	116.5	12	7
5	19	man	116.5	25	10
6	21	woman	121.5	34	14
7	20	man	116.5	34	8
8	20	man	111.5	46	11
9	21	man	130	36	9
10	20	man	108.5	22	8
11	19	man	128.5	18	12
12	20	woman	128.5	43	8

13	19	man	116.5	21	6
14	18	woman	106.5	45	10
15	23	woman	118.5	46	8
16	19	woman	128.5	39	10
17	20	man	113.5	22	7
18	20	man	103.5	35	9
19	19	man	101.5	29	9
20	21	man	98.5	22	10
21	18	man	125	30	7
22	19	man	101.5	34	15
23	19	man	115	31	10
24	19	man	111.5	45	8
25	19	man	115	35	9
26	19	man	111.5	28	7
27	19	woman	118.5	33	8
MEAN	19.67	8 women	115.59	32.11	9.44
SD	1.07	19 men	8.90	8.89	2.44
N	27		27	27	27

2.5 Sample sizes

Sample sizes in clinical research are relatively small due to difficulties with recruitment. Computing a priori power analyses to determine the sample size for the experiments within the present thesis was problematic due to the novelty of the experimental design. Where previous research was not useful in determining effect sizes, a priori power analyses were performed in G*Power program (Faul, Erdfelder, Lang, & Buchner, 2007) using a conservative estimate of medium effect size.

For Chapter 3, with two groups (high and low AQ) and ten measurements (scores for happy and angry morphs at five morph level proportions), it was determined that a minimum of 20 participants were required to detect a medium-size effect when a power of 0.80 with an alpha level of .05 was assumed. Due to the use of a median split and a potential loss of power, more participants were recruited to ensure detection of existing effects. The final sample sizes in this chapter ranged from 46 to 70.

For chapter 4, the same sample size was applied as the same studies were used but rather than comparisons between high and low AQ groups, individuals with ASD were compared to matched typically-developed control group. While one study that attempted to evaluate implicit social learning in ASD was found to produce large effect sizes (Travers et al., 2013), the task used in this study was a probabilistic contextual cueing task, which was very different in nature and measurements to contingency learning studies employed in this thesis. The final sample sizes in this chapter ranged from 39 to 51.

In chapter 5 memory for facial expressions was evaluated to better understand the effect obtained in previous studies. We were not aware of any studies looking at memory for facial expression in ASD, but one study examining memory for facial *identity* between typically-developed and ASD individuals reported a medium-size effect (Zaki & Johnson, 2013). The minimum sample size required to reach the effect size (f = .25) with a power of .80 and an alpha level of 0.5 suggested that a minimum of 28 participants would be required in order to obtain statistical power. The final sample sizes in this chapter ranged from 42 to 89.

Chapter 6 used eye-tracking methodology to aid interpretation of the results found in earlier studies. The studies that examined the distribution of attention in ASD individuals typically report a medium-large effect size when looking at data between two distinct groups of people with and without a disorder (Pelphrey et al., 2002; Riby & Hancock, 2008). As the experiment 9 aimed to split a general population sample, the effect was likely to be smaller. Based on the design used in chapter 6, an a priori power analysis for medium effect size (f= .25) computed with an alpha level of .05 and a power of .80 suggested that a minimum of 32 participants would be required. The final sample sizes in this chapter included 40 participants.

The affective priming experiments utilised in chapter 7, typically produce medium-size effects (Palumbo et al., 2015; Palumbo, Macinska, & Jellema, 2018). A minimum of 36 participants was required to detect a medium effect size (f= .25) calculated with an alpha level of .05 and a power of .80. The final sample sizes in this chapter ranged from 41 to 54.

Overall, as the median split method may result in a loss of statistical power effort was made to recruit more participants than the minimum suggested by the power analyses. Similarly, due to the difficulties with availably of participants with the clinical diagnosis of ASD, the sample sizes for this group were typically larger than the required to account for any potential exclusions and dropouts that may have resulted in insufficient samples in this group.

Chapter 3: Implicit learning of social and non-social information in typical development.

The ability to implicitly learn about complex regularities or contingencies in one's environment is a fundamental aspect of human cognition. Although automatic and seemingly effortless, implicit learning plays a significant role in guiding and structuring our perceptions and behaviour (Reber, 1993). This is especially true during social interactions, where an implicit interpretation of accumulating social cues can be vital for modulating one's social response appropriately to the current situation (Frith & Frith, 2008; Lieberman, 2000). The aim of this chapter was to examine the capabilities for implicit learning in typically-developed individuals with varying levels of ASD-traits by employing a novel experimental paradigm developed specifically for assessing implicit learning in both social and non-social domain.

<u>Implicit versus explicit learning</u>

The process of learning involves knowledge acquisition processes, bringing memories into the mind, forming associations, retaining and using them (Mayer & Moreno, 2003). A rough distinction is typically made between two types of learning processes: explicit and implicit. Explicit learning occurs when a conscious effort is made to acquire specific knowledge by paying attention to the material to be learnt, noticing similarities and differences between concepts and their meanings, thereby mentally building coherent connections between them and organizing them into new knowledge structures (Boshuizen & Schmidt, 1992; Schmidt, 1990). However, the abundance of perceptual signals humans are exposed to in a given moment is far too complex to be dealt with consciously, especially if coupled with limitations of cognitive processes required for deliberate learning to occur. As such, explicit learning is unlikely to be able to take care of all there is to learn (Lewicki, Hill, & Czyzewska, 1992) and this is where implicit learning processes come to play.

It has proven difficult to provide a satisfactory definition of implicit learning; however, some argue that implicit learning needs to be viewed in opposition to learning that is not implicit (Frensch & Rünger, 2003). Implicit learning is typically characterized as automatic, associative, nonconscious and unintentional, as distinguished from the conscious, deliberate and reflective explicit learning processes. This type of learning may occur by mere exposure to complex regularities present in the environment, largely independently of conscious attempts to learn (Cleeremans, 1997; Reber, 1967, 1993). One of the most important features of implicit learning is automaticity (de Houwer & Moors, 2012); implicit learning processes promptly and continually establish connections between the perceptual signals from the environment without deliberate and controlled attention (Ashby & Maddox, 2005; Dienes & Perner, 1999; Evans, 2008; S. B. Kaufman et al., 2010). Automatically detecting structural regularities and patterns in one's environment reduces uncertainty, making it more predictable, leading to feelings of security and sense of control, and it is thought to be a fundamental starting point for infants to perceive and understand the world around them (Cleeremans & Dienes, 2008; Gangopadhyay & Schilbach, 2012; Gibson & Pick, 2000; Perruchet & Pacton, 2006). Implicitly acquired knowledge may become apparent in one's sensitivity to environmental regularity and the ability to act in accord with learnt information (Amso & Davidow, 2012). Yet, the knowledge gained in implicit learning may not be fully accessible to consciousness, in that subjects typically cannot provide a verbal account of what they have learnt or might even be unaware of the fact that learning has occurred (Reber, 1993; Seger, 1994; Shanks, Rowland, & Ranger, 2005).

Research has shown that implicit learning plays a critical role in guiding our behaviour in many day-to-day activities, for example, in obtaining motor skills (Hikosaka, Nakamura, Sakai, & Nakahara, 2002; Poldrack et al., 2005), learning and processing languages (S. B. Kaufman et al., 2010; Nemeth et al., 2011; Rebuschat, Hamrick, Sachs, Riestenberg, & Ziegler, 2013; Saffran, Aslin, &

Newport, 1996) as well as in social learning and development of social skills (Heerey & Velani, 2010; Lieberman, 2000; Norman & Price, 2012). It has been proposed that the development of implicit knowledge precedes the acquisition of explicit knowledge, which is secondary in any learning process (Sun, Merrill, & Peterson, 2001). Children acquire implicit knowledge long before their cognitive capacity for explicit learning fully develops. Implicitly acquired information may or may not become explicit over time, but explicit knowledge is at least in part, governed by implicit processes, which are essential for any learning to occur (Sun et al., 2001).

Explicit and implicit learning mechanisms seem to be reflected in the brain as distinct neural structures. Experimental evidence suggests that implicit learning is not subserved by the same structures that underlie explicit learning, such as medial temporal lobe (MTL) system (N. J. Cohen, Poldrack, & Eichenbaum, 1997; Seger, 1994; Verfaelllie, LaRocque, & Keane, 2012). Specific neural correlates of implicit learning seem to be task-dependent (Greene, Gross, Elsinger, & Rao, 2007; Jiménez & Vázquez, 2011; Poldrack et al., 2005), with activation in the striatum, basal ganglia and prefrontal cortex reported most often (Aizenstein et al., 2004; Honda et al., 1998; Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003; Meier et al., 2013; Rauch et al., 1997; Yang & Li, 2012). Difficulty in identifying brain structures responsible for implicit learning leads to the assertion that implicit learning may not produce a single characteristic signature of neural activity (Reber, 2013; Reber, Batterink, Thompson, & Reuveni, 2017). Reber (2013) proposed that adaptive changes in connections within the brain that result from the implicit learning experience, spread across all neural circuity, leading to enhanced communication in distinct cortical regions to improve performance and increase neural efficiency. This is in contrast to explicit knowledge that is dependent on the medial temporal lobe memory system.

This theory may potentially explain the inconsistency in reported neural correlates of implicit learning and has so far been supported by a number of neuroimaging and neuropsychological studies (for a review see Reber et al., 2017).

Implicit learning and development of social intuition

During social interaction, people exchange a large number of nonverbal cues, which are interpreted in a seemingly effortless manner. Social cues serve several functions, with probably most important being a reduction in ambiguity; another person's cues carry valuable information about their mental state and intentions, and can be used to form predictions about their future actions (C. D. Frith & Frith, 2008; Heerey & Velani, 2010; Janacsek, Fiser, & Nemeth, 2012). The ability to make sense of social cues in response to others and guide one's behaviour towards them in an automatic fashion without requiring any deliberate reasoning processes is often referred to as social intuition, and it is crucial for effective social interaction and for fruitful communication (Lieberman, 2000).

Intuition has been defined as a set of interrelated cognitive and affective processes, in which there is no apparent intrusion of deliberate thought (Hodgkinson, Langan-Fox, & Sadler-Smith, 2008). It has been argued that the cognitive process that underpins the development of intuition is in fact, implicit learning (Dienes & Berry, 1997; Hudson, Nijboer, & Jellema, 2012; Lieberman, 2000; Reber, 1989). Intuition is thought to arise from accumulated knowledge gained through implicit learning experiences; implicit learning leads to the development of a knowledge base, upon which individuals draw when making intuitive judgements (Dienes & Berry, 1997).

Social intuition involves making rapid judgements about the emotions, intentions or attitudes of others. In case of social interactions, the intuitive sense has been proposed to emerge on the basis of implicitly learnt sequences of nonverbal cues, such as facial expressions, body postures or gestures linked to specific identities (Lieberman, 2000). Predicting others' behaviour based on previous nonverbal social communication, and adjusting one's own behaviour based on these predictions, greatly facilitates normal social functioning (Heerey & Velani, 2010; Janacsek & Nemeth, 2012; Lieberman, 2000). Given the abundance of social information, it is important to differentiate between meaningful cues and behavioural noise that does not bring any value to the interaction. Implicit learning can strengthen associations between predictive cues and outcomes, and weaken the link between non-descriptive cues and outcomes. The source of social intuition seems to be the knowledge of cue-outcome relationships acquired through implicit learning experiences, which built up the representative social knowledge base (Lieberman, 2000, 2003). For example, when people are able to accurately judge the personality of another person without being able to verbalize what the judgement was based on, this may well be explained in terms of complex behavioural regularities being learnt without full conscious awareness (Lewicki, Hill, Czyzewska, 1994). Intuition is proposed to be an end product of unconscious learning (Bowers, Regehr, Balthazard, & Parker, 1990), which have a capacity to influence social behaviour, even in the absence of explicit knowledge of social contingencies. There is an ample evidence suggesting that social intuition is an acquired ability that develops continuously throughout the lifespan (e.g. Cohen, Prather, Town, & Hynd, 1990). This could potentially be in line with the notion of the ever-expanding knowledge base accumulated through implicit learning from social experiences.

Implicit social learning differs from its counterpart in the non-social domain. Human behaviour is dynamic, variable and complex and therefore, detecting regularities in social interactions is more difficult than detecting regularities in the physical environment. While social interaction is typically governed by a set of implicitly understood rules, these rules tend to be fluid and flexible, embedded in the current social context. Behaviours desirable in one situation, maybe not be acceptable in another. This is in contrast, to interactions with physical objects, which outcomes are more fixed and predictable. Further to this, implicit social learning often relies on emotional associations and affective valences, as well as abstract concepts such as dispositions, attitudes and intentions of others, which are an intrinsic part of what is learned. On the contrary, these concepts do not exist in the non-social domain. The non-social objects may elicit an emotional response in the observer, but they do not themselves possess emotional/mental states or intentions.

Experimental paradigms to study implicit learning

Implicit learning has been investigated in a wide range of experimental paradigms in the context of the non-social domain, including artificial grammar learning (AGL; Reber, 1967), contextual cueing (CC; Chun & Jiang, 1998), serial reaction time task (SRT; Nissen & Bullemer, 1987). What all these paradigms have in common, is a presence of predictive information in the form of either covariation or temporal sequence, of stimuli. In the AGL task, participants are exposed to a series of letter strings, which follow a complex set of rules. Even though participants are unaware of the underpinning rules, it shows that they can apply these rules at a later stage, correctly categorising the letter strings as either grammatical or not (Dienes, Broadbent, & Berry, 1991; Reber, 1989). Similarly, in the contextual cueing task, participants are instructed to search for a target among distractors, whose spatial configuration repeats on some trials and is novel on others; participants' responses are facilitated on trials with repeated configurations without them being aware of any repetitions (Chun & Jiang, 1998). In sequence learning tasks such as the SRT, participants have to predict the onset of a stimulus based on the preceding stimuli (Nissen & Bullemer, 1987). Research using these (and many more) implicit learning tasks demonstrated that one can learn about the structure of the environment by mere exposure, without being aware of this structure. The result of such learning is apparent in participants' behaviour, which is governed by implicitly learnt rules, such as faster reaction times on predictable trials or correct categorisation of stimuli in forced-choice tests. However, while the aforementioned implicit learning tasks show to some extent the processes involved in the acquisition of language or motor skills, research on the development of social competence via implicit learning mechanism has been rather sparse.

Implicit learning of social information

Research from social psychology suggest that the structure of a person's face have a substantial influence on how people infer trait judgements (e.g. trustworthiness or intelligence) and make assumptions about their likely behaviours in a social interaction (Krumhuber et al., 2007; Stirrat & Perrett, 2010;

Sweeny, Grabowecky, Suzuki, & Paller, 2009; Todorov, Said, Engell, & Oosterhof, 2008; van 't Wout & Sanfey, 2008; Vernon, Sutherland, Young, & Hartley, 2014). Prolonged interaction with someone improves the accuracy judgement of that person's trait (Carney, Colvin, & Hall, 2007; Funder & Colvin, 1988; Funder, Kolar, & Blackman, 1995; Hall & Schmid Mast, 2007) and learnt characteristics of one person can unconsciously spread to influence judgement of another, physically similar person (Hill, Lewicki, Czyzewska, & Schuller, 1990; Lewicki, 1986; Verosky & Todorov, 2010, 2013). While fixed configurations of the face may lead to the attribution of personality characteristics, through interactions, knowledge of a person is continuously updated and with time, becomes more important than facial appearance (Todorov, Gobbini, Evans, & Haxby, 2007).

When interacting with strangers, intentions and emotional states predictive of future behaviour can also be inferred on the basis of dynamic social cues, such as gaze direction or facial expression. In one cleverly designed study, participants played a computerized game of rock–paper–scissors against an avatar they believed was another participant (Heerey & Velani, 2010). On some trials, the avatar generated a facial cue predictive of its next move. The results showed that even though no explicit knowledge of the predictive cue was acquired, participants' win-frequency increased over time. Interestingly, the degree to which participants could predict the avatar positively correlated to their self-reported liking of the avatar.

Another example of implicit social learning has been demonstrated by gaze-cueing experiments. In gaze-cueing paradigm, the gaze direction of the face may match or mismatch with the location of a subsequently appearing target, which the participant is tasked with rapidly detect (Bayliss & Tipper, 2006; Frischen et al., 2007). Importantly, the faces consistently gaze in the direction predictive of the targets, or away from the targets. Faces with predictive gaze are rated as more trustworthy and more worth financial investment than those whose gaze is unhelpful (Bayliss et al., 2009; Bayliss & Tipper, 2006; R. D. Rogers et al., 2014). What is interesting is that participants are unaware of gaze-cue contingencies, suggesting that the contingencies had affected the social judgments in an implicit manner.

A novel implicit learning paradigm has been introduced by Hudson, Nijboer & Jellema (2012), in which participants implicitly learnt the character's disposition toward them, based on nonverbal social cues: facial expression and gaze direction. Participants viewed videos of two characters. One character began to smile each time the gaze moved in the direction of the observer and expressed anger each time the direction of gaze moved away from the observer. Therefore, that character was looking at the observer when expressing happiness and looking away when expressing anger and thus, conveying an emotionally positive disposition toward the observer. The other character showed the reverse pattern, smiling with gaze moved away from the observer, and expressing anger with the gaze moved toward the observer and thus, conveying an emotionally negative disposition toward the observer. Importantly, both characters express emotions of joy and anger for the same amount of time and look at and away from the observer for the same amount of time. As such, the disposition of each character could only be learnt on the basis of the specific combination of social cues. Implicit learning was measured using a gaze-cueing paradigm. Participants showed an increased gaze-cueing effect for the character learnt to have a positive disposition toward them, presumably as they would have perceived them as more trustworthy, and consequently, a smaller cueing effect in response to the character with a negative disposition as they would have been expected to offer unreliable cues. At the same time, participants were unable to report an idiosyncratic pattern of gaze and expression behaviour of the characters. This suggests that intentions of another person can be implicitly attributed on the basis of social cues witnessed in a previous social encounter and affect one's subsequent responses to that individual, without one being aware of it.

Social implicit learning and autistic traits

The deficits in the social domain that characterise autism spectrum disorders may have their roots in impairments in implicit (social) learning with relatively intact explicit (social) processing (Jellema et al., 2009; Ruffman, Garnham, & Rideout, 2001; Senju, 2013), making impaired implicit (social) learning a potential causal factor. Moreover, there are indications that individual differences in autism spectrum traits are related to the ability to implicitly learn about others on the basis of social cues. In a previously mentioned study by Hudson et al. (2012), a further interesting finding was that implicit social learning was only seen in a participant group low in autistic traits. Similarly, in a gaze-cueing study by Bayliss and Tipper (2006), trustworthiness judgements for identities offering predictive cues correlated negatively with participants' extent of possessing autistic traits, with fewer autistic traits associated with stronger implicit learning effects. This suggests individuals high in autistic traits may have some difficulties in implicitly extracting social meaning from social cues, and/or in implicitly learning about these social cues, which could potentially lead to underdevelopment of social intuition. This is in line with the autism spectrum continuum theory, suggesting that social atypicalities consistent with ASD may be found throughout the entire population to differing degrees, with clinical levels of autism at the high end of this continuum (Baron-Cohen, Wheelwright, Skinner, et al., 2001; Constantino & Todd, 2003).

However, assessing implicit learning on the basis of gaze-cueing magnitude can be problematic; it may be that the observed difference between the low and high AQ groups existed in susceptibility to gaze-cueing, regardless of learning effects. While results from gaze-cueing tasks could have indeed tapped into participants' implicit learning abilities, it has been reported that the gaze-cueing effect is associated with the extent in which a person possesses autistic traits, with the higher scores on the AQ associated with gaze-cueing smaller effect (Bayliss & Tipper, 2005). Similarly, a number of studies found atypical gaze orienting patterns in adults with autism (Ashwin, Hietanen, & Baron-Cohen, 2015; Ristic et al., 2005; Vlamings, Stauder, van Son, & Mottron, 2005). If the gaze cueing effect was reduced in those, who possess higher levels of autistic traits, the obtained results may not actually reflect implicit learning. There is also some evidence that gaze appears to cue attention differently in people with autism than in typically-developed adults. Senju et al. (2004) found differences in cueing between counter-predictive gaze and arrow cues in typically-developed individuals, whereas those with autism exhibited the same effects for both types of cues. This suggests that in autism, gaze cues tend to be understood in a more mechanistic manner, rather than as meaningful and intentional (Hudson, Liu, et al., 2009).

Studies with autistic samples finding overall faster response times to gaze cueing seem to support this notion, as slower reaction times in typically-developed individuals are explained by the additional processing required to understand the intention behind the gazers' eye direction (Frischen et al., 2007). If the mechanistic approach to gaze-cueing task was to some extent used by those with higher levels of autistic traits, with the averted eyes treated in the same way as arrow cues, rather than intentional cues directed at the observer, the disposition of the characters, even if learnt, would be irrelevant to a successful completion of the task. Therefore, there is a need for alternate social implicit learning tasks, that do not rely on gaze-cueing effects.

<u>Current study</u>

The studies presented in Chapter 3 will introduce a modified version of the social implicit learning paradigm by Hudson et al. (2012) to assess differences in implicit learning of social information in relation to autistic traits. To disentangle the effects of implicit learning from, potentially atypical gaze-cueing abilities of high-autistic traits individuals, Experiment 1 introduces a novel measure of implicit learning. As implicit learning by definition excludes awareness, it has been argued that indirect measures are best suited to probe the existence of any implicitly learned information (de Houwer, 2006). The introduced measure will, therefore, assess the implicit learning of character dispositions' indirectly, by observing systematic perceptual biases between the two characters. To this end, in the Test phase morphed images consisting of various proportions of two characters, either smiling or frowning, are used, with participants having to indicate which character morph identity resembles more. The rationale is that when participants have implicitly learned that character A had a positive disposition toward them, they would be more likely to judge the smiling morph as more similar to character A. Similarly, the frowning morph should be intuitively associated as more similar to character B with negative disposition, and thus, more likely to be judged as such. In addition, a 'likability' questionnaire will be included as a more explicit/direct measure of implicitly learnt social contingencies, directing participants' attention toward their feelings about each character (both methods are described in detail in Section 2.2.3.). In Experiment 2, the indirect measure of implicit learning will be further refined to exclude the possibility that perceptual learning of low-level facial features may have interfered with the implicit learning of the characters' dispositions. Finally, in Experiment 3 the paradigm will be extended to include a non-social implicit learning condition, matching in design and level of difficulty the social implicit learning task, to directly compare implicit learning in social and non-social domains.

3.1 Experiment 1

Given the abundance of available social information, the implicit interpretation of simultaneous social cues can be vital for appropriately modulating one's social responses (Lieberman, 2000). However, there are indications that typically-developed people may differ in their ability to implicitly learn about others, which may affect their social functioning. In particular, increased levels of implicit social learning impairment have been reported with increasing levels of autistic traits (Bayliss & Tipper, 2006; Hudson, Nijboer, et al., 2012). Experiment 1 introduced a modified version of implicit learning paradigm introduced by Hudson et al. (2012) to assess the differences in implicit social learning in relation to autistic traits, as assessed by the AQ questionnaire. Participants were required to watch videos of two actors, whose facial expressions and gaze directions changed dynamically. The videos displayed hidden contingencies that could be learnt implicitly, with the specific combinations of facial expression and gaze direction used to portray the actor as having either a positive or negative disposition towards the observer.

It was hypothesised that the results from Hudson et al. (2012) will be replicated, with individuals high in autistic traits showing a diminished ability to implicitly learn the positive and negative dispositions of the actors, as compared to those low in autistic traits. Similarly, it was hypothesised that the positively portrayed character would attract higher likability scores than the negatively portrayed character, but only when judged by the low AQ group. No differences in character likability scores were predicted in those with a high level of autistic traits.

Methods

Participants

Fifty-four undergraduate psychology students from the University of Hull participated in the experiment in exchange for course credit. All participants had a normal or corrected-to-normal vision. After applying exclusion criteria (see Data Reduction below for details), the final sample consisted of 46 individuals (thirty-four women, twelve men), with an average age of 19.8 (*SD* = 3.4).

Stimuli

The photographs used in this and all subsequent studies were taken from the Warsaw set of Emotional Facial Expressions Pictures (WSEFEP; Olszanowski et al., 2015). This particular set was chosen for a number of reasons. First of all, rather than photographing posed facial displays, an attempt was made to capture genuine emotions of models by eliciting real emotional responses. In addition, obtained photographs were evaluated by a large number of untrained judges to establish whether a given expression was perceived as intended. As a result, the final set is comprised of those pictures that received the highest recognition marks (e.g. accuracy with intended display) from independent judges. The photographs are in colour and of high quality, depicting the models from the top of the shoulders upwards. All these factors lead to the enhanced ecological validity of the stimuli. For this Experiment 1, the stimuli consisted of photographs of four models with three facial expressions: happy, angry and neutral. Two male characters and two female characters were used, though each participant was only exposed to two of them (either the two males, or the two females), and these were counterbalanced across participants.

The models were selected on the basis of high rates of agreement for expressions of joy and anger (as reported in Olszanowski et al., 2015) and relatively large size of their eyes, to allow for easy manipulation of gaze direction (see Figure 2). A pilot study was conducted to ensure that the selected two female and two male characters were matched on attractiveness. Twenty undergraduate psychology students (ten women, ten men) scored each model on attractiveness on a discrete scale ranging from 1 to 10. Paired samples t-tests showed no significant differences in attractiveness scores between two male ($t(19)=.139$, $p = .891$) and two female models ($t(19)=.476$, $p = .640$). A one-way ANOVA revealed a similar pattern of results, regardless of the sex of participants (all p's > .759).

The photographs of each character were morphed with the use of Sqirlz Morph software (Xiberpix) into short videos of 2 seconds duration to create dynamic stimuli, displaying a natural facial movement (Perrett, May, & Yoshikawa, 1994) Social contingencies were achieved by manipulating gaze direction and facial expressions. Each video started with character's gaze directed either at the participant and then gradually averted horizontally until at a 30° angle away from the observer at the end of the clip, or began with a 30° aversion and ended with direct gaze (the video played backwards). To manipulate facial expressions, the video began either with a character displaying a happy facial expression, which gradually morphed into an angry expression, or began with an angry expression which morphed into a happy expression (video played backwards). The characters were oriented facing the observer throughout the presentation.

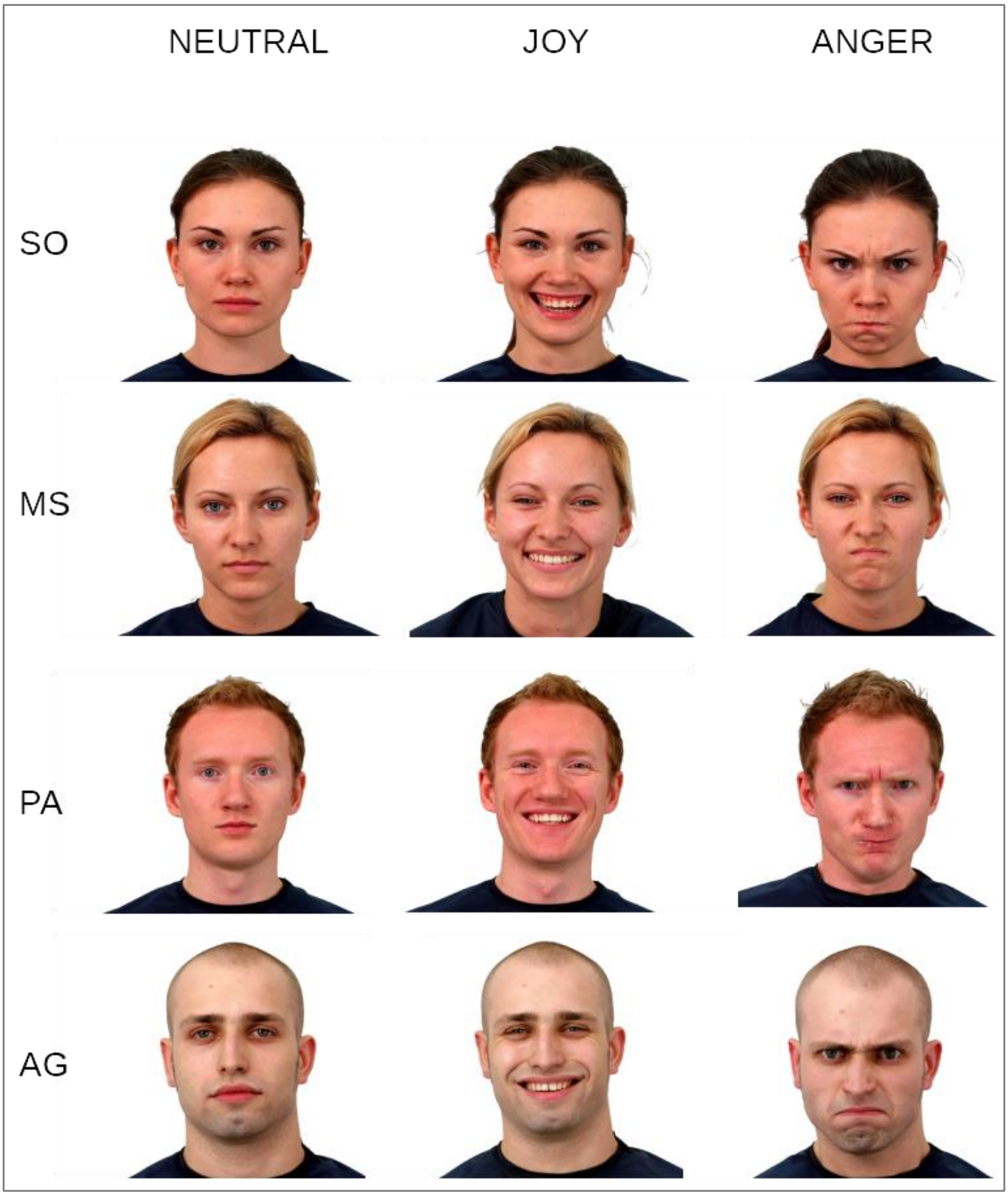


Figure 2 Characters used in the study. Two female characters: MS and SO (first two rows) and two male characters: AG and PA (last two rows).

Experimental procedure

Participants were seated at a viewing distance of 80 cm from a PC screen (21-inch monitor, 1024 x 768 pixels, 100 Hz). The stimuli were presented using E-Prime (v.2.0; Psychology Software Tools, Inc.). The experimental procedure started with the learning phase, which, after a short break was followed by the test phase.

Learning Phase

The learning phase procedure followed broadly the learning phase of Hudson et al. (2012). Participants viewed 80 videos of two different identities, 40 for each identity. As determined by pilot studies, this number of repetitions works well (with about 1 in 10 participants detecting the social contingencies), too many repetitions would mean that most participants detect the contingency (explicit learning) and too few that possibly no implicit learning would take place. Each video consisted of 20 frames, the first and last frame were displayed for 750ms and the other 18 frames for 30ms each to create a natural movement. Half of the videos started with the gaze directed towards the participant and then gradually averted away from the observer (indirect gaze direction), and half began with gaze averted and ended with direct gaze direction (the video played backwards). To manipulate facial expressions, the video began either with an identity displaying a happy expression, which gradually morphed into an angry expression, or began with an angry expression which morphed into a happy expression (video played backwards) (see Figure 3).

Crucially, each character was portrayed to express either positive or negative disposition toward the observer based on different combinations of gaze direction and facial expressions. For character A, gaze averting away from the observer was accompanied by a change from a happy to an angry expression, while gaze movement towards the observer was accompanied by a change from angry to happy (played backwards). This character can, therefore, be inferred to hold overall a positive disposition toward the observer; smiling when looking at the person and frowning when looking away. For character B, the reverse cue combinations were used; the character would frown when looking directly at the observer, but smile when looking away. This character can, therefore, be inferred to hold a negative disposition toward the observer. Each character displayed happy and angry expressions for exactly the same amount of time and looked at and away from the observer for exactly the same amount of time. This meant that the social disposition of each character could only be learnt on the basis of the specific combination of two cues; neither facial expression nor gaze direction on itself could not cause any social learning effects.

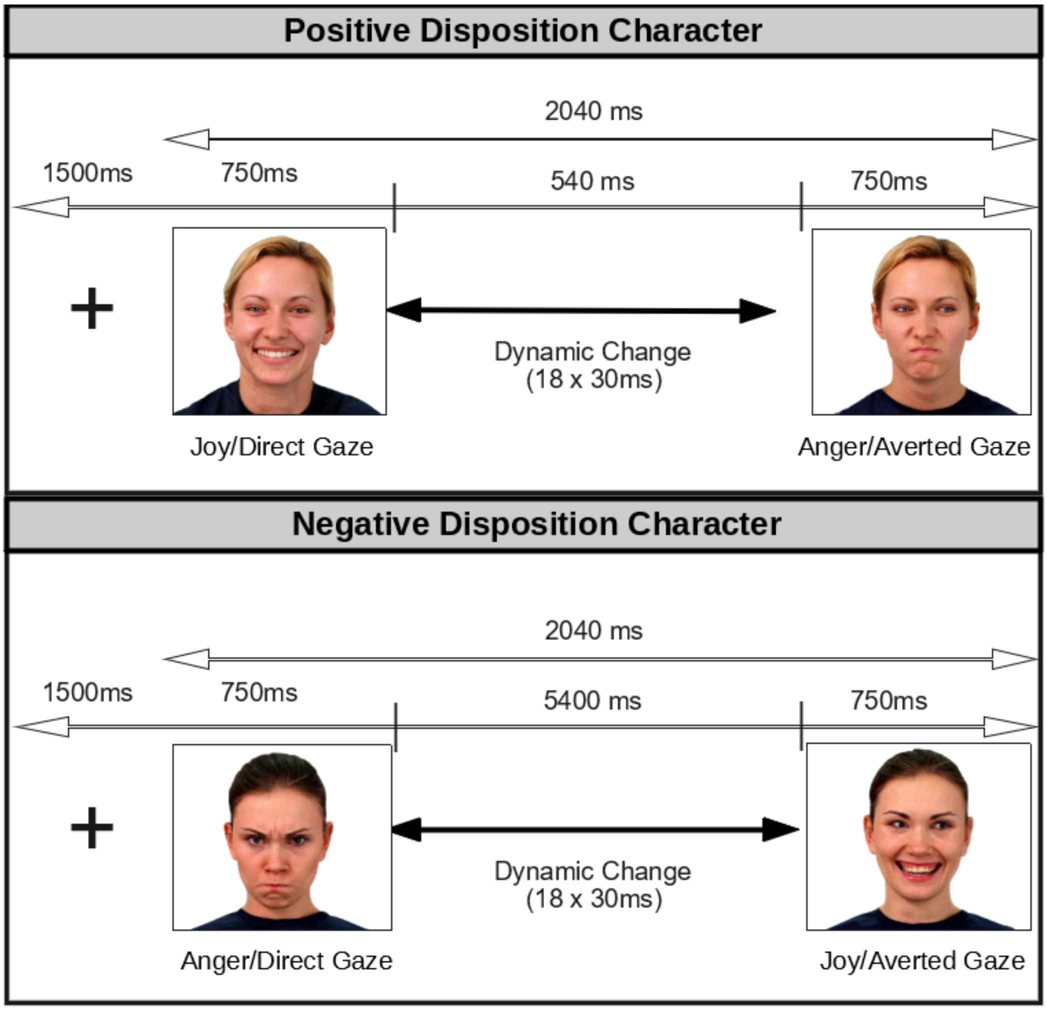


Figure 3 Learning phase in social domain (version 1). Actor MS portrayed as having a positive disposition toward the observer – smiling when looking at, but frowning when looking away from, the observer (top panel) and actor SO portrayed as having a negative disposition toward the observer – pattern reversed (bottom panel). Half of the videos started with the direct gaze (as pictured), and the other half started with averted gaze (the videos played backwards).

Participants were randomly assigned to either the male condition, where the two male models were used or the female condition, where the two female models were used. The social disposition of the characters used in the study was counterbalanced across participants; for half of the participant's character A was holding a positive disposition toward the observer while character B was holding a negative disposition toward the observer, while for the other half B was the positive and A the negative character toward the observer. This resulted in a total of four versions of the experiment (see: Table 2).

Table 2 A list of four versions of the experiment used in the study. Female characters: MS and SO. Male characters: AG and PA. The final column displays the number of participants that completed each version of the study, split by the AQ group (low versus high).

Version	Positive Disposition	Negative Disposition	Number of Participants
1	MS	SO	Low AQ: 5; High AQ: 7; Total: 12
2	SO	MS	Low AQ: 6; High AQ: 5; Total: 11
3	AG	PA	Low AQ: 6; High AQ: 6; Total: 12
4	PA	AG	Low AQ: 6; High AQ: 5; Total: 11

Question session to determine whether any contingencies had been discovered

Directly following the learning phase, participants were required to give verbal responses to the following questions: (1) "Could you describe what you just have seen?" (2) "How many different identities did you see?" (3) "What can you tell me about their facial expressions?" (4) "What can you tell me about their gaze direction?" (5) "Did you detect certain patterns between facial expressions, gaze directions and identities?", to check whether the participants became aware of the cue-identity contingencies, that is, whether the learning was truly implicit. At the same time, this short questionnaire served to find out whether the participants paid attention to the videos and were able to correctly identify emotions displayed by the models.

Testing Phase

In the testing phase, a morph of the two characters was presented in the centre of the screen, with the faces of two previously watched characters displaying neutral expressions on either side of the morphed identity (Figure 4). The morphed identity was either smiling or frowning, and was composed of different proportions of either agent, the smiling model A and the smiling model B or the frowning model A and the frowning model B. Five morph levels (proportions) were used: M1 = 60% A and 40% B, M2 = 55% A and 45% B, M3 = 50% A and 50% B, M4 = 45% A and 55% B, M5 = 40% A and 60% B.[1] A four catch trails were included in order to assess participants' engagement with the task, these were M0 = 80% A and 20% B and 20% A and 80% B. All morph levels are presented in Figure 5. There were in total 24 test trials (5 morph levels x 2 emotions x 2 repetitions plus 4 catch trials). Participants were required to select whether the morphed character resembled more closely model A (key 1) or model B (key 2). The rationale was that when participants would have implicitly learnt that character A had a positive disposition toward them and character B had a negative disposition toward them, then they would be more likely to judge the smiling morph as more similar to character A, and the frowning morph as more similar to character B, because intuitively character A would be associated with a 'positive' and character B with 'negative' attitude.

[1] Morph levels were determined through a pilot study. Specifically, the M3 morphs were tested to ensure that they are **perceptual** representation of 50% A and 50% B and are therefore, equally likely to be selected without any prior learning experience. The result of the pilot study revealed that morphs produced by the morphing software met this criterion.

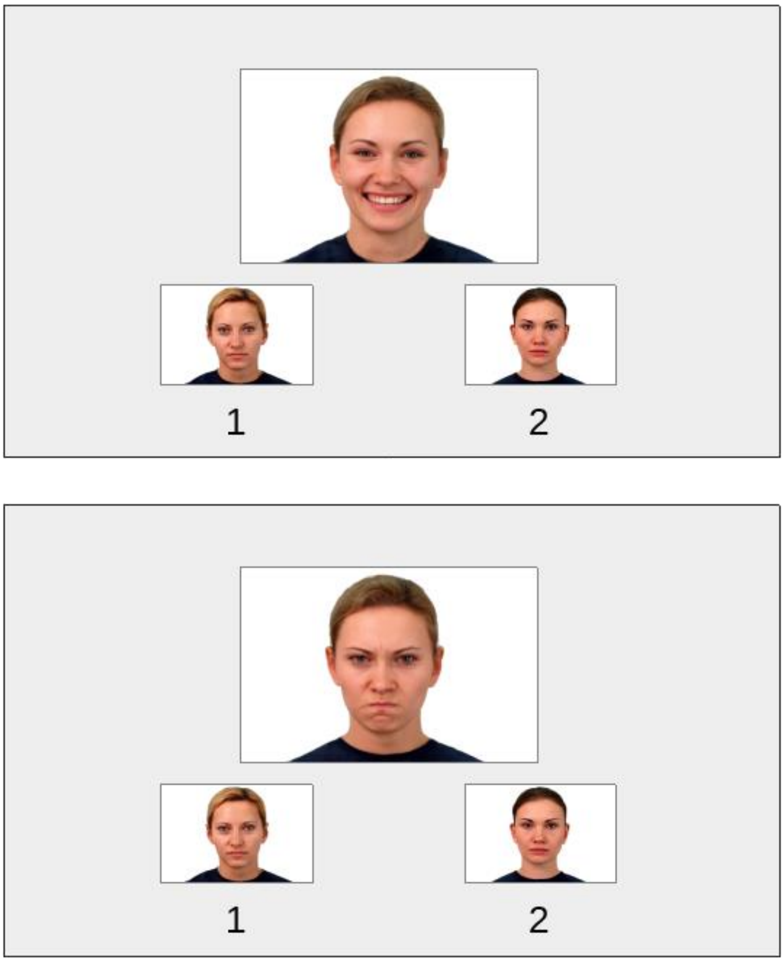


Figure 4 Example of two test trials (top and bottom panel). The central image shows morphs consisting of 50% of MS and SO (M3), for happy (top) and angry (bottom) facial expressions. The morphs were flanked by MS and SO displaying neutral expressions, labelled as 1 and 2. Participants were asked to decide whether the morph resembles more character 1 or character 2 by pressing the appropriate button.

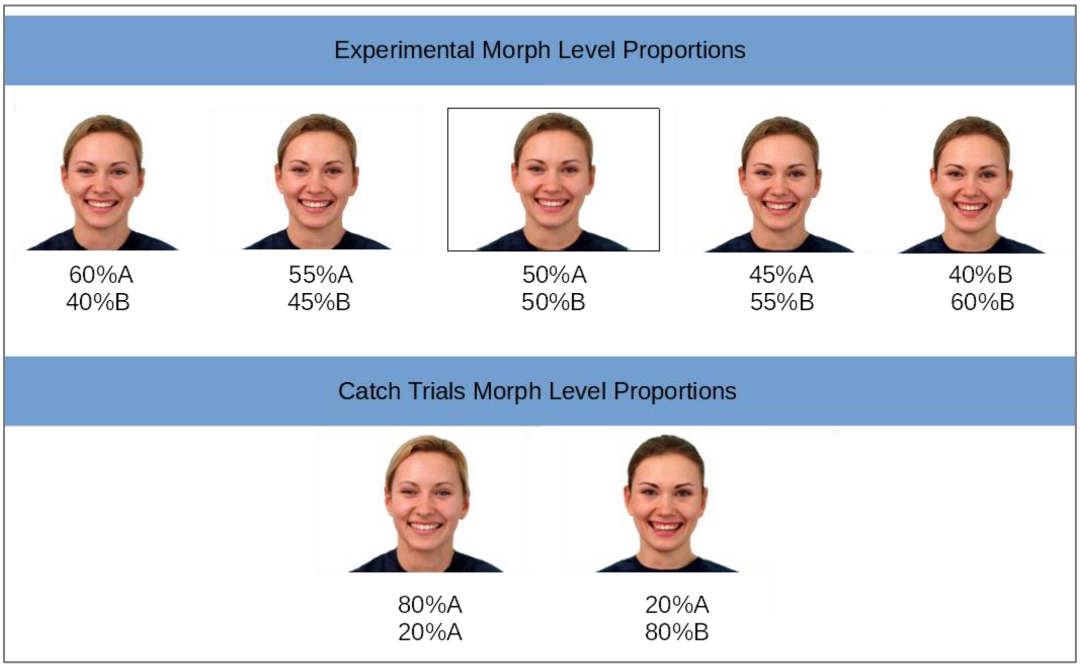


Figure 5 Morph level proportions used in the study, including catch trials – an example of a smiling morph. Morphs displaying expressions of joy and anger appeared in the random order one at the time, as visualised by the test trials in Figure 4.

Likability Questionnaire

Directly after the test phase, participants completed likability questionnaires for each character. Questions asked were as follows:

1. How much do you like this person?
2. How much does this person like you?
3. How much would you like to co-operate?
4. How much would you like to avoid this person?
5. How attractive do you find this person?

The questionnaires were coupled to a photograph of the character the questionnaire was about, who displayed a neutral facial expression. Participants were required to mark their answer on a scale from 0 – 100. For Question 4, an opposite scoring was applied (Score = 100 – Participant Score). The identity learnt as having a positive disposition toward the observer was expected to be judged more favourably than the identity learnt as having a negative disposition toward the observer.

AQ Questionnaire.

At the end of the experiment, an online version of the 50-item Autism Quotient (AQ) questionnaire was administrated to determine levels of self-reported autistic-traits (Baron-Cohen, Wheelwright, Skinner, et al., 2001). A median split was performed on the participants' AQ score to divide them into two groups: a low AQ group and a high AQ group. The AQ scores ranged from 7 to 34, with the median at 17, resulting in 23 participants in low AQ group (M = 13.65, SD = 2.52) and 23 in high AQ group (M = 22.13, SD = 3.70).

Results

Data Analysis

The results presented in this section were obtained by collapsing the data from all four versions of the experiment. The dependent variable consisted of the mean scores on the five levels of morphs used in the test phase (catch trials were not included in the analysis). A mean score of 1 would indicate that participants believed the morphs resembled the character with a positive disposition toward the observer, while a perfect mean score of -1 would indicate that participants believed the morph resembled the character with a negative disposition toward the observer. A score of 0 would indicate no biases in the perception of two identities, with participants judging the morphs purely on the basis of their physical properties (no implicit learning effect).

Data Reduction

Participants were excluded if they: (1) discovered the contingencies as learning was then no longer implicit (five participants) or (2) failed to correctly respond to at least 75% of catch trials in the test phase (three participants) suggesting they did not pay proper attention. In total, data from eight participants were removed from the analysis. As per the questioning session, all participants correctly identified the emotions portrayed by the characters used in the study.

Demographics

After applying exclusion criteria, an independent samples t-test showed that the high and low AQ groups did not differ on age ($t(44) = 1.33$, $p = .191$). A chi square test revealed however, a significant difference between groups in terms of gender ratio ($X_2(1, N = 46) = 4.06$, $p = .044$).

Morph Perception Task Results

A repeated measures ANOVA was conducted with Morph Facial Expression (happy, angry) and Morph Level (M1, M2, M3, M4, M5) as within-subject factors and AQ Group (low AQ, high AQ) as a between-subject factor. The results are illustrated in Figure 6 (for clarity low and high AQ groups are shown in separate graphs). There was a main effect of Morph Facial Expression ($F_{1,44} = 13.22$, $p = .001$, $\eta p2 = .231$), indicating that implicit learning has taken place and a main effect of Morph Level ($F_{4,176} = 17.16$, $p < .001$, $\eta p2 = .626$), reflecting participants were sensitive to different morph level proportions. Results showed a significant interaction between Morph Facial Expression and AQ Group ($F_{1,44} = 9.39$, $p = .004$, $\eta p2 = .176$). Follow up paired samples t-tests revealed a significant difference in judgements of smiling and frowning morphs in low AQ group ($t(22) = 4.91$, $p <.001$, $d = 1.03$), but no such difference was found in high AQ group ($t(22) = .391$, $p = .700$). There was no main effect of Group ($F_{1,44} = 0.36$, $p = .850$, $\eta p2 = .001$). All remaining interactions were also non-significant (all p's > .121).

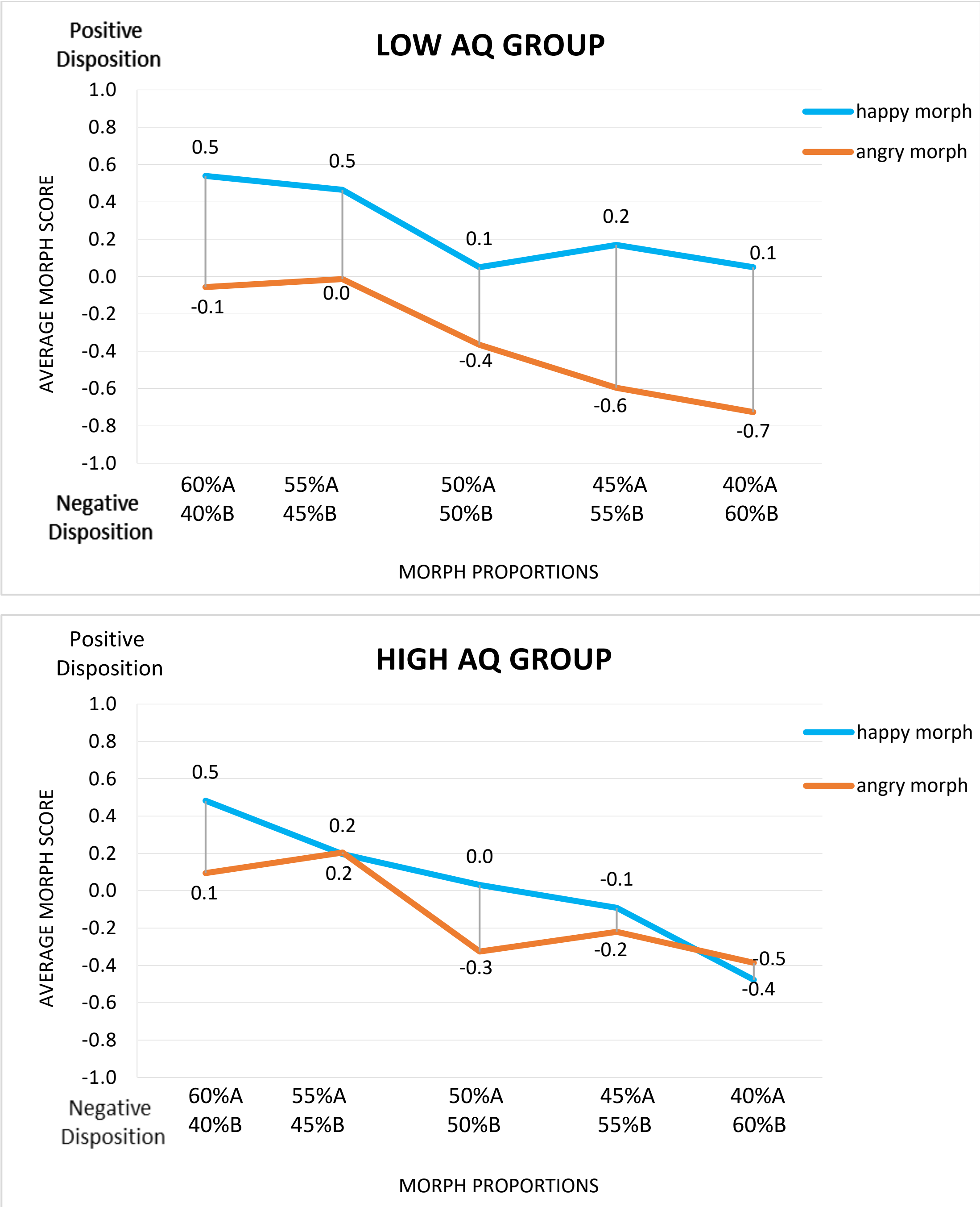


Figure 6 The mean scores across all morph levels (proportions of character A and character B) shown for each group. The amount of implicit learning is represented by a difference between mean score for happy and angry morph. Clear implicit learning effect can be observed in the Low AQ Group (top panel). Implicit learning in the High AQ Group was not evident (bottom panel).

Likability Questionnaire Data Results

A 2x5x2 repeated-measures ANOVA was performed to analyse the questionnaire data, with Character Disposition (positive, negative) and Question Type (5 questions) as within-subject factors and AQ Group (low AQ, high AQ) as the between-subject factor. Data from one participant were incomplete and were not included in the analysis. The results from the remaining forty-five participants are presented in Figure 7 (for clarity low and high AQ groups are shown in separate graphs). There was a main effect of Character Disposition ($F_{1,43} = 24.63$, $p < .001$, $\eta p2 = .364$), with higher likability scores for characters with positive disposition ($M = 66.13$, $SD = 14.22$) as compared to negative disposition ($M = 53.26$, $SD = 15.08$). A similar pattern of the results was found for both groups, with no interaction between Character Disposition and AQ Group ($p = .643$). There was a main effect of Question Type ($F_{2.98,128.29} = 10.72$, $p < .001$, $\eta p2 = .200$) and a significant interaction between Character Disposition and Question Type ($F_{2.91,125.29} = 5.08$, $p = .001$, $\eta p2 = .106$). Follow-up t-tests revealed significant differences in likability scores between characters with a positive and negative disposition for all Question Types (p's $< .005$ after Bonferroni corrections), except for Question 5 on attractiveness ($p = .108$). Importantly, the three-way interaction between Character Disposition, Question Type and AQ Group was non-significant ($p = .538$).

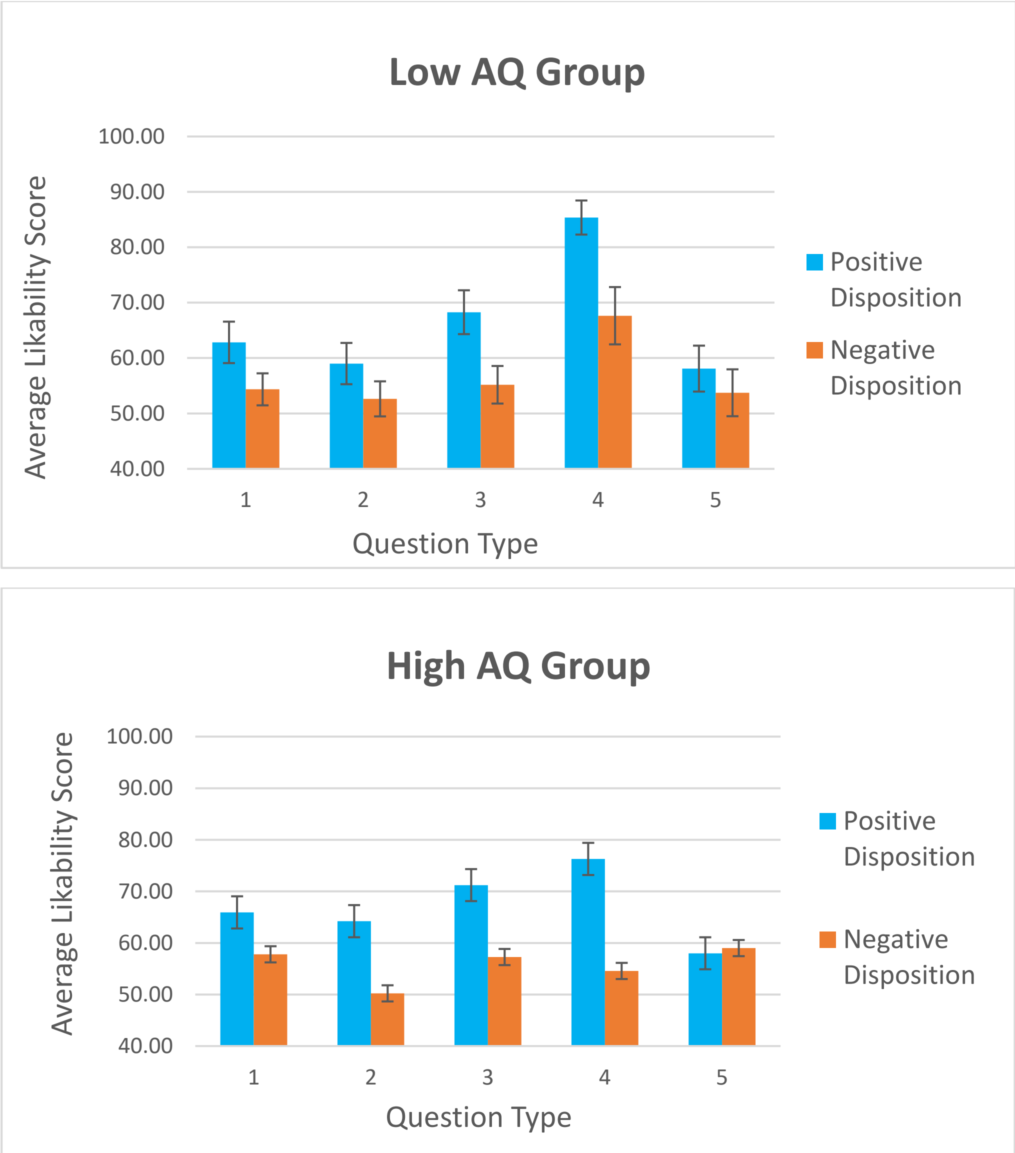


Figure 7 The mean scores for positive-disposition and negative-disposition identity for Low AQ Group (top panel) and High AQ Group (bottom panel). Error bars represent SE.

Discussion

This study examined implicit learning of social cue contingencies in the typically-developed population and whether this capacity was related to the extent of autistic traits measured with the AQ questionnaire. First of all, the results revealed that implicit social learning took place in TD individuals in the current paradigm. Participants showed biases in their perception of the morphs in line with the displayed character dispositions. Secondly, the results from the Morph Judgement task suggest that the capacity for implicit learning was influenced by individual differences in autistic traits. Those with lower levels of autistic traits (low AQ group) implicitly learnt the social dispositions to a larger extent than those with more autistic traits (high AQ group). On the contrary, the likability questionnaire data did not differ between the groups. Participants showed a clear preference toward characters with a positive disposition, which received significantly higher ratings than characters with a negative disposition.

Perceptual bias in the judgement of morphs

The findings from the current study are in line with previous research on implicit social learning, which suggest that people are sensitive to social cues and can be implicitly guided by them (Bayliss & Tipper, 2006; Heerey & Velani, 2010; Hudson, Nijboer, et al., 2012; Lewicki et al., 1992; van 't Wout & Sanfey, 2008). The implicitly learnt dispositions of an individual may serve as useful predictors of an individual's future behaviour toward the individual, affecting one's subsequent responses to that individual. In the current paradigm, the positive or negative dispositions of another individual could be implicitly understood on the basis of specific social cue combinations conveyed in a social encounter (i.e. the learning phase), without one being aware of the contingencies. It is important to note that the characters encountered in the learning phase were smiling and frowning for exactly the same amount of time. They were also looking at and away from the observer for exactly the same amount of time. As such, the implicit learning could not have occurred on the basis of any single cue (facial expression or gaze direction). The cues must have been integrated to correctly infer the dispositions of the characters in line with the hidden contingencies. This seems to happen implicitly, outside of conscious awareness; the participants were not motivated to learn the expression/gaze contingencies, and indeed the question session afterwards revealed they had not noticed that each identity had an idiosyncratic pattern of gaze and expression behaviour. Yet, they were biased in their perception of the morphs in line with the hidden contingencies. The smiling and frowning morphs were judged differently, even though they in principle portrayed the same person (created from a combination of physical features of the two characters presented in the learning phase). The only difference was the facial expression they conveyed, which was sufficient to induce a perceptual distortion, with a smiling morph consistently judged as resembling more a character with a positive disposition and frowning morph consistently judged as resembling more a character with a negative disposition.

This perceptual bias was, however, not observed in those with higher levels of autistic traits. This may indicate that those in the high AQ group were not able to learn implicitly from the combinations of the social cues. However, in principle, other factors unrelated to the ability to learn implicitly could have contributed to the observed results. Reduced accuracy and sensitivity to emotional facial expressions have been previously reported in those with higher levels of autistic traits, especially for sadness, anger and disgust (Poljac, Poljac, & Wagemans, 2013). However, this was only evident for expressions low in emotional content while only intense facial expressions of joy and anger were used in this study, which have been found to be recognised correctly even by individuals with high-functioning autism (Golan, Baron-Cohen, Hill, & Rutherford, 2007). Therefore, the lack of learning effect would be unlikely to result from difficulty in understanding social cues, especially that a question session with the participants confirmed that they were able to easily identify facial expressions displayed by the characters and noted changes in gaze direction. It seems that those with more autistic traits did not automatically acquire the meaning of social contingencies that one identity held a positive disposition towards then and the other a negative disposition, and consequently showed a smaller bias in their perception of the morphs. However, if this was the case, it is not clear why a discrepancy was found between the morph judgement task and likability questionnaire ratings in those high in autistic traits.

<u>Likability questioners</u>

The current study assessed implicit social learning using both indirect and direct measures to tap into implicitly acquired knowledge. Further to the perceptual biases observed in the morph judging task, low AQ participants showed a clear preference towards the positive-disposition identity, as indicated by significantly higher ratings on the likability questionnaire. Low AQ participants consistently reported that they liked the character displaying positive disposition more and would like to cooperate with them more than with the character displaying negative disposition. Interestingly, attractiveness ratings seemed to be not affected by the dispositions of the characters. Likability may be more related to the observer's own perspective and feelings, whereas attractiveness may be seen as a property belonging to the character, determined by the concrete physical features, irrespective of one's own relation to that character. It could be that the attractiveness represents a different dimension than liking; one can still judge someone as attractive, even though they may not like them as a person.

While those with low AQ scores showed evidence of learning on both measures of implicit learning, in those with high AQ scores the influence of implicitly acquired associations was only evident when measured explicitly by likability questionnaire assessing feelings toward each character directly. This could mean that the high AQ group has also learnt dispositions of the identities, however, this knowledge failed to bias their perceptions of them in the same ways as it did for the low AQ group. Yet, when explicitly asked to express their attitudes toward the identities, the responses indicated that they were indeed affected by the previous learning experience.

This dissociation between results obtained through direct versus indirect assessments is in line with previous studies that found impaired social implicit learning in relation to high AQ scores when implicit learning is assessed with indirect measures, a magnitude of gaze-cueing in particular (Bayliss & Tipper, 2006; Hudson, Nijboer, et al., 2012). While indirect measures have been argued to have a better capacity to uncover implicitly acquired knowledge, they typically require this knowledge to be employed flexibly in novel tasks, which are often unrelated to initial learning. Dissociations between explicit and implicit perception have been previously reported in individuals with ASD (Ruffman et al., 2001; Senju, 2013).

<u>Low-level perceptual learning as an alternate explanation.</u>

There is a possibility that the variations in implicit learning between individuals low and high in autistic traits may be due to a more generalized impairment in perceptual learning, rather than to a form of social learning. There is some evidence that individuals with ASD do not extract relevant information from repeated exposure to visual patterns to the same extent as TD individuals (Plaisted, O'Riordan, & Baron-Cohen, 1998), and that those with high AQ scores outperform those with low AQ scores on these tasks (Reed, Lowe, & Everett, 2011).

The task employed in the current study could have been solved on the basis of low-level visual cues. This is so because the morphed face displaying a smile has eyes which look at the observer, which is an expression/gaze configuration that also occurs during the learning phase in the identity with a positive disposition towards the observer but *not* in the identity with a negative disposition towards the observer. In the latter identity, the eyes are averted whenever a smile is displayed (see Figure 8). Thus, one could argue the smiling morphed face has a closer low-level visual match to the positive-disposition identity than to the negative-disposition identity, and similarly that the frowning morphed face has a closer visual match to the negative-disposition identity than to the positive-disposition identity. Thus, in principle, it could be that participants remember the perceptual image of a character with a positive disposition, with a smile accompanying by directed gaze. When the morphed target was shown with a smile and eyes directed at the observer later in the test phase, this could trigger the perceptual image of that character. Likewise, the perceptual image of a character with negative disposition would be triggered by a morphed target that frowns with eyes ahead. Experiment 2 is designed to examine this possibility.

Figure 8 Example of the low-level perceptual learning. MS character (top-left corner) displaying expression/gaze combination of smiling morph (right-bottom corner. SO character (bottom-left corner) displaying expression/gaze cue combination of frowning morph (top-right corner).

3.2 Experiment 2

The aim of Experiment 2 was to investigate whether the social learning observed in Experiment 1 could have occurred on the basis of the closer matching of low-level features of the morphs – eye and mouth configuration – with one of the two actors, rather than on the basis of differences in actors' dispositions toward the observer. To eliminate the possibility of such low-level perceptual learning, the test phase of the social condition was modified; the morphs of the two identities were presented with eyes covered by small rectangles (see Figure 8). As both characters smile (and frown) equal amount of time during the learning phase, the facial expression on its own is not sufficient to perceptually discriminate between the two actors. It is the combination of the facial expression and gaze direction during the learning phase that can give rise to the implicit understanding of characters' disposition. If the behavioural results in the conditions with and without the eyes covered follow the same pattern, then we conclude that perceptual learning was not a contributing factor to the learning outcome.

Methods

Participants

Seventy-four undergraduate psychology students from the University of Hull participated in the experiment in exchange for course credit. Students, who took part in Experiment 1, were not allowed to participate. All participants had a normal or corrected-to-normal vision. After applying exclusion criteria (see Data Reduction below for details), the final sample consisted of sixty-nine individuals (forty-two women, twenty-seven men), with an average age of 21.62 (SD = 5.99).

Stimuli and Procedure

The stimuli and procedure were the same as those in Experiment 1, except for the following changes in the test phase. To exclude the possibility of perceptual learning of low-level facial features as an alternative explanation for the learning in the social condition, the morphs of the two identities were presented with eyes covered. Each eye was covered by a small rectangle with a purple fill (see Figure 8). The rectangles were small enough to not hide any other features of the face of the morphs (e.g. eyebrows), but large enough to completely cover the eyes.

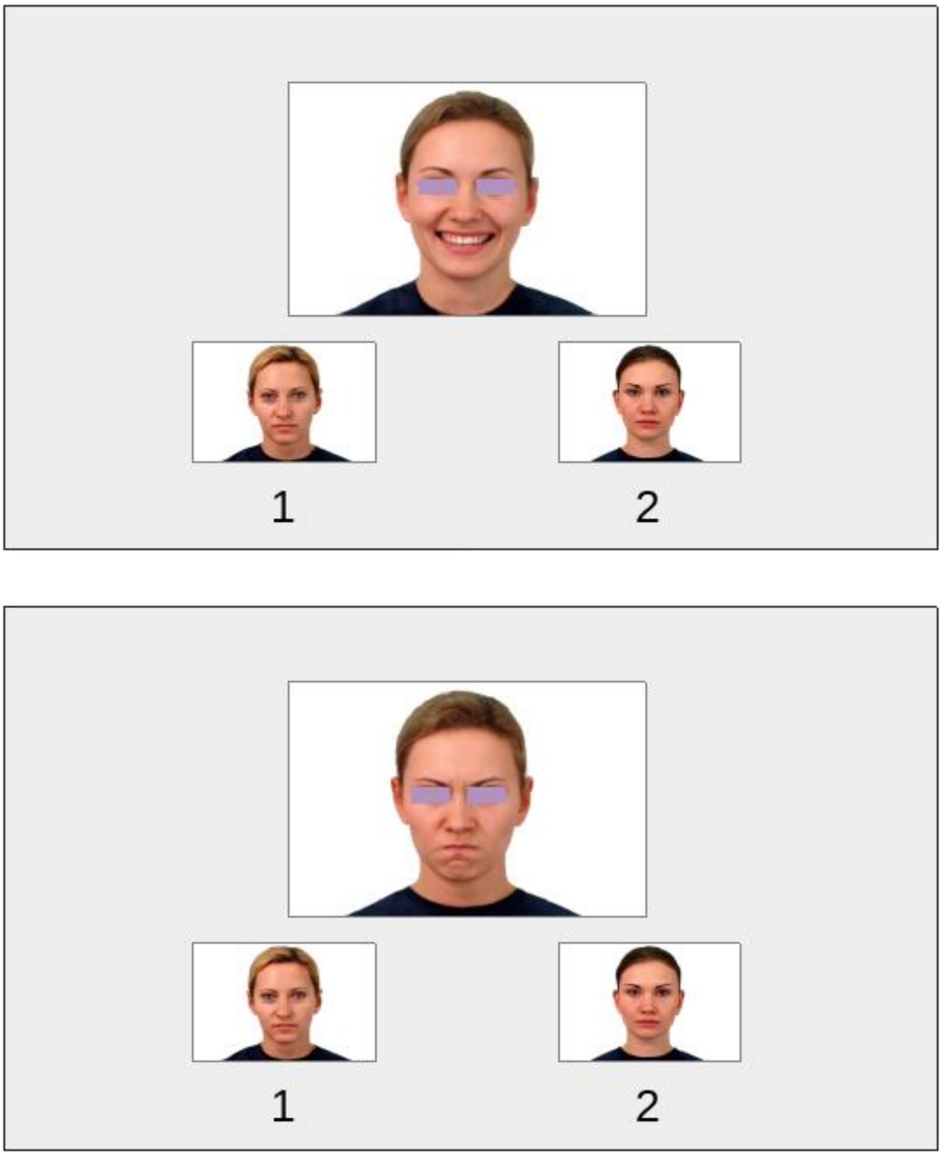


Figure 9 Example of 50% morph proportion of two female characters with eyes covered.

Results

Data Analysis and Data Reduction

Data analysis and exclusion criteria were the same as in Experiment 1. Two participants discovered the hidden contingencies in the task and two participants failed to correctly respond to at least 75% of catch trials. In addition, one participant's data were not included in the analysis, as she did not follow the task instructions. In total, data from five participants were removed. As per the questioning session, all participants correctly identified the emotions portrayed by the characters used in the study.

Demographics

As in Experiment 1, a median split was performed on the participants' AQ score as to divide them into a low AQ group and a high AQ group. The AQ scores ranged from 5 to 42, with the median at 16, resulting in 35 participants in low AQ group (*M* = 12.54, *SD* = 2.79) and 34 in high AQ group (*M* = 23.00, *SD* = 5.19). An independent samples t-test showed that the high and low AQ groups did not differ in age ($t(67)$ = .916, p = .329). A chi-square test revealed, however, a significant difference between low and high AQ groups in terms of gender ratio ($X_2(1, N = 69) = 4.51$, $p = .034$), with similar number of women and men in the low AQ group, but more women than men in the high AQ group.

Morph Perception Task Results

A repeated-measures ANOVA was conducted with Morph Facial Expression (happy, angry) and Morph Level (M1, M2, M3, M4, M5) as within-subject factors and AQ Group (low AQ, high AQ) as a between-subject factor. The results are illustrated in Figure 10 (for clarity low and high AQ groups are shown in separate graphs). There was a main effect of Morph Facial Expression ($F_{1,64} = 8.56$, $p = .005$, $\eta p^2 = .118$), indicating that implicit learning has taken place and a main effect of Morph Level ($F_{4,256} = 33.92$, $p < .001$, $\eta p^2 = .346$), reflecting participants were sensitive to different morph level proportions. Results showed a significant interaction between Morph Facial Expression and AQ Group ($F_{1,64} = 17.90$, $p < .001$, $\eta p^2 = .219$). Follow up paired samples t-tests revealed a significant difference in judgements of smiling and frowning morphs in low AQ group ($t(34) = 5.25$, $p <.001$, $d = 0.94$), but no such difference was found in high AQ group ($t(33) = .798$, $p = .340$). All remaining effects and interactions were non-significant (all p's > .256).

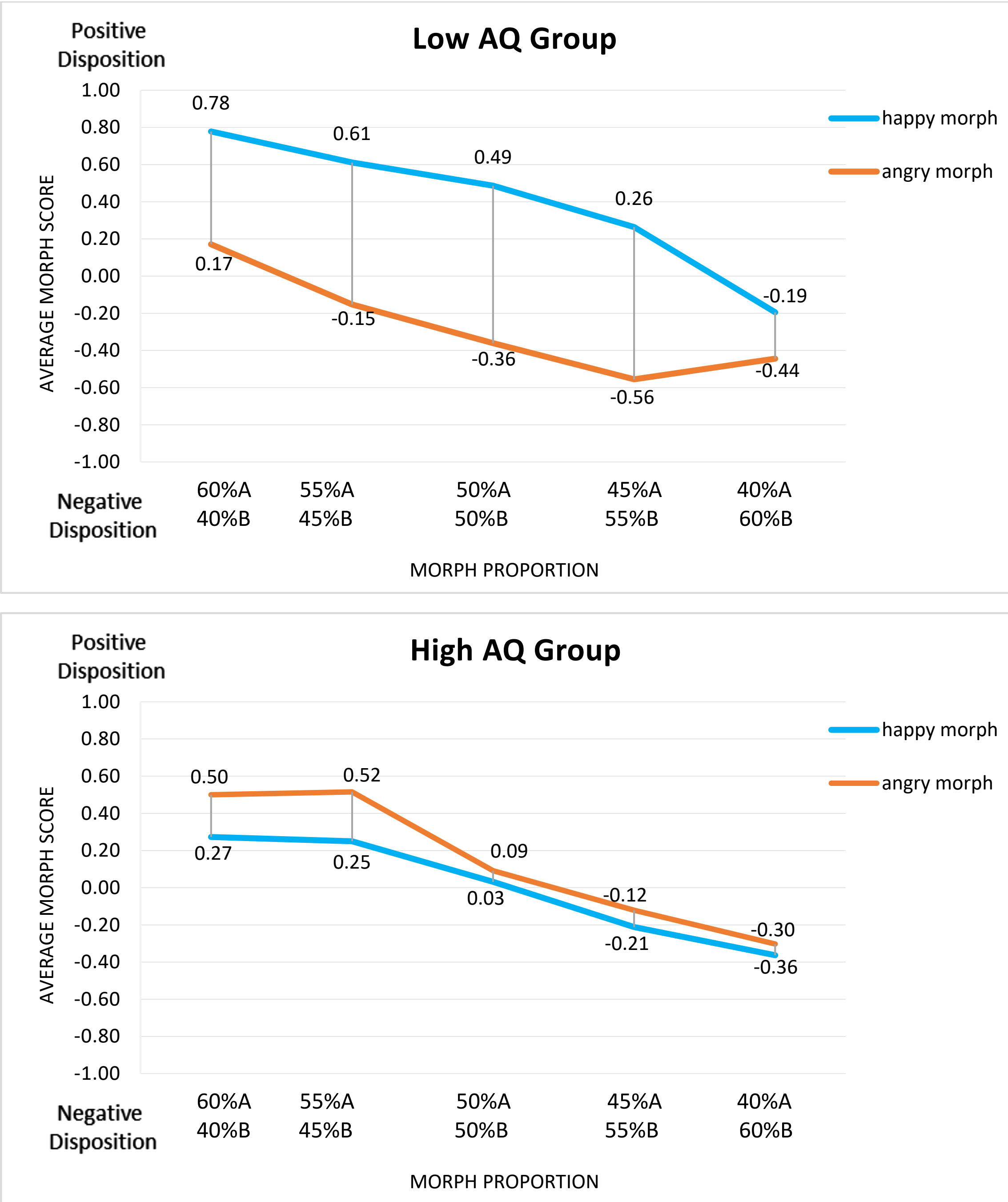
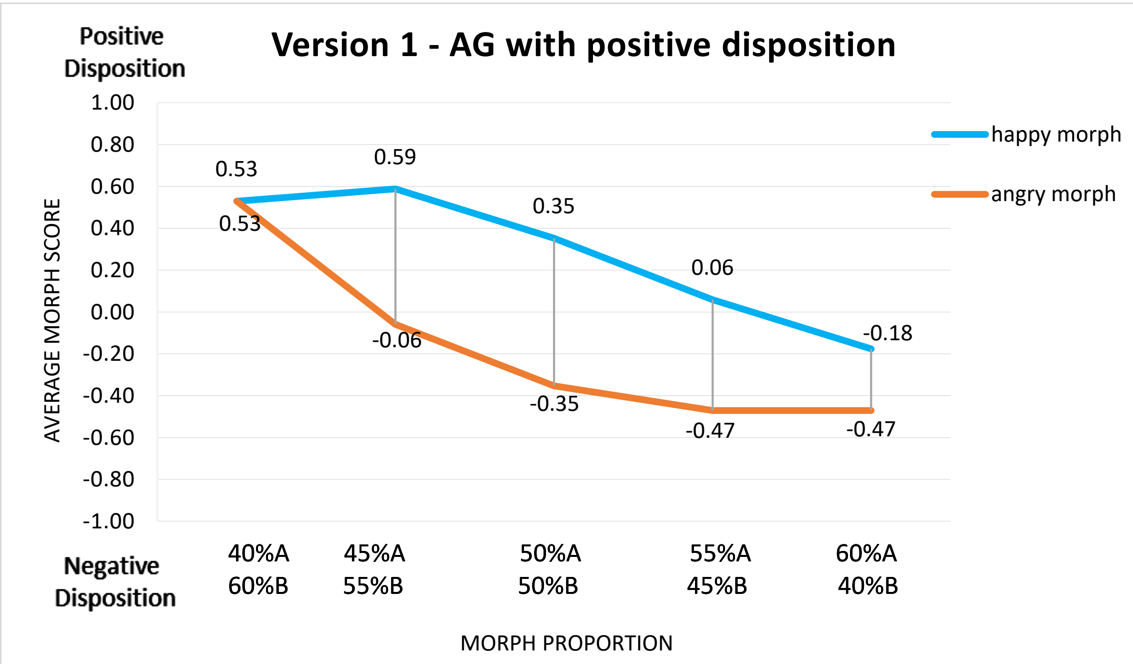
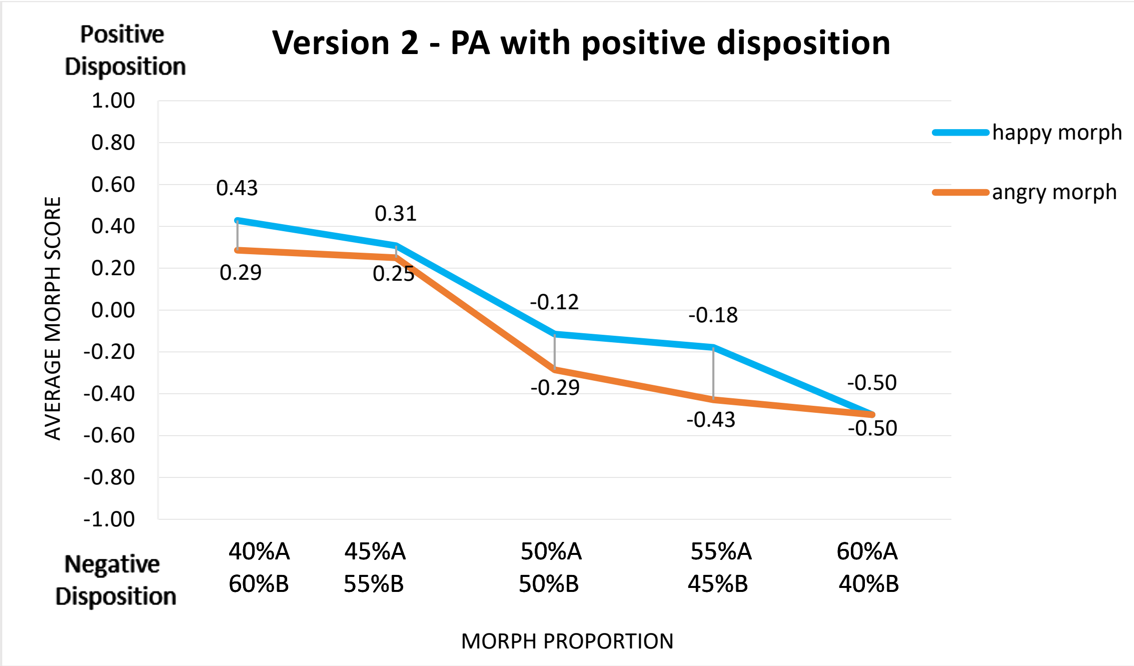


Figure 10 The mean scores across all morph levels (proportions of character A and character B) shown for each group. The amount of implicit learning is represented by the difference between mean scores for the happy and angry morphs. Clear implicit learning effect can be observed in the Low AQ Group (top panel). Implicit learning in the High AQ Group is not evident (bottom panel).

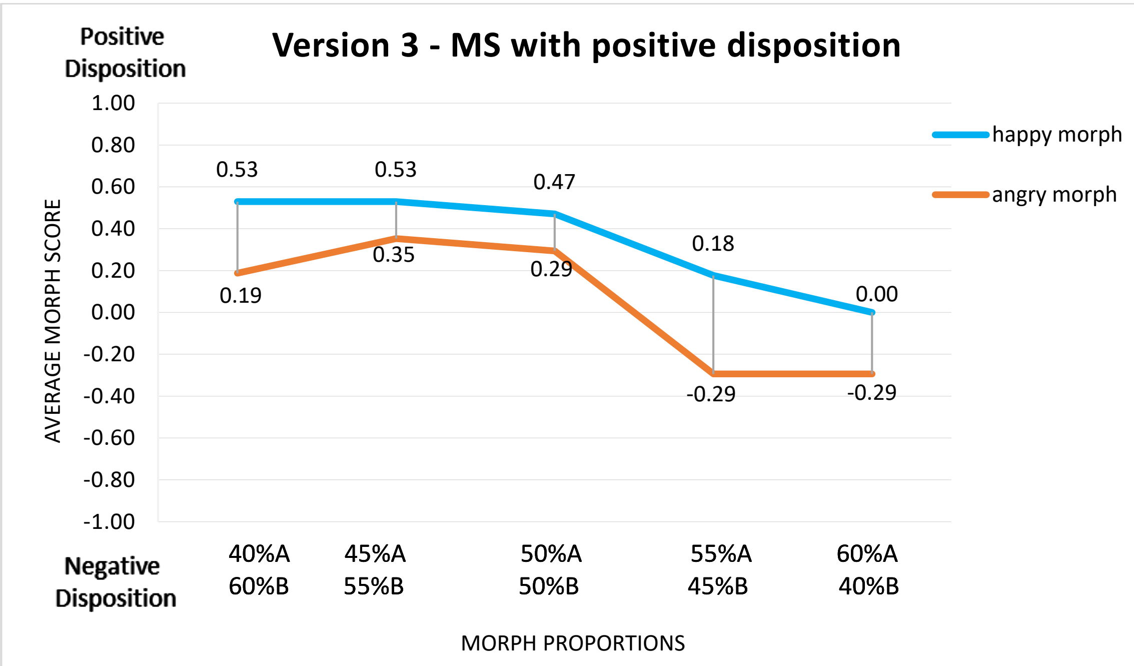
<u>Possible identity effects</u>

Additional analysis was performed to ensure that the obtained results are not driven by one version of the experiment and are present regardless of the specific character used as a positive or negative identity. A repeated-measures ANOVA was conducted with Morph Facial Expression (happy, angry) and Morph Level (M1, M2, M3, M4, M5) as within-subject factors and Experiment version (MS with positive disposition, SO with positive disposition, AG with positive disposition, PA with positive disposition) as a between-subject factor. The results are illustrated in Figure 11 (for clarity each version of the experiment is shown in separate graphs). There was a main effect of Morph Facial Expression ($F_{1,62} = 6.76$, $p = .012$, $\eta p2 = .098$) and a main effect of Morph Level ($F_{4,248} = 12.65$, $p < .001$, $\eta p2 = .379$). Most importantly, the interaction between Morph Facial Expression and Experiment version was non-significant ($F_{3, 62} = 0.31$, $p = .817$, $\eta p^2 = .015$), suggesting that the implicit learning effect was present across characters. All remaining effects and interactions were non-significant (all *p*'s > .05).





Version 2 - PA with positive disposition
Positive Disposition
Negative Disposition
AVERAGE MORPH SCORE
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
0.43
0.31
-0.12
-0.18
-0.50
0.29
0.25
-0.29
-0.43
-0.50
40%A 60%B
45%A 55%B
50%A 50%B
55%A 45%B
60%A 40%B
MORPH PROPORTION
happy morph
angry morph



Version 3 - MS with positive disposition
Positive Disposition
Negative Disposition
AVERAGE MORPH SCORE
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
0.53
0.53
0.47
0.18
0.00
0.19
0.35
0.29
-0.29
-0.29
40%A 60%B
45%A 55%B
50%A 50%B
55%A 45%B
60%A 40%B
MORPH PROPORTIONS
happy morph
angry morph

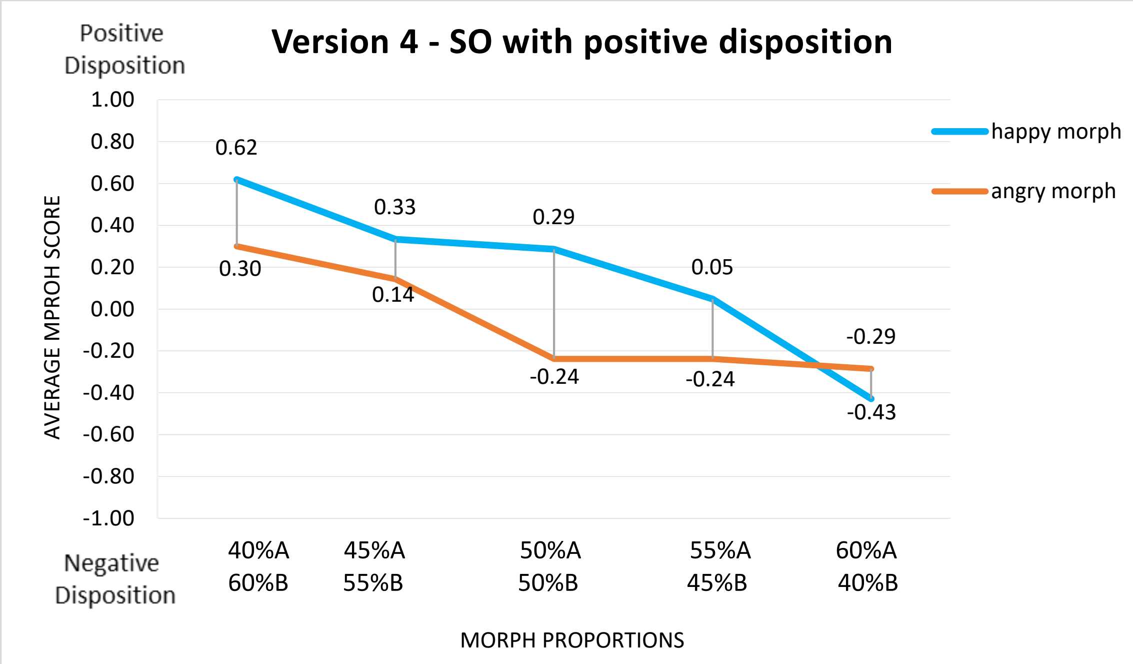


Figure 11 The mean scores across all morph levels (proportions of character A and character B) shown for each model used in the experiment. Although there are some variations in the amount of implicit learning, the overall pattern of results remains the same. Participant number for each version was a follows version 1: 17, version 2: 16, version 3: 17, version 4: 19.

<u>Gender Differences</u>

Differences in social cognition between men and women have been noted in the past. Female superiority has been shown in emotion recognition, social communication and mind-reading (for a review see Kret & De Gelder, 2012). As the chi-square analysis revealed differences in gender ratio for low and high AQ groups, additional analysis was performed with Morph Facial Expression (happy, angry) and Morph Level (M1, M2, M3, M4, M5) as within-subject factors and gender of the participant as between-subject factors. The sample consisted of 40 women and 26 men.

The results are presented in Figure 12. There was a main effect of Morph Facial Expression ($F_{1,\,64} = 7.97$, $p = .006$, ηp2 = .111) and a main effect of Morph Level ($F_{4,256} = 12.70$, $p < .001$, ηp2 = .345). However, the interaction between Morph Facial Expression and Gender was non-significant ($F_{1,\,64} = 0.65$, $p = .424$, ηp2 = .010), suggesting no gender differences in the capacity for implicit social learning. All remaining interactions were also non-significant (all p's > .05).

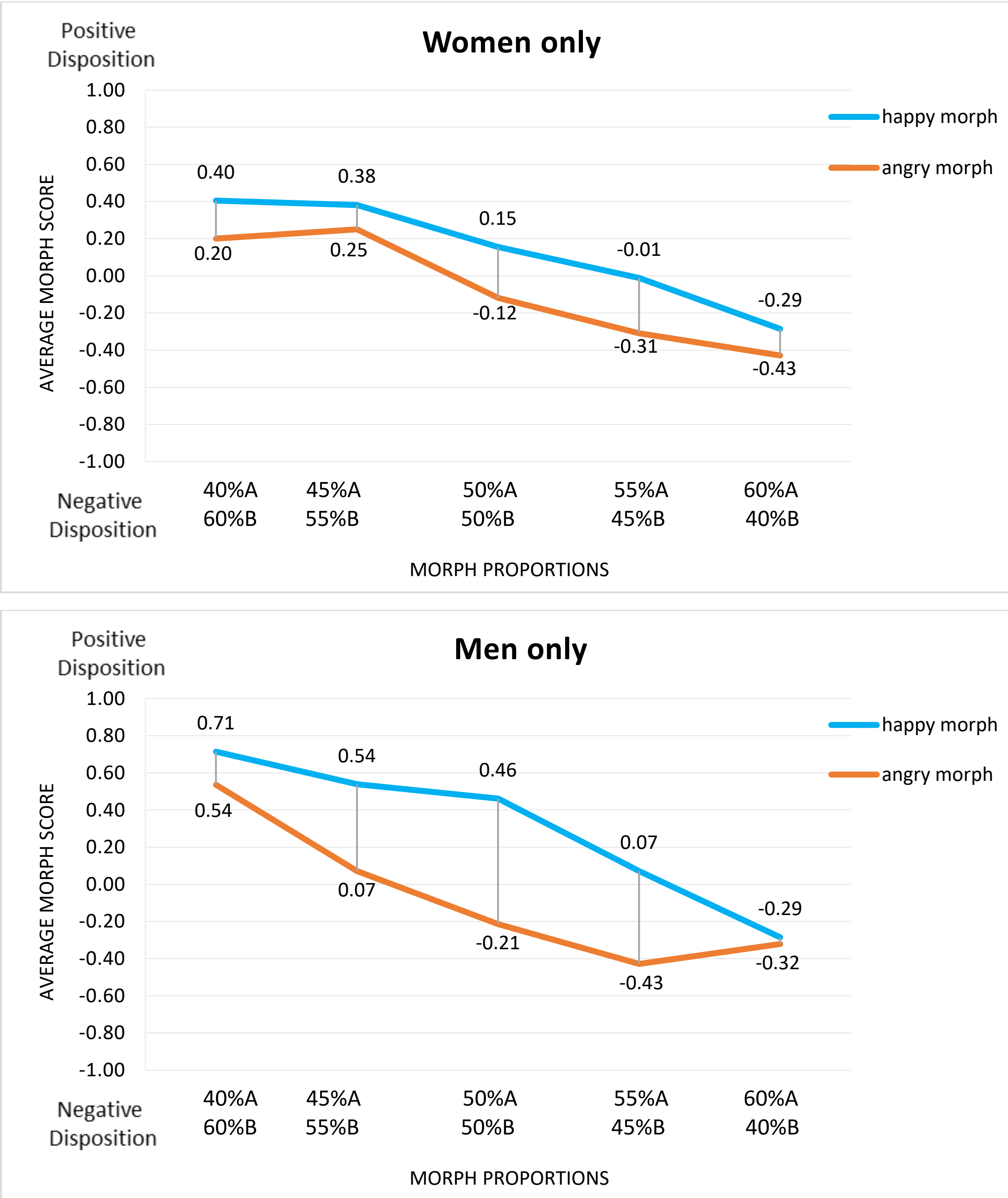


Figure 12 The mean scores across all morph levels (proportions) shown for each sex. Although men (bottom panel) seem to show more implicit learning than women (top panel) in this particular task, this difference did not reach significance.

Questionnaire Data Results

A repeated-measures ANOVA was performed to analyse the likability questionnaire data, with Character Disposition (positive, negative) and Question Type as within-subject factors and AQ Group (low AQ, high AQ) as between-subject factor. To recap, the list of questions was as follows:

1. How much do you like this person?
2. How much does this person like you?
3. How much would you like to co-operate?
4. How much would you like to avoid this person?
5. How attractive do you find this person?

The results are presented in Figure 13 (for clarity low and high AQ groups are shown in separate graphs). There was a significant main effect of Character disposition ($F_{1,63} = 6.46$, $p = .014$, $\eta p2 = .093$), with higher likability scores attracted by characters with positive disposition ($M = 63.73$, $SD = 14.16$) compared to negative disposition ($M = 57.27$, $SD = 15.19$). A similar pattern of results was found for both groups, with no interaction between Character Disposition and AQ Group ($p = .556$). The main effect of AQ group was also non-significant ($p = .835$). There was a main effect of Question Type ($F_{3.24, 203.98} = 17.71$, $p < .001$, $\eta p2 = .219$) and a significant interaction between Character Disposition and Question Type ($F_{2.98,188.17} = 4.24$, $p = .006$, $\eta p2 = .063$). Bonferroni corrected follow-up t-tests revelled significant differences in likability scores between characters with positive and negative disposition for Question 2 ($p = .010$) and Question 3 ($p = .045$), but not for Question 1 ($p = .080$), Question 4 ($p = .120$) nor Question 5 ($p = .973$). There was also a significant interaction between Question Type and AQ Group ($F_{3.24, 203.98} = 6.07$, $p < .001$, $\eta p2 = .088$). The three-way interaction between Character Disposition, Question Type and AQ Group was non-significant ($p = .884$).

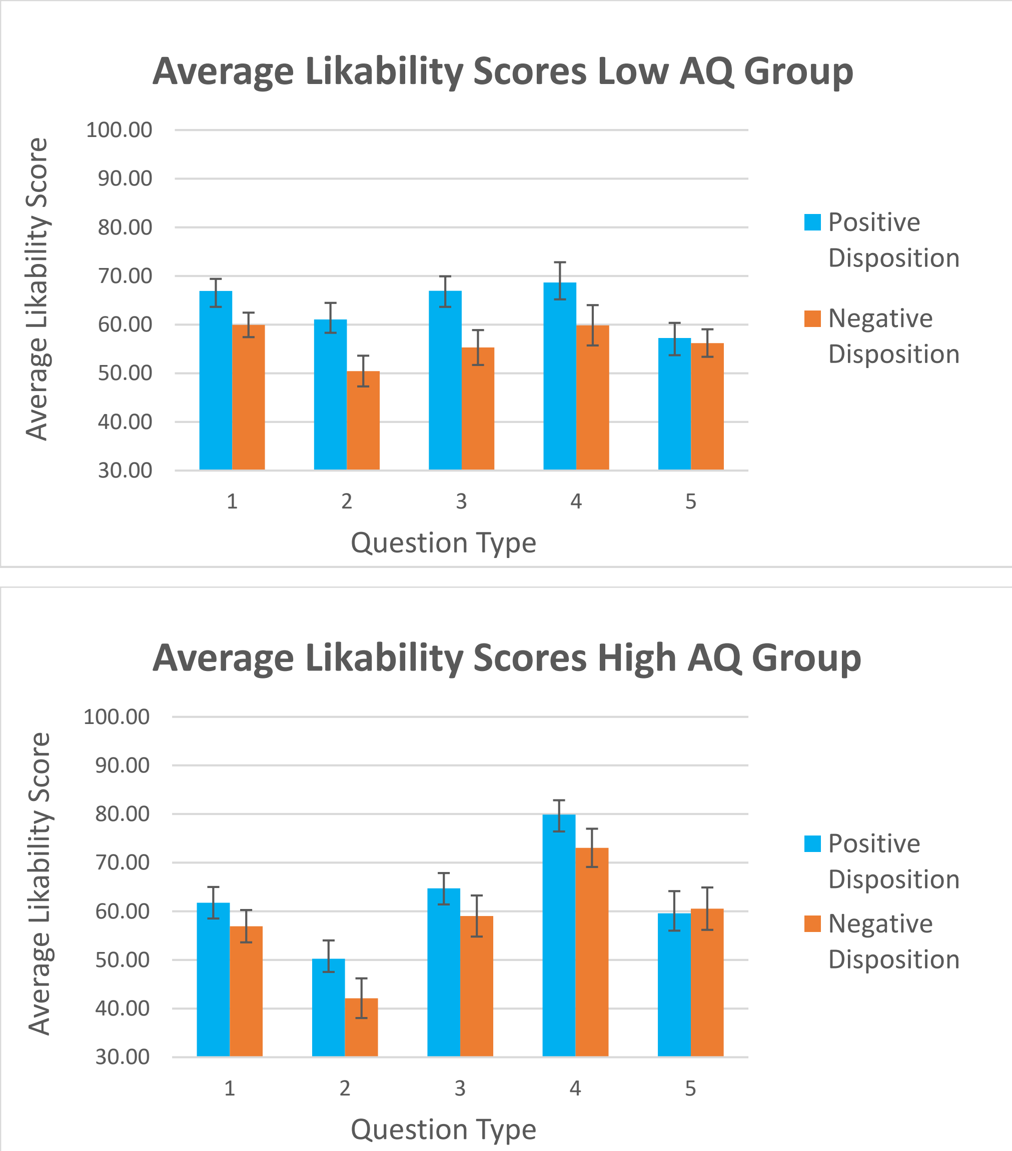


Figure 13 The mean scores for the positively- and negatively-portrayed identity for Low AQ Group (top panel) and High AQ Group (bottom panel). Error bars represent SE.

Discussion

This experiment explored whether the implicit learning observed in Experiment 1 could have occurred due to the perceptual learning of low- level features of the characters' faces. With the gaze direction cue removed in the test phase, any observed learning could be assumed to be social; only by inferring the actors' disposition towards them would participants have been able to associate the actor's identity with the morphs emotional displays presented in the test phase. In line with findings from Experiment 1, the results showed strong implicit learning effects. This pattern of results is against perceptual learning as a potential explanation for the observed learning outcomes. Since both characters displayed emotions of joy and anger for an equal amount of time; facial expressions of the morphed images would not have had enough informative value to allow to discriminate between the two characters. It seems that the combination of social cues witnessed in the learning phase influenced participants' implicit associations, which subsequently emerged as perceptual biases in morph judging task. The results revealed that the learning was present in all experimental versions of the experiment. This suggests that each character was capable of inducing implicit learning effects and that the association with smiling (or frowning morphs) were independent of character identity.

As in Experiment 1, implicit social learning was observed only for the low AQ group. It seems that the ability to implicitly learn about others on the basis of social cues is compromised in individuals with higher levels of autistic traits. The differences in the low and high AQ group were even more pronounced than in Experiment 2, with the high AQ group showing even a reversed (although non-significant) pattern in their judgement of the morphs. One possibility is that this reflects that performance of individuals high in autistic traits in Experiment 1 could have been affected by perceptual learning mechanism, even though it was not effective enough to match the performance of low AQ group. When perceptual cues were no longer available to inform morph judgements, a further reduction in performance of the high AQ group was seen. The reliance on low-level visual cues to guide the perception of social information have previously been found in ASD (Hudson & Jellema, 2011; Palumbo et al., 2015).

All in all, these results provide further evidence that implicit social learning is to some extent dysfunctional in individuals high in autistic traits, who seem to be less competent in picking up regularities in the social environment. However, it is not clear whether differences in the ability to learn implicitly is specific to *social* learning, or whether it reflects an impairment in implicit learning in general, irrespective of the domain. If it reflects an impairment in implicit learning *per se*, then we should also find impairments in implicit learning in the high AQ group in the non-social domain. In case the impairment does not apply to the non-social domain, meaning it is not a general implicit learning impairment, then it might even be so that in the non-social domain the high AQ group outperforms the low AQ group, as those with more autistic traits, are thought to be more sensitive to lawful systematic contingencies (Hudson, Burnett, & Jellema, 2012). Since tasks such as artificial grammar task or serial reaction time task are structurally different to social learning paradigm presented in this chapter, they may vary in difficulty and specific implicit learning mechanism they rely on. To allow for a direct comparison of implicit learning in social and non-social domains, Experiment 3 will extend the current paradigm by introducing a non-social task, which will mimic its social counterpart as closely as possible.

3.3 Experiment 3

It may be that implicit learning can be either intact or impaired depending on the type of information to be learnt (Seger, 1994). This suggestion is supported by the evidence form clinical populations, such as patients with cerebellar degeneration or Parkinson's disease (Siegert, Taylor, Weatherall, & Abernethy, 2006; Witt, Nuhsman, & Deuschl, 2002), where distinct patterns of deficits on different implicit learning tasks have been found within the same group of patients. However, it is still unclear to what extent the distinction between social and non-social domain is important for implicit learning. As human behaviour is dynamic and context-dependent rather than deterministic, detecting regularities in others' social behaviour could be more difficult than detecting regularities in the physical environment (Hellendoorn, Wijnroks, & Leseman, 2015). Therefore, ideally equally regular patterns embedded in social and non-social information should be compared if a dissociation between implicit social and non-social learning is to be investigated.

In this experiment the current social implicit learning paradigm was extended to the non-social domain, to allow for a direct comparison of implicit learning of social and non-social information, with tasks matched for internal structure and difficulty. Participants viewed videos of two geometric objects, of which the colour and the position of an internal object changed dynamically. Similarly to the social learning condition, the stimuli displayed hidden contingencies that could be learned implicitly and were matched on a number of cues. While in the social condition, specific combinations of facial expression and gaze direction were used to portray the actor as having either a positive or negative disposition towards the observer, in the non-social condition, the combination of colour and internal movement was used to predict the shape of the object as either a square or a circle. As there is evidence suggesting that non-social implicit learning is intact even in ASD, it was hypothesised that the high AQ group would be able to implicitly learn the contingencies within the non-social condition, possibly even better so than individuals. who possess fewer autistic traits.

Methods

Participants

Eighty-nine undergraduate psychology students from the University of Hull participated in the experiment in exchange for course credit. All participants had a normal or corrected-to-normal vision. After applying the exclusion criteria (see Data Reduction below for details), the final sample consisted of seventy individuals (fifty-two women, eighteen men), with an average age of 20.93 (SD = 5.01).

Stimuli

Computer-generated images of two geometric figures – a square and a circle - with two colours - light grey or dark grey - were used as non-social stimuli. A small red square was placed either at the top or at the bottom of each figure (see Figure 14). The images of each figure were morphed into short dynamic videos (using Sqirlz Morph software). Two features of the figures were manipulated: colour and internal movement of the red square. Each video started with the red square at the top of the figure, which then gradually moved downward, ending at the bottom of the figure, or the other way around (began at the bottom of the figure and ended at the top; the video played backwards). To manipulate the colours of the figures, the video began either with a light grey object, which gradually morphed into a dark grey object, or began with dark grey object morphed into a light grey object.

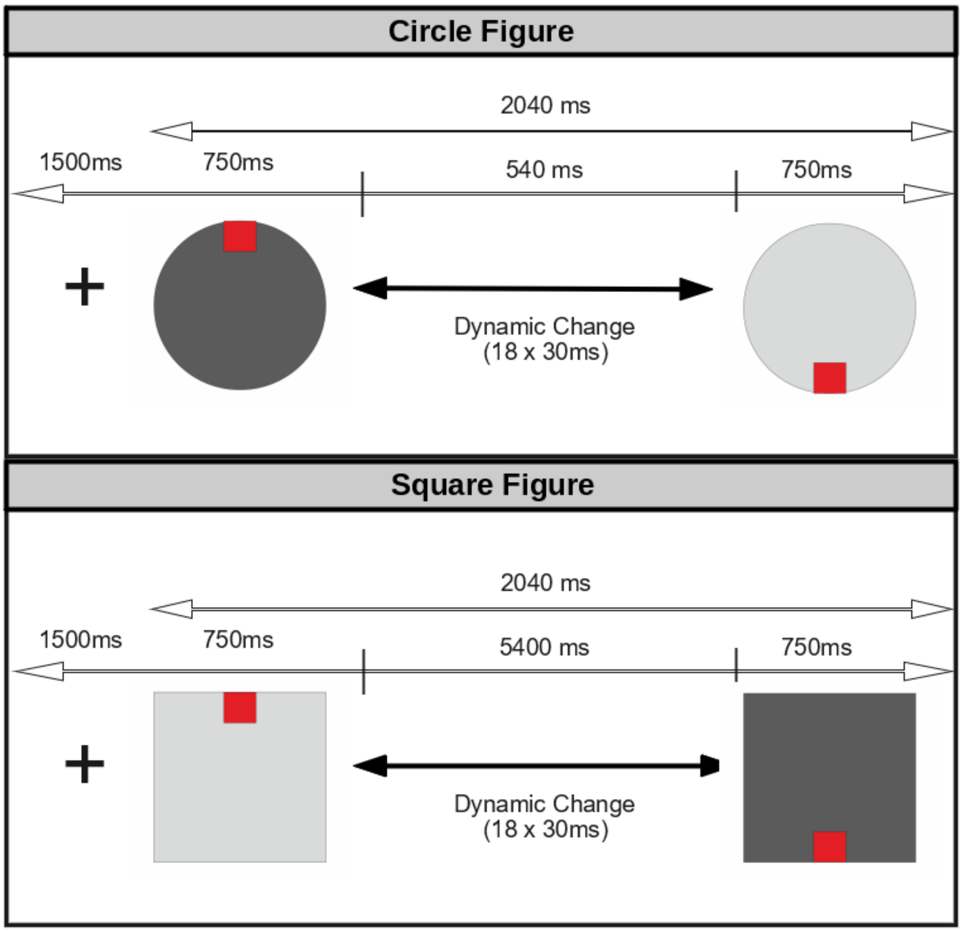


Figure 14 Learning phase in the non-social domain. Top panel: the dark colour of the figure with the internal square at the top of the figure or light colour of the figure with the internal square at the bottom of the figure signify circle. Bottom panel: the reverse pattern is used for the square.

Experimental procedure

Using the same setting as in Experiments 1 and 2, participants were seated at a viewing distance of 80 cm from a PC screen (21-inch monitor, 1024 x 768 pixels, 100 Hz). The stimuli were presented using E-Prime (v.2.0; Psychology Software Tools, Inc.).

Learning Phase

The learning phase used in the current study was consistent with the learning phase of Experiment 1 and 2. Participants viewed 80 videos with two geometric objects, 40 for each object. As in the social implicit learning experiments, each video consisted of 19 frames, the first and last frame were displayed for 750ms and the other 18 frames for 30ms each so as to create a fluent movement. The non-social condition was designed to match as closely as possible the contingencies presented in the social condition. Each object (just like each identity) portrayed a different combination of the two cues: colour (equivalent to facial expression) and internal movement (equivalent to gaze direction). For the circle, internal movement of the red square from the top to the bottom of the circle was accompanied by the change of the colour of the circle from dark grey to light grey, while the internal movement of the red square from the bottom to the top was accompanied by the change from light grey to dark grey (the video played backwards). For the square, the reverse cue combinations were used.

Question session to determine whether any contingencies had been discovered

Directly following the learning phase, participants were required to give verbal responses to a series of questions checking whether they had picked up the cue-identity contingencies. The questions were: (1) "Could you describe what you just have seen?" (2) "How many different objects did you see?" (3) "What can you tell me about their colours?" (4) "What can you tell me about their internal movement?" (5) "Did you detect certain patterns between colours, internal movement and figures?" Answers were manually recorded.

Testing Phase

The testing phase was again consistent with the testing phase from Experiments 1 and 2. The morph of the two objects was presented in exactly the same way as in the social condition (Figure 15). The morph figure was of either light or dark grey colour with the red square either at the top or at the bottom of the figure and was constructed of different proportions of circle and square. The same morph levels (proportions of figure 1 and figure 2; M1 = 60% A and 40% B, M2 = 55% A and 45% B, M3 = 50% A and 50% B, M4 = 45% A and 55% B, M5 = 40% A and 60% B) were used, including the catch trials.[2] Participants were required to select whether the morphed figure resembled more closely the square (key 1) or the circle (key 2). If implicit learning has occurred, then this would be reflected by participants being more likely to judge the morphed figure as a circle if the red square was at the top of the dark grey figure or at the bottom of the light grey figure, or as square if the red circle was at the top of light figure and at the bottom of the dark figure.

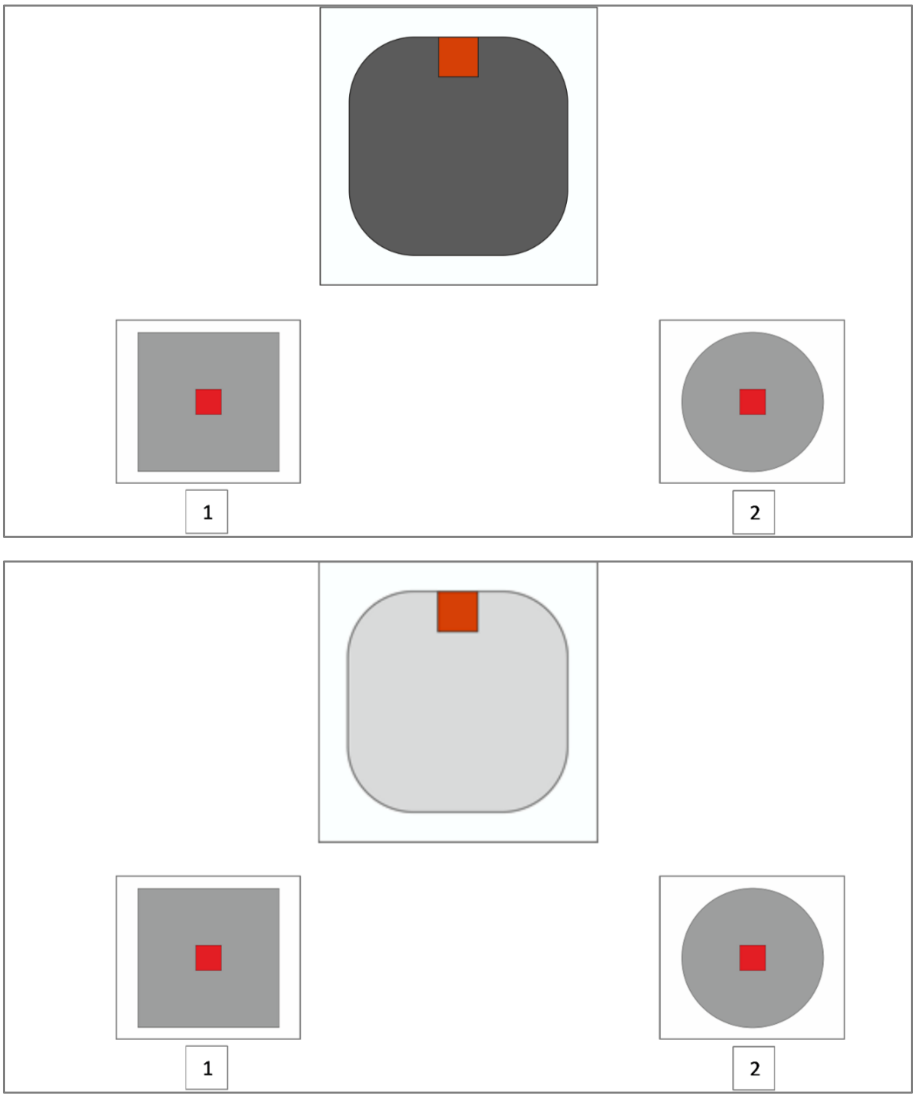


Figure 15 Example of two test trials. The central panel shows morphs consisting of 50% square and 50% circle in dark (top panel) and light (bottom panel) grey colour. The morphs were flanked by

[2] Morph levels were determined through a pilot study. Specifically, the M3 morphs were tested to ensure that they were **perceptual** representation of 50% A and 50% B and are therefore, equally likely to be selected without any prior learning experience. The result of the pilot study revealed that morphs produced by the morphing software were biased toward the square figure. The shape of M3 morph was systematically adjusted and tested until the bias was no longer present.

'neutral' versions of the square and the circle, with mid-grey colour and with the internal red square located in the middle of the figures.

In this way the level of difficulty in the social and non-social conditions was matched as far as possible; while in the social condition facial expression and gaze direction determined a correct identity, in the non-social condition colour and the internal movement of the red square determined a correct geometric figure (see Figure 16 for direct comparison between social and non-social conditions).

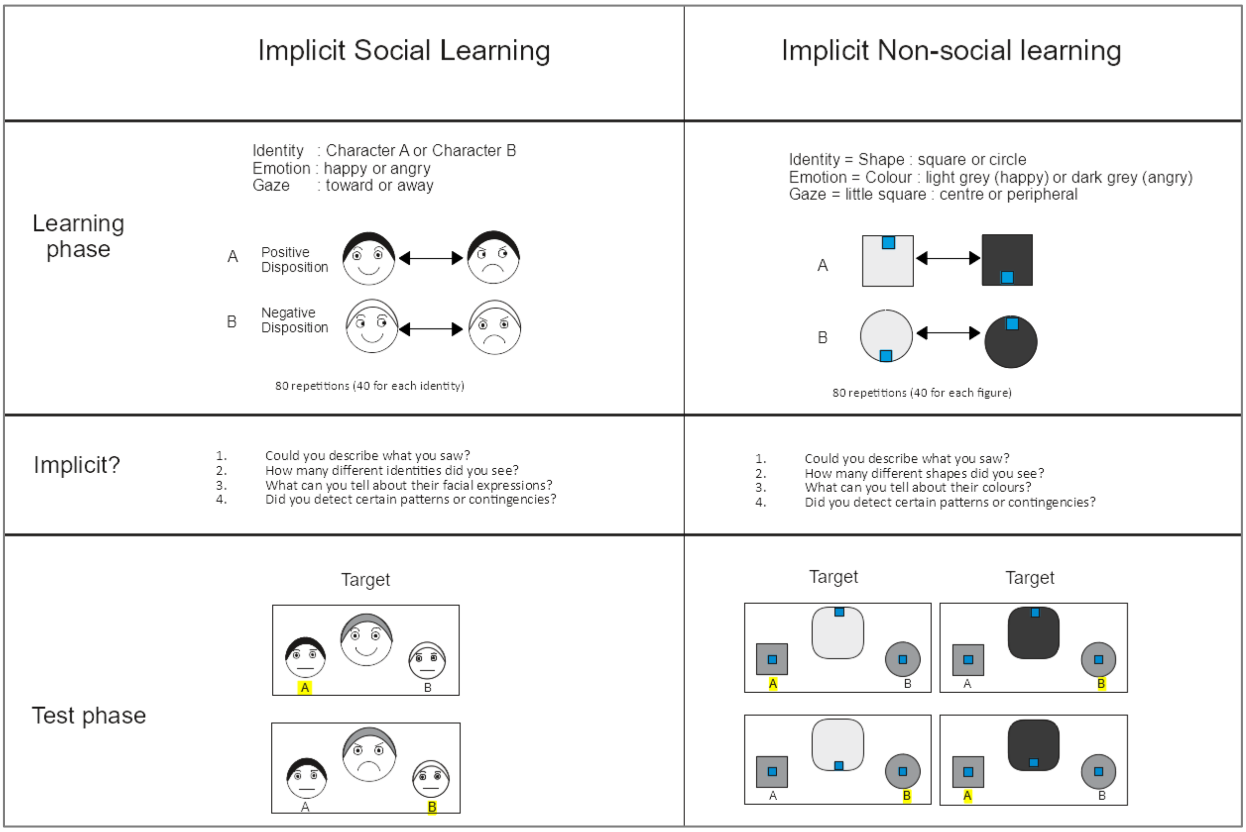


Figure 16 Design comparison between social and non-social implicit learning tasks. The correct answers in the Test Phase are highlighted in yellow.

Results

Data Analysis and Data Reduction

Data analysis and exclusion criteria were the same as in Experiments 1 and 2. Four participants discovered the hidden contingencies in the task and 15 participants failed to correctly respond to at least 75% of catch trials. In total, data from 19 participants were removed.

Demographics

As in Experiment 1, a median split was performed on the participants' AQ scores so as to divide them into a low AQ group and a high AQ group. The AQ scores ranged from 5 to 42, with the median at 16.50, resulting in 35 participants in the low AQ group (*M* = 12.80, *SD* = 2.67) and 35 in the high AQ group (*M* = 22.80, *SD* = 4.85). An independent samples t-test showed that the high and low AQ groups did not differ in age ($t(68) = .944$, $p = .944$) nor gender ratio ($X_2(1, N = 70) = 1.20$, $p > .05$).

Morph Perception Task Results

A repeated-measures ANOVA was conducted with a Geometric object (square, circle) and Morph Level (M1, M2, M3, M4, M5) as within-subject factors and AQ Group (low AQ, high AQ) as a between-subject factor. The results are illustrated in Figure 17 (for clarity low and high AQ groups are shown in separate graphs). There was a main effect of Geometric Figure ($F_{1,68} = 37.38$, $p < .001$, $\eta p2 = .357$), indicating that implicit learning has taken place and a main effect of Morph Level ($F_{3.42,232.30} = 16.83$, $p < .001$, $\eta p2 = .198$), reflecting participants were sensitive to different morph level proportions. Most importantly, the interaction between Geometric Figure and AQ Group was non-significant ($F_{1,68} = .667$, $p = .417$, $\eta p2 = .010$). All remaining effect and interactions were non-significant (all *p*'s > .212).

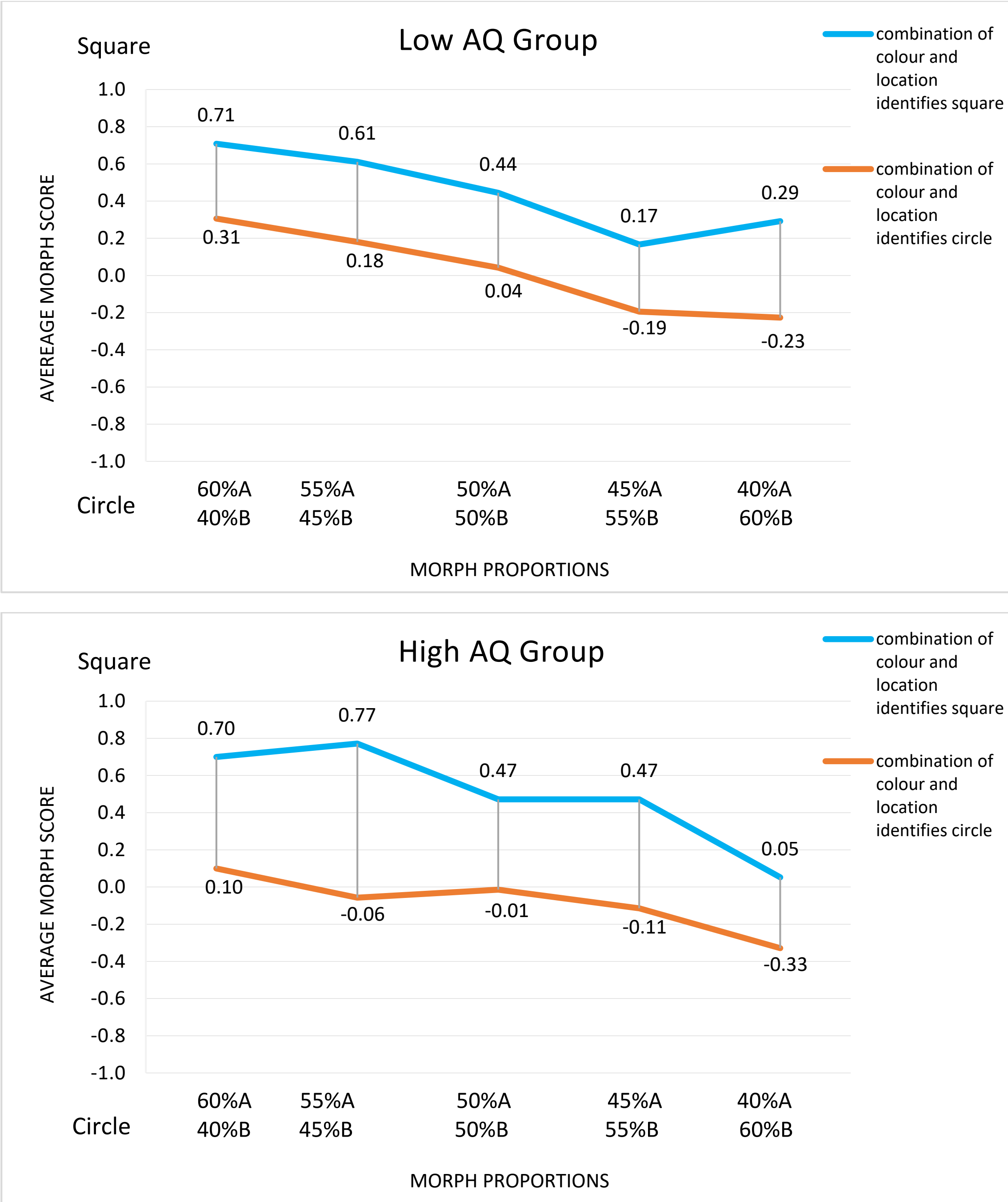


Figure 17 The mean scores across all morph levels (proportions) shown for each group. The amount of implicit learning is represented by a difference between the mean score for square- and circle- morph. Clear implicit learning effects can be observed in both AQ Groups.

Discussion

This experiment set out to examine non-social implicit learning in individuals with a varying extent of autistic traits. The results indicated that participants were able to implicitly learn non-social contingencies, which subsequently influenced their perception of ambiguous geometric shapes. Unlike the social learning task, implicit learning in non-social domain did not seem to depend on individual differences in autism spectrum traits, with the low and high AQ groups performing equally well. Although those high in autistic traits seemed to be more sensitive to implicit contingencies in the physical world, this advantage was not significant.

These results are in line with a recent meta-analysis that found an intact ability to learn implicitly in non-social contexts even in high functioning ASD individuals (Foti et al., 2014). The meta-analysis reviewed evidence for impairments in implicit learning abilities in ASD on serial reaction time, contextual cueing and pursuit rotor tasks. Out of 11 studies considered, only two showed differences in performance in comparison to TD individuals, showing overall preserved implicit learning in ASD.

ASD individuals may be capable to successfully engage in implicit learning when explicitly required to allocate their attention toward relevant stimuli in the context of structured tasks, but fail to do so in everyday social interactions, due to abnormal processing of emotional cues that mediate learning (Vivanti & Dissanayake, 2014; Vivanti & Rogers, 2014). Implicit learning in the social domain differs in a number of ways: (1) relies inherently on associated emotions and affective valences (which may or may not be present in non-social domain), (2) incorporates abstract concepts such as disposition, attitude and intention being an intrinsic part of what is learned (which concepts are absent from the non-social domain). Social implicit learning may be impaired in those high in autistic trait due to failure in attributing emotional value to the representation of social stimuli. As a result, affective states cannot assist in guiding the response or attitude towards the stimuli. There is evidence of reduced levels of brain activation in individuals with ASD during implicit, but not explicit emotion processing (Kana et al., 2016). Future studies could investigate whether this finding extends to the typical population high in autistic traits.

This is the first study to demonstrate a dissociation between social and non-social implicit learning when comparing TD individuals who scored either high or low on the AQ. Distinct patterns of learning in social and non-social tasks in the high AQ group support the notion that implicit learning is not a unitary construct (Seger, 1994) and that it can be intact or impaired depending on the type of information to be learnt. Studies have shown that implicit learning tasks used in the literature differ in the nature of the regularity present as well as in the underlying neural systems they engage (Forkstam & Petersson, 2005; Stadler, 1997). Similarly, there is an abundance of evidence suggesting that social stimuli form a distinct stimulus class, processed by a dedicated social brain (Adolphs, 1999; Frith & Frith, 1999). Since the underlying structure of social and non-social tasks presented in this chapter were similar and matched in the level of difficulty, it seems that the only factor that determined the presence of implicit learning effect is the type of domain (social versus non-social).

3.4 General Discussion

The set of studies presented in Chapter 3 aimed to examine social implicit learning in relation to individual differences in autistic traits and understand how this learning may differ from implicit learning in a non-social domain by using structurally similar tasks with a matched level of difficulty. In Experiment 1, implicitly learnt contingencies between character identity, facial expressions and gaze direction biased the perception of morphed faces depicted with expressions of either joy or anger. Smiling morphed faces were consistently associated with the positive-disposition character, regardless of its physical appearance. On the other hand, frowning morphed faces were consistently associated with the character with a negative disposition toward the observer. This bias was strong enough to overcome a 20% difference in low-level physical features of the displayed face. For example, smiling morphed faces composed of 60% negative and 40% positive character were still judged as resembling positively-portrayed character more than the negative one. This suggests that the implicitly acquired knowledge has a strong capacity to influence one's perception. As expected, the implicit learning effect depended on individual differences in autism spectrum traits. Those high in autistic traits showed some impairments in social implicit learning, as compared to low AQ group when indirect measures of learning were employed.

However, variations in implicit learning between individuals low and high in autistic traits in Experiment 1 could in principle have occurred on the basis of the closer matching of low-level features of the morphs (i.e. eye and mouth configuration) with the low-level features of one of the identities, rather than on differences in actors' dispositions toward the observer. To eliminate the possibility of perceptual learning, in Experiment 2 the test phase of the social condition has been modified, by covering the eyes of morphed faces by a small rectangle, thus eliminating the gaze direction cue. The rationale was that when participants would have implicitly learnt the dispositions of the characters, the character with positive disposition should be associated with a positive facial expression (smile) rather than a negative facial expression (frown), regardless of the gaze direction. The results revealed that perceptual learning did not contribute to implicit learning effect observed in Experiment 1. The groups differed significantly in their ability to learn implicitly, with those high in autistic traits showing even smaller implicit learning effect than in Experiment 1. Although results from Experiment 2 demonstrated that autistic traits seem to affect one's ability to implicitly learn social information, it was not clear whether differences in the ability to learn implicitly was specific to social learning. In Experiment 3, the social learning paradigm was extended to include a matching, non-social implicit learning task. In the non-social task, the combination of colour and internal movement was used to predict the shape of the object as either a square or a circle. The results supported the notion that implicit learning of social information is somewhat different than implicit learning in the non-social domain, within the latter domain similar learning effect observed across all participants, regardless of autism spectrum traits.

Functional significance of implicit learning

The ability to implicitly learn about complex regularities or contingencies in one's environment is a fundamental aspect of human cognition. Although automatic and seemingly effortless, implicit learning plays a significant role in guiding and structuring our perceptions and behaviour (Reber, 1993). This is especially true during social interactions, where an implicit interpretation of accumulating social cues can be vital for modulating one's social response appropriately to the current situation (Frith & Frith, 2008; Lieberman, 2000). Studies presented in this chapter support the notion that implicit learning is a cognitive substrate for, and allows the forming of, social intuition. Participants implicitly learnt patterns of social cues displayed by the actors, which later influenced their perception and even their attitude toward them. The learning can be assumed to be implicit, as sensitivity to sequences of social cues was evident without participants' awareness of what was learnt and even that the learning has occurred. The questioning sessions confirmed that participants did not acquire the explicit knowledge of cue contingencies. These findings are in line with previous studies on social implicit learning (Heerey & Velani, 2010; Hudson, Nijboer, et al., 2012; Norman & Price, 2012), which demonstrated that people are sensitive to social signals in their environment and are capable of learning the specific patterns in which these signals occur, and unknowingly apply this knowledge in future interactions.

Diminished Social Learning in those high in autistic traits

Individual differences in implicit social learning abilities have been reported in the past. In particular, those high in autism spectrum traits have been found to show impairments in extracting predictive information from social cues and behaviours (Bayliss & Tipper, 2006; Hudson, Nijboer, et al., 2012). However, studies looking at social implicit learning in relation to autistic traits typically used the gaze-cueing effect to measure it. This could be problematic since smaller gaze-cueing effects have been previously reported in those high in autistic traits (Bayliss & Tipper, 2005) and therefore, the results from these studies were open to interpretation. However, the results from Experiment 1 and 2 were in line with previous findings, consistently demonstrating diminished social implicit learning in the high AQ group, even when methods of measuring implicit learning in these studies did not rely on participants' gaze-cueing abilities. This suggests that social implicit learning is indeed impaired in those with higher level of autistic traits. It seems that their ability to pick up social cues in a meaningful manner is somehow compromised.

The difference between implicit learning in the social and non-social domains

The striking dissociation between social and non-social implicit learning found in experiments 2 and 3 is in line with evidence from clinical populations, such as patients with cerebellar degeneration, Parkinson's disease or dyslexia (Howard Jr, Howard, Japikse, & Eden, 2006; Siegert et al., 2006; Witt et al., 2002), where distinct patterns of deficits in different implicit learning tasks seem to characterise specific clinical populations. It has therefore been argued that implicit learning is not a unitary construct, but rather that it can be either intact or impaired depending on the type of information to be learnt (Seger, 1994). Studies have shown that implicit learning tasks differ quite a lot in the nature of the regularity present as well as in the underlying neural systems they engage (Forkstam & Petersson, 2005; Stadler, 1997). Since the underlying structure of social and non-social tasks presented in this chapter was similar and matched on the level of difficulty, the factor that determined the presence (or absence) of implicit learning was the domain, in which the learning was embedded.

Learning in the social domain requires an understanding of abstract concepts such as intentions, attitudes and dispositions, which contrasts to non-social learning where these concepts are absent. Social stimuli inherently come with attached meaning and affect, and therefore for social intuition to develop fully, this meaning needs to be integrated into what is being learnt. At the very basic level, unconscious evaluation of stimuli as either pleasant or unpleasant should occur, and it is this evaluation that can later elicit appropriate emotional responses (Klauer & Musch, 2003). Even though, individuals in high AQ group were fully capable of recognising facial expressions and gaze direction displayed by the characters, their ability to automatically decode the meaning and implications of socially relevant stimuli could have been compromised. Indeed, there is evidence that involuntary interpretation of social cues is compromised in ASD (Jellema et al., 2009; Senju et al., 2009) and in line with autism spectrum continuum, those high in autistic traits may also be affected at least to some extent.

However, the self-reported likability of characters presented in the study was similar across all participants. If AQ group could ascribe feelings of liking towards characters with a positive disposition toward them, they must have surely understood the meaning and intention behind the sequences of social cues. This could mean that individuals high in autistic traits implicitly learnt character dispositions toward them but this knowledge affected them differently than those low in autistic traits. The dissociation between results obtained through direct versus indirect assessments is in line with previous studies that found impaired social implicit learning in relation to high AQ scores when implicit learning effect is assessed with indirect measures (Bayliss & Tipper, 2006; Hudson, Nijboer, et al., 2012). While indirect measures have been argued to have a better capacity to uncover implicitly acquired knowledge, they typically require this knowledge to be employed in novel tasks, which are often unrelated to initial learning. Dissociations between explicit and implicit perception have been previously reported in individuals with ASD (Ruffman et al., 2001; Senju, 2013).

Could other factors than implicit learning explain the results?

According to the notion of an autism spectrum continuum, those high in autistic traits to some extent share social deficits visible in autism (Baron-Cohen, Wheelwright, Skinner, et al., 2001; Grinter et al., 2009; Suda et al., 2011). Therefore, several factors other than the ability to learn implicitly could have in principle contributed to the observed differences in social implicit learning. One could argue that the high AQ group could have been mildly impaired in their ability to recognise facial expressions. Indeed, reduced accuracy and sensitivity to emotional facial expressions have been previously reported in those with high levels of autistic traits, especially for sadness, anger and disgust (Poljac et al., 2013). However, this was only evident for expressions low in emotional content and therefore, it could not account for current results as both experiments used only intense facial expressions of joy and anger, which have been found to be recognised correctly even by individuals with high-functioning autism (Golan et al., 2007). Moreover, during the debrief all participants were able to correctly identify the expressions portrayed by the characters, regardless of variations in autistic traits. Therefore, the obtained results could not be explained by problems with the understanding of facial expressions. But how about the integration of displayed social cues? Individuals with ASD exhibit weak central coherence (Happé & Frith, 2006), which is an impaired ability to integrate individuals features into a coherent percept. If this impairment extends to those with high levels of ASD traits, failure to integrate gaze direction and facial expression, could have impeded their ability to infer character disposition, regardless of flawless emotion recognition. However, studies have found that integration of eye gaze and facial attributes (e.g. head movement; Hudson et al. 2011) is evident in those with ASD and so the same can be expected of those with high AQ scores. Intact implicit learning in the non-social condition further suggests that those high in autistic traits are able to successfully integrate three different cues into a coherent percept (Experiment 3). When extracting patterns from the physical world, all participants performed equally well, suggesting similar competence in implicit learning outside of the social environment.

<u>Implicit affective tagging hypothesis</u>

One possibility is that tan implicit affective tagging mechanism, responsible for attaching affective value (positive or negative valence) to social stimuli could be somewhat defective in those with higher levels of autistic traits. This would explain why implicitly acquired knowledge failed to affect subsequent behaviour (test responses) in an automatic fashion. One could say it did not reach the level of abstraction for it to be successfully transferred across contexts, rather it remained inflexible and context-dependent, as there was no affective value associated with it. As the essential difference between the social and non-social conditions is that in the social condition the cue contingency conveys the character's affective (positive or negative) disposition toward the observer, whereas no such affective meaning is associated with the non-social stimuli, the affective tagging hypothesis would be compatible with intact implicit learning in the non-social condition. Further, Haffey et al. (2013) demonstrated that variations in autism spectrum traits were associated with automatic mimicry of rewarding social stimuli. Participants high in AQ scores showed reduced mimicry towards human hands associated with high rewards, as compared to those low in AQ scores. No such difference was observed for robot hand associated with high rewards. This ties in with the social motivation theory (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012) which claims that in ASD social stimuli are not intrinsically rewarding. All these findings are in line with affective tagging hypothesis, suggesting that affective values fail to get attached to social stimuli. Future studies could assess whether affective valences play a crucial role in implicit learning and bring about learning differences between the social and non-social domain in those with high AQ scores.

It is as yet unknown whether the deficits in implicit social learning in the high AQ group are specific to implicit social learning and do not extend into explicit social learning. The lack of automatic processing of social cues may be compensated for through deliberate learning and reasoning about others' intentions (Klinger, Klinger, & Pohlig, 2007). For example, Senju and colleagues (2013) found a striking dissociation between the implicit and explicit theory of mind; while the performance of individuals with ASD on an implicit theory of mind task revealed intriguing impairments compared to that of controls, they showed an intact explicit theory of mind. As a result, one may expect intact explicit social learning in individuals with high AQ scores. However, the interpretation of social cues using effortful cognitive processes would be slower and possibly less accurate than in involuntary processing, which may be the primary reason for difficulties in social interactions found in ASD. Future studies should contrast the ability for implicit and explicit learning.

3.5 Conclusions

In summary, studies in this chapter provided evidence that people are capable of implicitly learning contingencies within their environment. This is particularly important for social interactions, where sensitivity to others' dispositions is of particular importance. People seem to implicitly learn associations between social cues and use this knowledge to guide their behaviour, even in the absence of explicit knowledge. Implicit learning seems to be a building block for the development of social intuition and it is crucial for normal social functioning. A striking dissociation between social and non-social implicit learning has been found in individuals high in AQ scores, with failure to acquire implicit knowledge evident only in the social domain. However, conflicting findings from two implicit learning measures (direct and indirect) employed in the social learning paradigm leave the results open to interpretation. One possibility is that implicit learning in the high AQ group has occurred to some extent; however, the implicit associations between social cues and character were not strong enough to emerge when probed indirectly. It could be that the implicit affective tagging mechanism is somewhat defective in those with higher levels of autistic traits. This could potentially lead to problems with implicit knowledge transfer, where the lack of attached affective value leads to more rigid and inflexible knowledge, that is context-dependent rather than abstract. Impaired ability to form implicit memories on the basis of social signals may lead to difficulties in social communication, which is one of the major symptoms reported in ASD. It is tempting to speculate about the implications of the current findings for individuals with ASD. In line with the theory of an autism spectrum continuum (Baron-Cohen, Wheelwright, Skinner, et al., 2001), extrapolation of the results of the high AQ group to individuals with ASD would suggest more severe deficits in the implicit social learning ability in ASD, which might underpin core deficits in social understanding in ASD. This is what will be done in the next chapter.

Chapter 4: Implicit learning of social and non-social information in ASD.

Implicit Learning in ASD

The ability to detect regularities in one's environment provides the means to achieve a certain level of predictability, as the accumulating knowledge gained from experiences allows for making predictions about future events (Cleeremans & Dienes, 2008; Gangopadhyay & Schilbach, 2012; Gibson & Pick, 2000; Perruchet & Pacton, 2006). Implicit understanding of the environment plays an important role within this context as it enables one to interact with that environment more efficiently by directing one's focus toward only those aspects of the environment that are unexpected (Gibson & Pick, 2000; Hellendoorn et al., 2015). On the contrary, if all incoming information needs to be attended to, as nothing is expected, the word would be perceived as chaotic and unpredictable, leading to sensory overload and feelings of being overwhelmed (Pellicano & Burr, 2012). It has been argued that from birth infants with ASD may experience difficulties in automatically/implicitly noticing regularities in their environments, which leads to a cascade of impairments in almost every developmental domain (Hellendoorn et al., 2015; Klinger et al., 2007; Northrup, 2017).

Implicit learning is thought to mediate a variety of high-level cognitive skills, such as the acquisition of language, motor skills (Perruchet & Pacton, 2006) and social intuition (Lieberman, 2000). Therefore, there seems to be a clear overlap between autism symptomatology and the aspects of cognitive development relying on implicit learning abilities, supporting the notion of impaired implicit learning in ASD. Repetitive behaviours and restricted interests associated with ASD can also be explained by difficulties in implicitly detecting environmental regularities, and are thought to emerge as a form of adaptive strategy, in an attempt to make the environment more predictable and explicitly understood (Hellendoorn et al., 2015; Klinger et al., 2007).

What is the evidence for an impairment in implicit learning in ASD?

Even though behavioural difficulties related to implicit learning in ASD are seemingly obvious, empirical evidence for implicit learning impairment in ASD is mixed. Several studies have reported deficits in ASD on several tests of implicit sequence learning (B. Gordon & Stark, 2007; Larson & Mostofsky, 2008; Mostofsky, Goldberg, Landa, & Denckla, 2000), as well as in studies of artificial grammar learning (Klinger et al., 2007) and prototype formation (Klinger & Dawson, 2001; Klinger et al., 2007). Further, different patterns of neural activity during implicit learning tasks in ASD have been demonstrated, suggesting atypical approaches to learning (Müller, Cauich, Rubio, Mizuno, & Courchesne, 2004; Zeeland, Dapretto, Ghahremani, Poldrack, & Bookheimer, 2011). However, not all data support this notion. The majority of recent studies have failed to find general impairments in implicit learning in ASD for sequence learning (Barnes et al., 2008; Brown, Aczel, Jiménez, Kaufman, & Grant, 2010; Müller et al., 2004; Nemeth et al., 2010; Travers, Klinger, Mussey, & Klinger, 2010), artificial grammar learning (Brown et al., 2010), prototype formation tasks (Molesworth, Bowler, & Hampton, 2005) and contextual cueing (Barnes et al., 2008; Brown et al., 2010; Kourkoulou, Kuhn, Findlay, & Leekam, 2013; Kourkoulou, Leekam, & Findlay, 2012). In fact, a recent meta-analysis concluded that implicit learning in ASD is intact (Foti et al., 2014).

According to the learning compensation model, individuals with ASD may compensate for their implicit learning deficit using explicit learning strategies (Klinger et al., 2007). Research has shown greater difficulties in implicit versus explicit tasks in this population (Callenmark et al., 2014; Jellema et al., 2009; Nuske et al., 2013; Ruffman et al., 2001; Senju, 2013; Vivanti & Hamilton, 2014; Vivanti & Rogers, 2014), providing some support for this perspective. A propensity to engage in activities mediated by explicit rules rather than those requiring implicit understanding is often reported in ASD (Klin et al., 2003; Klinger & Dawson, 2001; Larson & Mostofsky, 2008; Ozonoff & Miller, 1995). Since explicit learning is strongly correlated with IQ (G. F. Gebauer & Mackintosh, 2007; S. B. Kaufman et al., 2010), this should be particularly evident in individuals with normal or high intelligence. Indeed, this is exactly what has been found (Klinger et al., 2007). In line with this account, individuals with ASD are prone to solving learning tasks more explicitly than controls (Larson & Mostofsky, 2008) and this may explain mixed data on implicit learning in ASD. While they may be able to learn contingencies, they fail to do so in an automatic manner (Hellendoorn et al., 2015).

However, it is important to note that all reported studies examined implicit learning in non-social domains, with tasks such as artificial grammar learning, serial reaction task or contextual cueing. There is an emerging body of research suggesting that implicit learning is not a one-for-all ability, but rather may be found either intact or impaired depending on the type of information to be learnt. Several studies reported a different performance on various implicit learning tasks within the same group of patients (Howard Jr et al., 2006; Negash et al., 2007; Siegert et al., 2006; Travers et al., 2013; Witt et al., 2002). Individuals with ASD may show domain-specific implicit learning deficits, in particular when social learning is involved. Human behaviour is dynamic, variable and complex and therefore detecting regularities in social interactions may be more difficult than detecting regularities in the physical environment. Implicit learning in the social domain relies inherently on associated emotions and affective valences, with abstract concepts such as disposition, attitude and intention being an intrinsic part of what is learned. Surprisingly, empirical studies on this form of implicit learning in ASD are not available. Where an attempt was made to include social tasks in tests of implicit learning abilities, these were lacking any sort of mental attributions or affect (Brown et al., 2010; Travers et al., 2013). In these studies, the stimuli happened to be social (typically cartoon characters), but might as well be substituted by physical objects without changing the essence of the task. For example, Brown et al. used a probabilistic classification learning task, in which participants had to decide which flavour of ice cream will be chosen by Mr Potato Head toy. The choices made by the character were determined by the presence of specific cues in its appearance, such as glasses or moustache, and participants were expected to implicitly learn the association between specific cues and ice cream flavour selected by Mr Potato Head. While this probabilistic learning task certainly had social elements to it, such as face and cartoon character, these were not arranged in a socially meaningful way nor linked to any affective or mental states.

One possibility for why social implicit learning may be impaired in ASD is a failure in attributing emotional value to the representation of social stimuli. As a result, affective states cannot assist in guiding the response or attitude towards the stimuli. There is fMRI evidence supporting this view: reduced levels of brain activation in individuals with ASD during implicit emotion processing were found in the medial prefrontal cortex and superior temporal gyrus, while activations during explicit emotion processing did not differ from controls (Kana et al., 2016). This suggests, that the emotional value of the stimuli is processed in typically-developed subjects, even when it is not explicitly required; in contrast individuals with ASD may not automatically engage structures playing role in detecting emotional information perceived incidentally. Further to this, the same study found reduced functional connectivity between the medial prefrontal cortex and the amygdala in ASD only for emotional processing that is automatic or implicit. These findings suggest that neural mechanisms underlying implicit, but not explicit, emotion processing may be altered at multiple levels in individuals with ASD. While explicit instruction can help people with ASD navigate the social and emotional world more effectively over time, a failure to use implicit emotions could significantly affect the quality of social interaction in individuals with ASD.

<u>Current study</u>

The collection of studies presented in Chapter 3 included exclusively typically-developed participants, with variations in autistic traits determined to enable a tentative examination of the link between implicit learning and ASD. Although the pattern of findings from my previous studies might indicate even more pronounced deficits in social implicit learning in ASD, those findings were exclusively applicable to the typically-developed population. In Chapter 4, the implicit learning experiments were conducted with students with a diagnosis of high-functioning ASD.

As in Chapter 3, perceptual biases of morphed stimuli were assumed to reflect implicit learning abilities, which was explored in social learning conditions, with morphs presented with eyes visible (replication of Experiment 1) and eyes covered (replication of Experiment 2), as well as non-social learning condition (replication of Experiment 3). The experiments were identical to the previously described studies allowing to directly compare capacities for social and non-social implicit learning in the typically-developed group (TD group) with the current data from the group with ASD (ASD group).

Since difficulties in the social domain are well-established in ASD and given the results of individuals with high AQ scores from the previous chapter, it was hypothesised that participants in the ASD group will not be able to learn implicitly in the social learning conditions, reflected by the absence of response bias (i.e. judgements will accurately reflect the proportions of the two characters). For the non-social condition, it was hypothesised that the ASD individuals will no longer show a deficit in implicit learning (Brown et al., 2010, Foti et al., 2014) and will learn the contingencies similarly as the TD individuals, as this task is free from affective valences or mental attributions.

4.1 Experiment 4

Brief videos of two characters, whose facial expressions and gaze directions changed dynamically were presented to the individuals with ASD. Specific combinations of facial expression and gaze direction were used to convey either a positive or negative disposition towards the observer. Participants were asked to judge the morphed faces of the two characters displaying either an expression of joy or anger. Perceptual biases of the morphs in line with the hidden social contingencies were an indication of social implicit learning. The results from the ASD group were compared to a subset of participants from Experiment 1, matched on age, gender and intellectual ability.

The primary hypothesis was that individuals with ASD have a deficit in their ability to learn social information implicitly and therefore, will not show a perceptual bias in their judgement of the morphed test faces. Similarly, it was expected that there will be no preference for the character with the positive disposition in this population, as measured by likability questionnaires. However, there was also a possibility that the ASD group would be able to use an alternative strategy based on low-level visual facial features of each character to solve implicit learning tasks.

Method

Participants

Seventeen undergraduate students with ASD took part in Experiment 4. After applying exclusion criteria two participants were excluded from the analysis (see data exclusion below). The final sample consisted of fifteen participants (five females, ten males), with a mean age of 19.67 (*SD* = 0.90), a mean total IQ score of 118.40 (*SD* = 7.58) and a mean ADOS score of 9.87 (*SD* = 2.70). The control group consisted of a subset of participants from Experiment 1, matched for age, sex and intellectual abilities. The data of twenty-two participants were included in the analysis (ten women, twelve men), with a mean age of 19.36 (*SD* = 1.56) and a mean total IQ score of 114.56 (*SD* = 7.22). The ASD and TD groups did not differ significantly in terms of age ($t(35) = .829$, $p = .413$), gender ratio ($X_2(1, N = 37) = .544$, $p = .461$) nor IQ ($t(35) = .944$, $p > .138$). The AQ scores were significantly higher in the ASD group than in the TD group ($t(35) = 6.89$, $p < .001$). Participants' characteristics are presented in Table 3.

Table 3 Participants' characteristics.

	AGE	SEX	IQ-total	AQ	ADOS
ASD GROUP (n = 15)	19.67 (0.90)	5 women 10 men	118.40 (7.58)	31.20 (9.92)	9.87 (2.70)
TD GROUP (n = 22)	19.36 (1.56)	10 women 12 men	114.56 (7.22)	16.59 (5.86)	-

Stimuli and Procedure

The stimuli and procedure were identical to those of the previously described Experiment 1 (Chapter 3), therefore it is only summarised in this section.

Learning Phase

Participants viewed 80 videos of two characters (40 videos for each character). Both actors smiled and frowned half of the time and both looked at, and away, from the observer half of the time. However, unbeknown to participants, the specific combination of facial expression and gaze direction of the characters determined their disposition toward the participant, with one character portrayed as having a positive disposition and the other, a negative disposition. On the basis of the cues displayed by each character, participants were able to implicitly learn the characters' dispositions.

Questioning session to determine whether contingencies have been discovered.

After a learning phase, they were asked a series of questions checking their understanding of the videos and whether they had discovered hidden contingencies. Questions were as follows: (1) "Could you describe what you just have seen?" (2) "How many different identities did you see?" (3) "What can you tell me about their facial expressions?" (4) "What can you tell me about their gaze direction?" (5) "Did you detect certain patterns between facial expressions, gaze directions and identities?"

Test Phase

To assess implicit learning, participants were presented with morphs, consisting of various proportions of the two characters (A and B) seen in the learning phase (M1 = 60% A and 40% B, M2 = 55% A and 45% B, M3 = 50% A and 50% B, M4 = 45% A and 55% B, M5 = 40% A and 60% B). The morphs were either smiling or frowning and participants were asked to indicate which of the two characters the morph resembled most. If implicit learning has occurred, smiling morphs should be associated with the positively portrayed character and frowning morphs with the negatively portrayed character.

Likability Questionnaires

Following the test phase, participants completed likability questionnaires for each character, which were used as a direct measure of participants' preference/attitude towards the characters. Questions asked were as follows:

6. How much do you like this person?
7. How much does this person like you?
8. How much would you like to co-operate?
9. How much would you like to avoid this person?
10. How attractive do you find this person?

Higher likability scores were expected for the character holding a positive disposition toward the participant.

Results

Data Analysis and Data Reduction

The exclusion criteria were similar to those in Experiment 1. One participant with ASD discovered the hidden contingencies in the task and failed to correctly respond to at least 75% of catch trials. Data from this participant was removed from the analysis.

In addition to the above criteria, ASD participants were expected to correctly identify full-blown facial expressions of joy and anger displayed by the characters (as per questioning session described in Section 2.2.2), failure to do so would mean the participant data would not be included in the analysis. However, all ASD participants were able to recognise and name facial expressions in the questioning session.

The data analysis followed that of Experiment 1. Further to this, data from both experiments from Experiment 1 was collated and added to the data from the current experiment to conduct correlational analysis between the participants' AQ score and amount of implicit learning observed. The amount of implicit learning was quantified as the difference between an average rating of character with a positive disposition and an average rating of the character with a negative disposition toward the observer. This value was then correlated with the AQ score.

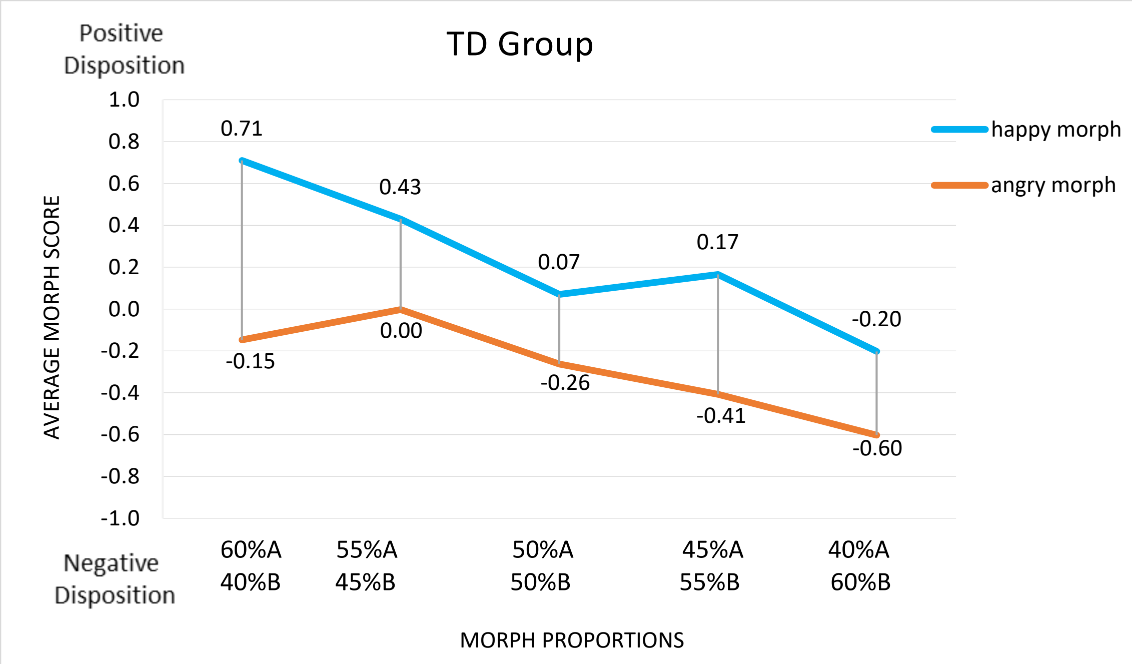
Similarly, the correlational analysis between the participants' AQ score and likability effect as measured by the questionnaires was also conducted. The likability effect was quantified as a difference between the average rating for the character with a positive disposition and an average rating of the character with a negative disposition toward the observer. This value was then again correlated with the AQ score.

Morph Perception Task Results

A repeated-measures ANOVA was performed, with Morph Facial Expression (happy, angry) and Morph Level (M1, M2, M3, M4, M5) as within-subject factors and Group (TD, ASD) as the between-subject factor. The results are presented in Figure 18. The main effect of the factor Morph Facial Expression was non-significant ($F_{1,35} = 1.78$, $p = .191$, ηp2 = .048), with similar scores for both happy and angry morphs. However, the Morph Facial Expression and Group interaction was significant ($F_{1,35} = 5.38$, $p = .026$, ηp2 = .133), suggesting differences in the capacity for implicit learning between the typically-developed and ASD groups (see Figure 18). Follow-up t-tests revealed that while there was a significant difference between Morph Facial Expression for the TD group ($t(21) = 2.52$, $p = .020$, $d = 0.54$), this difference was absent in ASD group ($t(14) = .862$, $p = .403$, $d = 0.22$).

The main effect of Morph Level was significant ($F_{4,140} = 16.33$, $p < .001$, ηp2 = .318), indicating that participants were sensitive to the different morph proportions. The remaining effects and interactions were all non-significant (all p's > .209).

Correlational analysis of the overall data from the current experiment and Experiment 1 revealed that there was a significant negative association between the AQ score and amount of implicit learning observed ($r(61) = -.34$, $p = .008$). The higher the AQ score, the less implicit learning has occurred (see Figure 19).



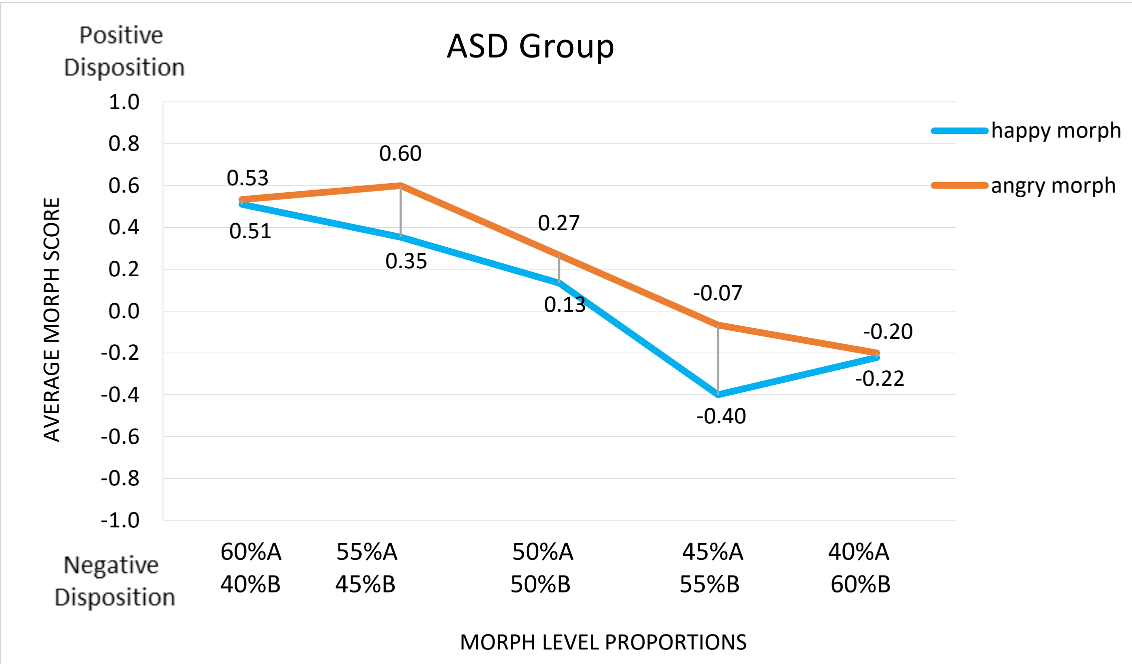


Figure 18 The mean scores across all morph levels (proportions if character A and character B) shown for each group. The amount of implicit learning is represented by the difference between the mean score for happy and angry morph. A clear implicit learning effect can be observed in the TD Group (top panel). There is no evidence of implicit learning in ASD group; in fact, the happy morph seems to be more associated with the character holding a negative disposition (although this did not reach significance; bottom panel).

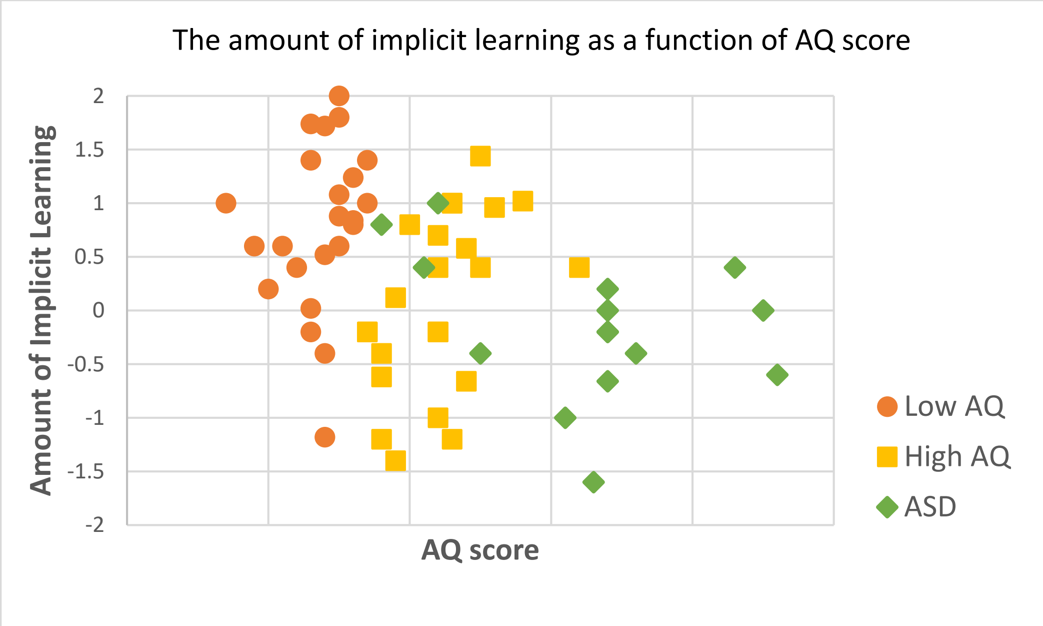


Figure 19 The association between the amount of implicit learning observed and participants' AQ score for Low AQ, High AQ and ASD groups.

Questionnaire Data Results

A repeated-measures ANOVA was performed to analyse the questionnaire data, with Character Disposition (positive, negative) and Question Type as within-subject factors and Group (TD, ASD) as between-subject factor (Figure 20).

Overall, characters with positive disposition attracted higher likability scores (*M* = 63.18, *SD* = 15.29) as compared to characters with negative disposition (*M* = 58.97, *SD* = 13.81), however this difference was not significant ($F_{1,33}$ = 1.77, *p* = 193, ηp2 = .051). Most importantly, however, there was a significant interaction between Character Disposition and Group ($F_{1,33}$ = 5.28, *p* = .028, ηp2 = .138). Follow up t-tests revealed a significant difference in ratings of character with positive and negative disposition in the TD group (*t*(21) = .306, *p* = .006, *d* = 0.69), with higher average ratings for character with positive disposition (*M* = 65.48; *SD* = 15.56) than negative disposition (*M* = 53.99; *SD* = 13.56). No such difference was found in ASD group (*p* = .535), with negative-disposition character actually attracting slightly higher ratings ((*M* = 64.21; *SD* = 13.31) than positive-disposition character (*M* = 60.88; *SD* = 14.55). There was a main effect of Question Type ($F_{2.69,88.70}$ = 6.50, *p* = .001, ηp2 = .165). All remaining effects and interactions were non-significant (*p*'s >.05).

Correlational analysis of the overall data from the current experiment and Experiment 1 showed no association between the AQ score and likability effects observed ($r(61) = -.04$, $p = .745$). This is likely due to the lack of differences between likability scores between Low and High AQ groups (see Figure 21).

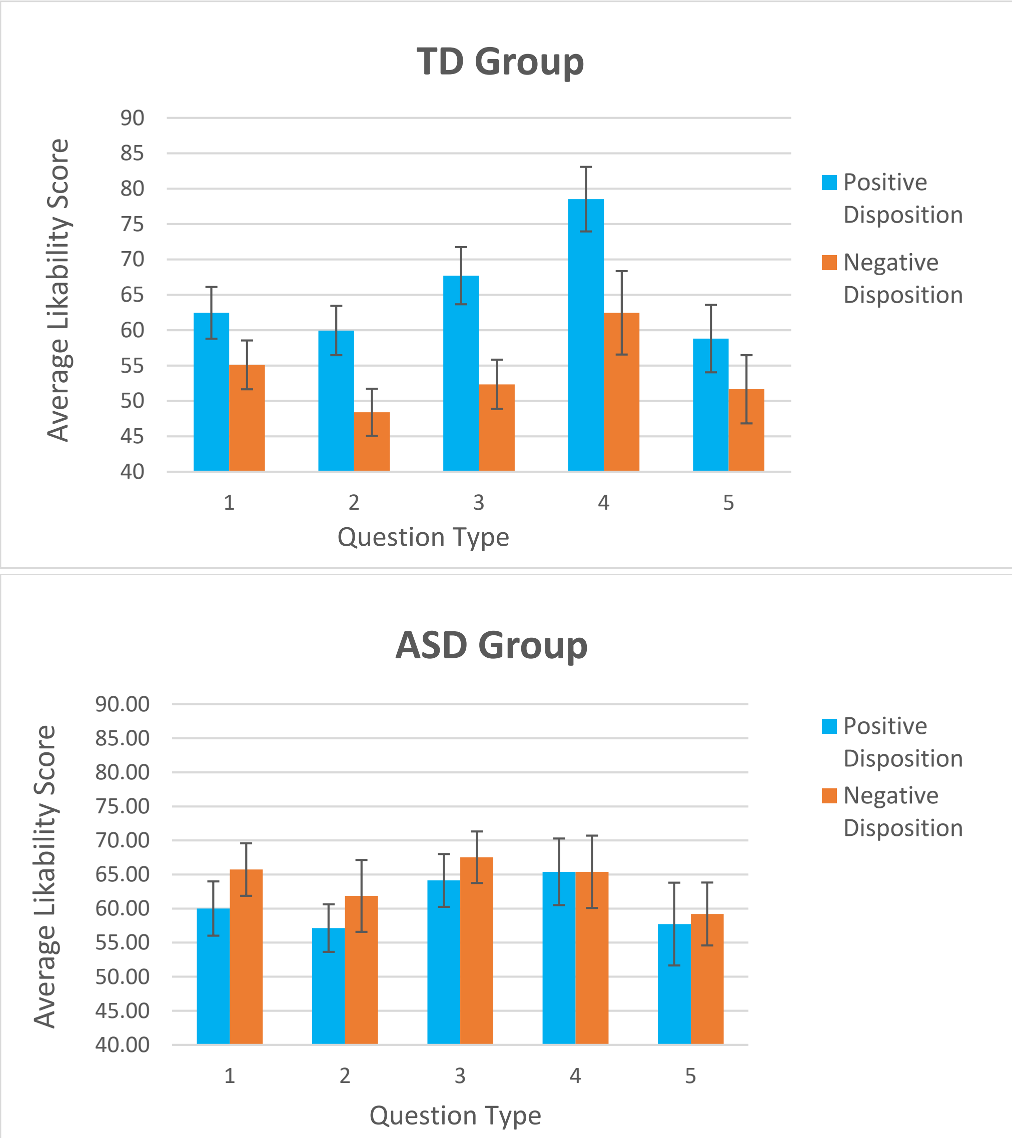


Figure 20 The mean scores for the positively- and negatively-portrayed identity for the TD Group (top panel) and ASD Group (bottom panel). Error bars represent SE.

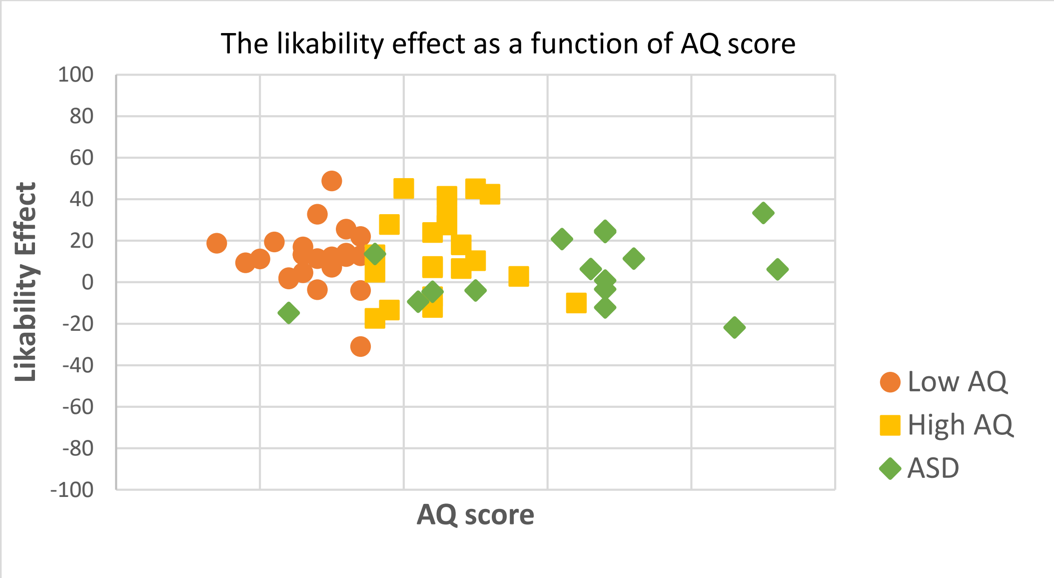


Figure 21 The association between the likability effect observed and participants' AQ score for Low AQ, High AQ and ASD groups.

Discussion

This study examined implicit learning abilities in ASD set within the social domain. In line with initial predictions, marked impairment in social implicit learning was found in the ASD group, as compared to typically-developed controls. The differences between the groups were found using both direct and indirect implicit learning measures. Typically-developed group judged smiling morph as resembling the positively portrayed character and the frowning morph as the negatively portrayed character, even though they were not explicitly aware of the character dispositions (as confirmed in questioning session). In contrast, participants with ASD did not seem to be affected by the social contingencies in their judgements of morphed-faces of the two characters. Likewise, the likability questionnaires indicated similar responses for both characters in ASD, while typically-developed participants showed a clear preference toward character implicitly portrayed as having a positive disposition. These results suggest that implicit social learning is impaired in ASD and could account, at least in part, for the difficulties in social interaction observed in this population.

This is a first study to report impairment in implicit learning that is specific to the social domain. Social stimuli differ from non-social domain mainly because of the affective valences or mental attributions that are inherently attached to them. This difference could be crucial for understanding social impairments in ASD. Interestingly, even though the social learning condition contained specific low-level cues in a form of eyes and moth configurations that could have been used to correctly guide participants' responses in the test phase, these did not seem to aid ASD individuals, suggesting some impairments also in perceptual learning. In Experiment 5, gaze direction cue was further manipulated to assess their potential contribution to the social implicit learning effects obtained in Experiment 4.

4.2 Experiment 5

This study was a replication of Experiment 5 from the previous chapter, where a modified version of the test phase has been employed, in which the eyes of the morphed faces are covered. This was to eliminate the possibility of low-level perceptual learning on the basis of the closer matching of low-level features of the morphs – eye and mouth configuration – with one of the two characters, rather than implicit social learning on the basis of differences in characters' dispositions toward the observer. As both characters smile (and frown) an equal amount of time during the learning phase, the facial expression on its own is not sufficient to perceptually discriminate between the two actors. It is the combination of the facial expression and gaze direction during the learning phase that can give rise to the implicit understanding of characters' disposition.

In order to explore the potential contribution of perceptual learning, the ASD group was compared to a subset of participants from Experiment 2, matched on age, gender and intellectual ability. Since participants with ASD seemed unable to acquire social information in an implicit manner, even when the low-level social cues are available to aid their learning (Experiment 4), it seemed unlikely that social implicit learning would occur when the gaze direction cues are removed from the test phase. Therefore, it was hypothesised that ASD group would fail to show perceptual biases of the morphed faces in line with hidden social contingencies, as compared to typically developed subjects. In addition, similar scores on the likability questionnaires for both positive and negative characters were expected from the ASD group.

Method

Participants

Twenty-five undergraduate students with ASD took part in experiment X. After applying exclusion criteria, five participants were excluded from the analysis (see Data reduction below). The final sample consisted of twenty participants (three women, seventeen men), with a mean age of 19.55 (*SD* = 0.83), a mean total IQ score of 114.83 (*SD* = 9.58) and a mean ADOS score of 9.30 (*SD* = 2.20). The control group consisted of a subset of participants from Experiment 2 (who completed the exact same experiment), matched for age, sex and intellectual abilities. The data of thirty participants were included in the analysis (eight women, twenty men), with a mean age of 20.18 (*SD* = 2.52) and a mean total IQ score of 112.30 (*SD* = 6.98). The ASD and TD groups did not differ significantly in terms of age ($t(46) = 1.07$, $p = .290$), gender ratio ($X_2(1, N = 48) = 1.22$, $p = .270$) nor IQ ($t(46) = 1.06$, $p = .296$). The AQ scores were significantly higher in the ASD group than in the TD group ($t(46) = 5.97$, $p < .001$). Participants' characteristics are presented in Table 4.

Table 4 Participants' characteristics.

	AGE	SEX	IQ-total	AQ	ADOS
ASD GROUP (n = 20)	19.55 (0.83)	3 women 17 men	114.83 (9.58)	30.65 (9.25)	9.30 (2.20)
TD GROUP (n = 28)	20.18 (2.52)	8 women 20 men	112.30 (6.98)	16.04 (7.67)	-

Stimuli and Procedure

The stimuli and procedure were identical to those of the previously described Experiment 2 (Chapter 3). In short, participants viewed videos of two characters, with hidden contingencies that could be learnt implicitly on the basis of a combination of facial expressions and gaze direction. Implicit learning was measured by determining the extent of perceptual bias toward morphs consisting of varying proportions of the two characters. Morphs were either smiling or frowning and had their eyes covered, to exclude the possibility of perceptual learning of the low-level features of the face. As in previous studies, likability questionnaires were also administered.

Results

Data Analysis and Data Reduction

Data analysis and exclusion criteria were similar as in Experiment 2. Three participants with ASD discovered the hidden contingencies in the task and two other participants failed to correctly respond to at least 75% of catch trials. Data from these five participants were removed. Questioning session (for details see Section 2.2.2) confirmed that participants were able to correctly identify emotions displayed by the characters.

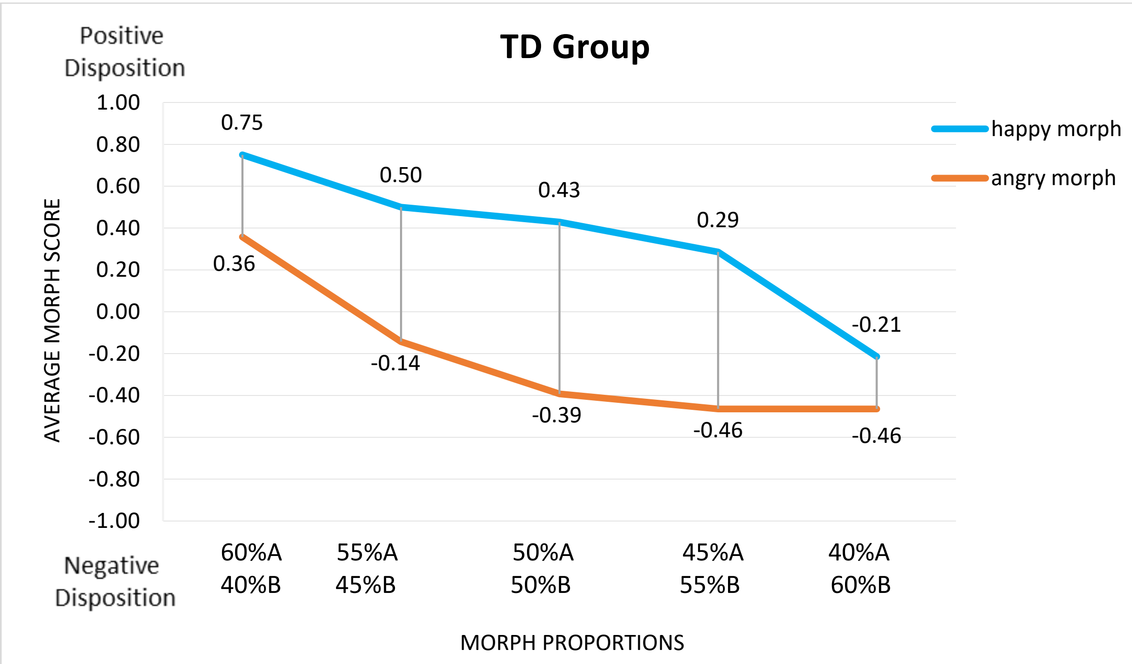
As in Experiment 4, data from Experiment 2 was collated and added to the data from the current experiment to conduct correlational analysis between the participants' AQ score and amount of implicit learning observed and between the AQ score and likability effects.

Morph Perception Task Results

A repeated-measures ANOVA was performed, with Morph Facial Expression (happy, angry) and Morph Level (M1, M2, M3, M4, M5) as within-subject factors and Group (TD, ASD) as the between-subject factor. The results are presented in Figure 22. The main effect of the factor Morph Facial Expression was non-significant ($F_{1,46} = 1.85$, $p = .180$, ηp2 = .039), with similar scores for both happy and angry morphs. However, the Morph Facial Expression by Group interaction was significant ($F_{1,46} = 16.13$, $p < .001$, ηp2 = .260), suggesting group differences in the capacity for implicit learning between typically-developed and ASD group. To explore further the interaction between Morph Facial Expression and Group, additional t-tests were performed for each group, with Morph Facial Expression (happy, angry). The results showed a significant difference in perception of morphs in TD group ($t(27) = 3.71$, $p = .001$, $d = 0.70$), with the average scores higher for Happy Morph (M =0.35, $SD = 0.50$) than Angry Morph ($M = -0.22$, $SD = 0.52$).

Surprisingly, there was also a significant difference in perception of morphs in ASD group ($t(19) = 2.20$, $p = .041$, $d = 0.49$), however, in opposite direction, with the average scores significantly higher for Angry Morph ($M = -0.02$, $SD = 0.55$) than Happy Morph ($M = -0.30$, $SD = 0.45$). In addition, the main effect of Group was significant ($F_{1,46} = 4.64$, $p = .037$, ηp2 = .018), reflecting overall higher ratings of the morphs in TD group than ASD group, regardless of facial expression. The main effect of Morph Level was also significant ($F_{4,184} = 22.27$, $p < .001$, ηp2 = .326), indicating that participants were sensitive to the different morph proportions. The remaining interactions were all non-significant (all *p*'s > .207).

Correlational analysis of the overall data from the current experiment and Experiment 2 revealed that there was a significant negative association between the AQ score and amount of implicit learning observed ($r(89) = -.39$, $p < .001$). The higher the AQ score, the less implicit learning has occurred (see Figure 23).



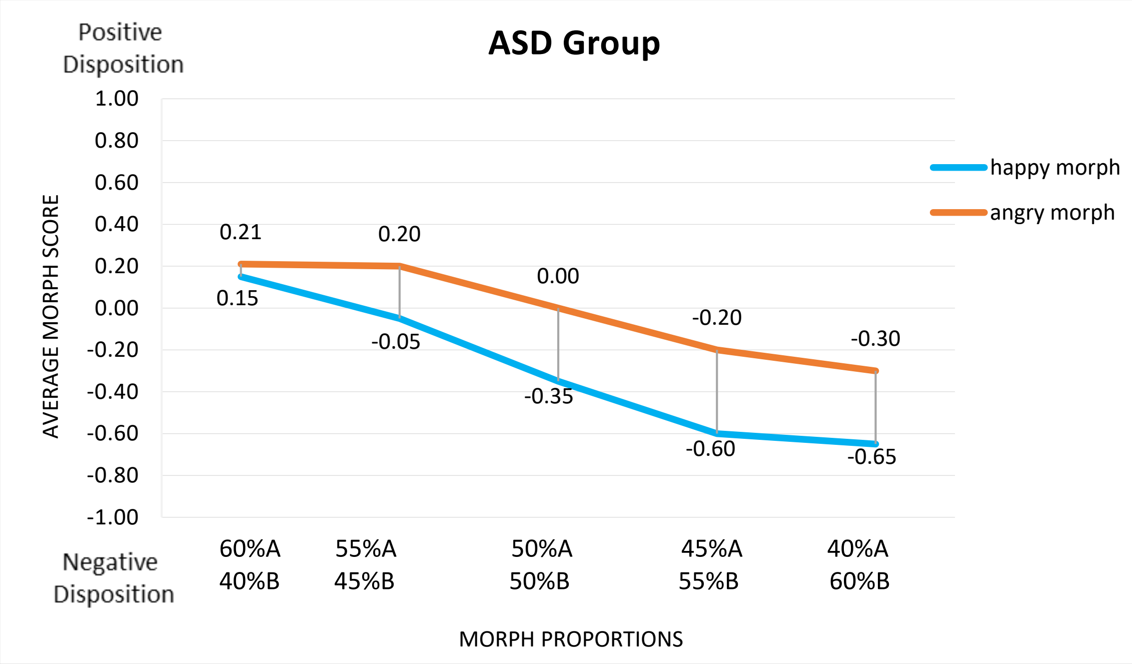


Figure 22 The mean scores across all morph levels (proportions) shown for each group. The amount of implicit learning is represented by a difference between the mean score for happy and angry morph. Clear implicit learning effect can be observed in the TD group (top panel).[3] *For the ASD group, an opposite learning effect was found, with happy morph associated with the character holding a negative disposition, even more so than angry morph (bottom panel).*

[3] It can be noted that the implicit learning effect of control group is similar to that of Low AQ group in Experiment 2. This is due to an inclusion of a large proportion of male participants, who happen to fell within the range of Low AQ group in Experiment 2. These male participants needed to be included in the control group in order to match ASD participants in gender (ASD groups consisted mainly of male participants).

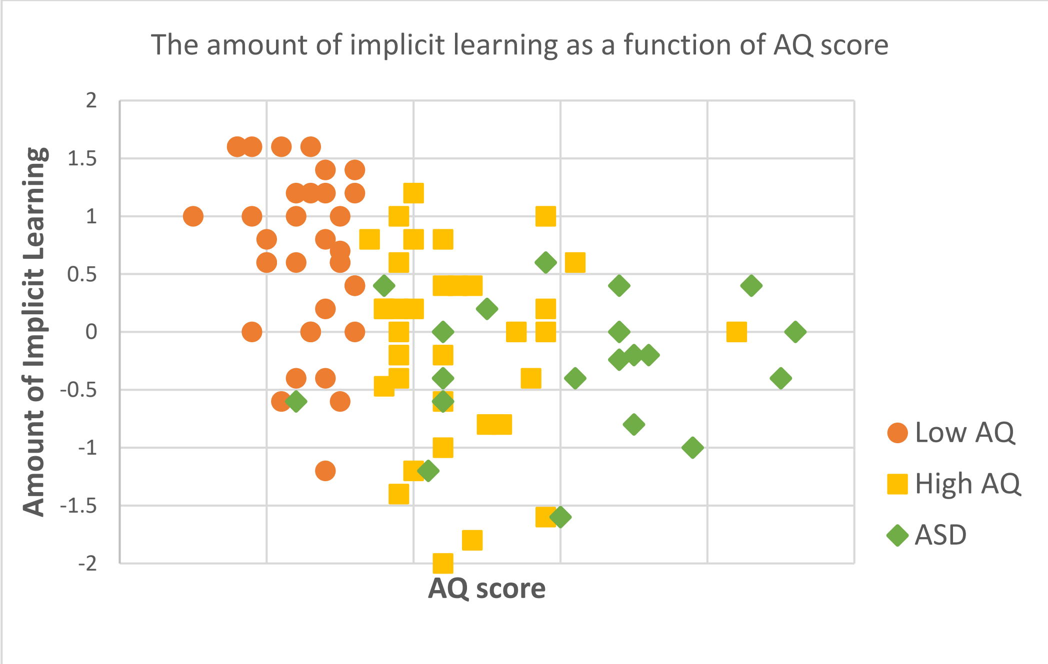


Figure 23 The association between the amount of implicit learning observed and participants' AQ score for Low AQ, High AQ and ASD groups.

<u>Questionnaire Data Results</u>

A repeated measures ANOVA was performed to analyse the questionnaire data, with Character Disposition (positive, negative) and Question Type as within subject factors and Group (TD, ASD) as between subject factor. The results are presented in Figure 24. There was a main effect of Character Disposition ($F_{1,46}$ = 8.23, p = .006, ηp2 = .152), with higher likability scores attracted by characters with positive disposition (M = 61.75, SD = 14.38) as compared to negative disposition (M = 54.56, SD = 14.85). This was qualified by a significant interaction between Character Disposition and Group ($F_{1,46}$ = 5.67, p = .021, ηp2 = .110). Follow up paired sample t-tests with character's positive versus negative disposition, revealed significantly higher ratings of positive-disposition character in TD group (t(27) = 3.62, p = .001, d = 0.69), but not for ASD group (t(19) = .327, p = .747, d = 0.07).

There was a main effect of Question Type ($F_{4,184}$= 6.42, p <.001, ηp2 = .122) and a significant interaction between Character Disposition and Question Type ($F_{4,184}$= 3.04, p = .018, ηp2 = .062). Follow-up Bonferroni corrected t-tests revealed significant higher scores for positive-disposition character as compared to negative-disposition character for Question 2 on likability (p = .010) and Question 3 on cooperation (p = .005), a trend for Question 1 (p = .075) and Question 4 (p = .065) but not Question 5 (p = .550). All remaining interactions were non-significant (p's >.05).

Correlational analysis of the overall data from the current experiment and Experiment 2 showed no association between the AQ score and likability effects observed (r(85) = -.13, p = .241. This is likely due to the lack of differences between likability scores between Low and High AQ groups (see Figure 25).

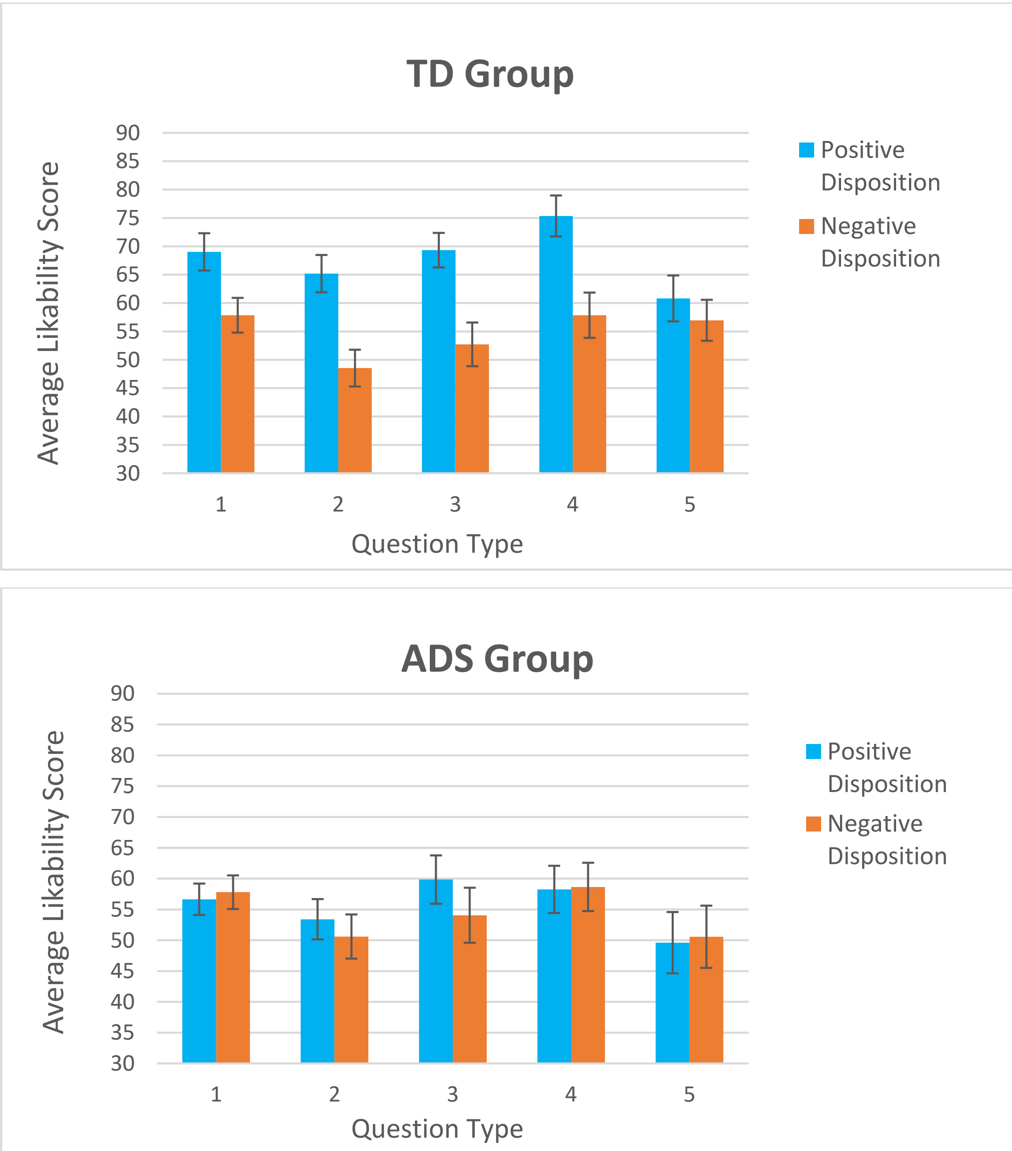


Figure 24 The mean scores for positively- and negatively-portrayed identity for TD Group (top panel) and ASD Group (bottom panel). Error bars represent SE.

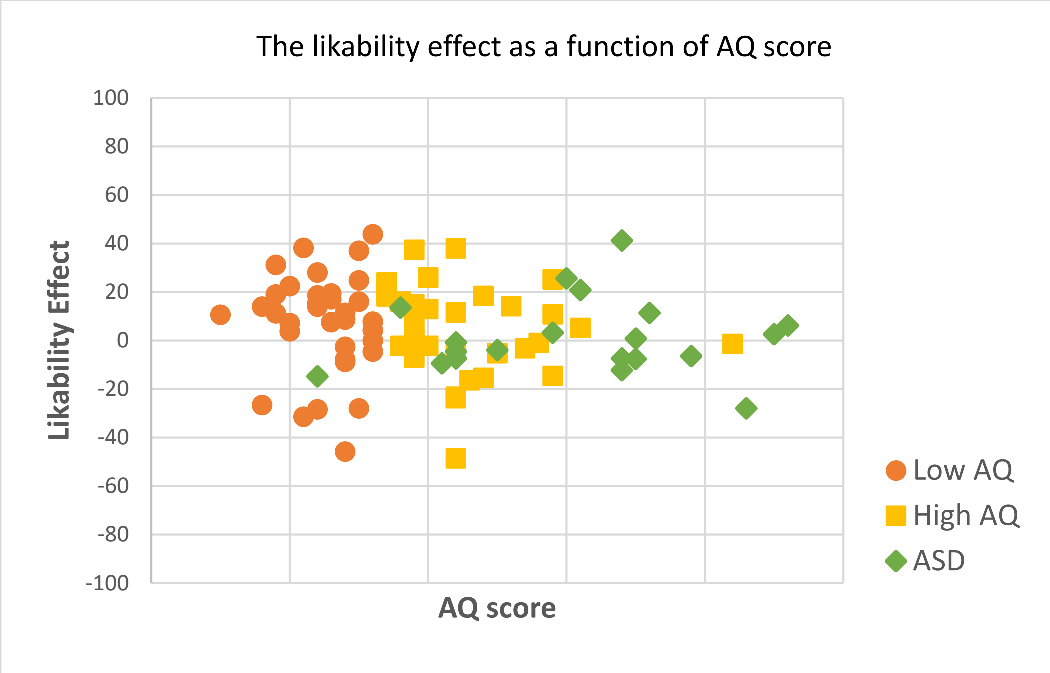


Figure 25 The association between the likability effect observed and participants' AQ score for Low AQ, High AQ and ASD groups.

<u>Additional Analysis with ASD Participants who Discovered Contingencies.</u>

There were five ASD participants across Experiment 4 and 5 who discovered contingencies hidden in the implicit learning task, therefore, an additional paired samples t-test was performed to understand whether their judgements of the morphs would be affected by this information. The results revealed that positive-disposition character received higher scores than negative-disposition character, which is in line with the contingencies ($t(4) = 4.22$, $p = .013$). This may indicate ASD individuals are guided social contingencies when explicitly aware of them. However, this result needs to be interpreted with caution due to an extremely small sample size.

Discussion

The aim of Experiment 5 was to further examine implicit social learning in ASD by investigating whether a possible role for perceptual learning can be excluded. Hereto the eyes of the test faces were covered. In line with expectations, ASD individuals still failed to show perceptual bias in line with implicitly presented contingencies. However, the follow-up analyses revealed that implicit learning has occurred within this population. Yet, the ASD group seemed to have built implicit associations that were in the opposite direction to those present in the learning phase of the experiment. Surprisingly, individuals with ASD judged morphed faces with an expression of joy as resembling more the character with a negative disposition. Similarly, morphed faces with an expression of anger were judged as resembling more the character with a positive disposition. This was in direct contrast to typically developed participants, who judged both characters in line with learnt contingencies. These results cannot be attributed to the low-level perceptual learning on the basis of the closer matching of low-level features of the morphs – eye and mouth configuration – with one of the two characters. As both characters smile (and frown) an equal amount of time during the learning phase, the facial expression on its own was not sufficient to perceptually discriminate between the two actors. It is the combination of the facial expression and gaze direction during the learning phase that can give rise to the implicit understanding of characters' disposition. This suggests that implicit social learning has occurred on the basis of differences in characters' dispositions toward the observer.

It is not yet clear whether the social implicit learning impairment in ASD is unique to social information or rather relies on domain-general abilities. If in a non-social implicit learning paradigm (which does not involve any emotional attributions) the individuals with ASD are able to learn the information (contingencies) implicitly than that would indicate that their capacity for implicit learning of contingencies is intact. Previous studies suggest that individuals with ASD are capable to learn implicitly on tasks such as artificial grammar, serial reaction time or contextual cueing. However, since all those that are structurally very different from the current social learning paradigm, comparisons of these non-social implicit learning tasks with our social implicit learning task would not be very insightful. Therefore, in Experiment 6, a non-social learning task matched on difficulty and number of cues with the social learning task will be used to be able to directly compare implicit learning abilities in ASD in both domains.

4.3 Experiment 6

This study was a replication of Experiment 3. Individuals with ASD viewed videos of two geometric objects, of which the colour and an internal movement changed dynamically. Similarly to social learning condition, figures displayed hidden contingencies that could be learned implicitly and were matched on a number of cues. While in the social condition, specific combinations of facial expression and gaze direction were used to portray the actor as having either a positive or negative disposition towards the observer, in non-social condition, the combination of colour and internal movement was used to predict the shape of the object as either a square or a circle.

Implicit learning was measured by perceptual biases toward the morphed figures consisting of various proportions of square and circle shapes. Results of the ASD group were compared to a subset of participants from Experiment 3 matched on age, gender and intellectual ability. In line with the generally accepted view of intact implicit learning in ASD (e.g. Foti et al., 2015) and the performance of typically-developed individuals high in autism spectrum traits reported in previous chapter, it was hypothesised that individuals with ASD will be equally skilled at implicitly learning contingencies in the non-social task as the TD individuals.

Method

Participants

Twenty-five undergraduate students with ASD took part in Experiment 6. After applying exclusion criteria four participants were excluded from the analysis (see Data reduction below). The final sample consisted of twenty-one participants (seven women, fourteen men), with a mean age of 19.76 (*SD* = 1.18), a mean total IQ score of 114.88 (*SD* = 9.19) and a mean ADOS score of 9.38 (*SD* = 2.33). The control group consisted of a subset of participants from Experiment 3, matched for age, sex and intellectual abilities. The data of thirty participants were included in the analysis (eight women, twenty men), with a mean age of 19.73 (*SD* = 1.23) and a mean total IQ score of 114.22 (*SD* = 6.84). The ASD and TD groups did not differ significantly in terms of age ($t(49) = 0.08$, $p = .934$), gender ratio ($X_2(1, N = 51) = 0.24$, $p = .628$) nor IQ ($t(49) = 0.30$, $p = .851$). The AQ scores were significantly higher in the ASD group than in the TD group ($t(49) = 7.26$, $p < .001$). Participants' characteristics are presented in Table 5.

Table 5 Participants' characteristics.

	AGE	SEX	IQ-total	AQ	ADOS
ASD GROUP (n = 21)	19.76 (1.18)	7 women 14 men	114.88 (9.19)	33.19 (9.22)	9.38 (2.33)
TD GROUP (n = 30)	19.73 (1.23)	12 women 18 men	114.22 (6.84)	17.93 (5.79)	-

<u>Stimuli and Procedure</u>

The stimuli and procedure were identical to those of the previously described Experiment 3 (Chapter 3). In short, participants viewed videos of two geometric figures, square (A) and circle (B), displaying contingencies that could be learnt implicitly on the basis of a combination of colour and internal movement. After a learning phase, they were asked a series of questions checking their understanding of the videos and whether they had discovered hidden contingencies. Questions were as follows: (1) "Could you describe what you just have seen? (2) "How many different objects did you see?" (3) "What can you tell me about their colours?" (4) "What can you tell me about their internal movement?" (5) "Did you detect certain patterns between colours, internal movement and objects?"

As in implicit social learning experiments, implicit learning was measured by perceptual bias toward morphs consisting of varying proportions of the two objects. The morph figure was of either light or dark grey colour with the red square either at the top or at the bottom of the figure and was constructed of different proportions of circle and square. The same morph levels (proportions of object A (square) and object B (circle); M1 = 60% A and 40% B, M2 = 55% A and 45% B, M3 = 50% A and 50% B, M4 = 45% A and 55% B, M5 = 40% A and 60% B) were used, including the catch trials. Participants were required to select whether the morphed figure resembled more closely the square (key 1) or the circle (key 2).

Results

Data Analysis and Data Reduction

The exclusion criteria were identical as in Experiment 3. One participant with ASD discovered the hidden contingencies in the task and three other participants failed to correctly respond to at least 75% of catch trials. Data from these four participants were removed from the analysis.

In addition to the data analyses that were identical to those conducted in Experiment 3, the data from the Experiment 3 was collated and added to the current data to conduct correlational analysis between the participants' AQ score and amount of implicit learning observed.

Morph Perception Task Results

A repeated-measures ANOVA was performed, with Geometric Figure (circle, square) and Morph Level (M1, M2, M3, M4, M5) as within-subject factors and Group (TD, ASD) as between-subject factor. The results are presented in Figure 26. There was a significant main effect of the factor Geometric Figure ($F_{1,49} = 25.73$, $p < .001$, $\eta p2 = .345$), suggesting that implicit learning had taken place. Importantly, the Geometric Figure and Group interaction was non-significant ($F_{1,49} = .15$, $p = .702$, $\eta p2 = .003$), suggesting no differences in the capacity for implicit learning between typically-developed and ASD groups. The main effect of Morph Level was significant ($F_{4,196} = 10.67$, $p < .001$, $\eta p2 = .179$), indicating that participants were sensitive to the different morph proportions. The main effect of the group and remaining interactions were all non-significant (all p's > .132).

Interestingly, the correlational analysis of the overall data from the current experiment and Experiments 3 revealed that there was a significant negative association between the AQ score and amount of implicit learning observed ($r(91) = -.21$, $p = .043$). However, this was not as pronounced as in the implicit social learning experiments (see Figure 27).

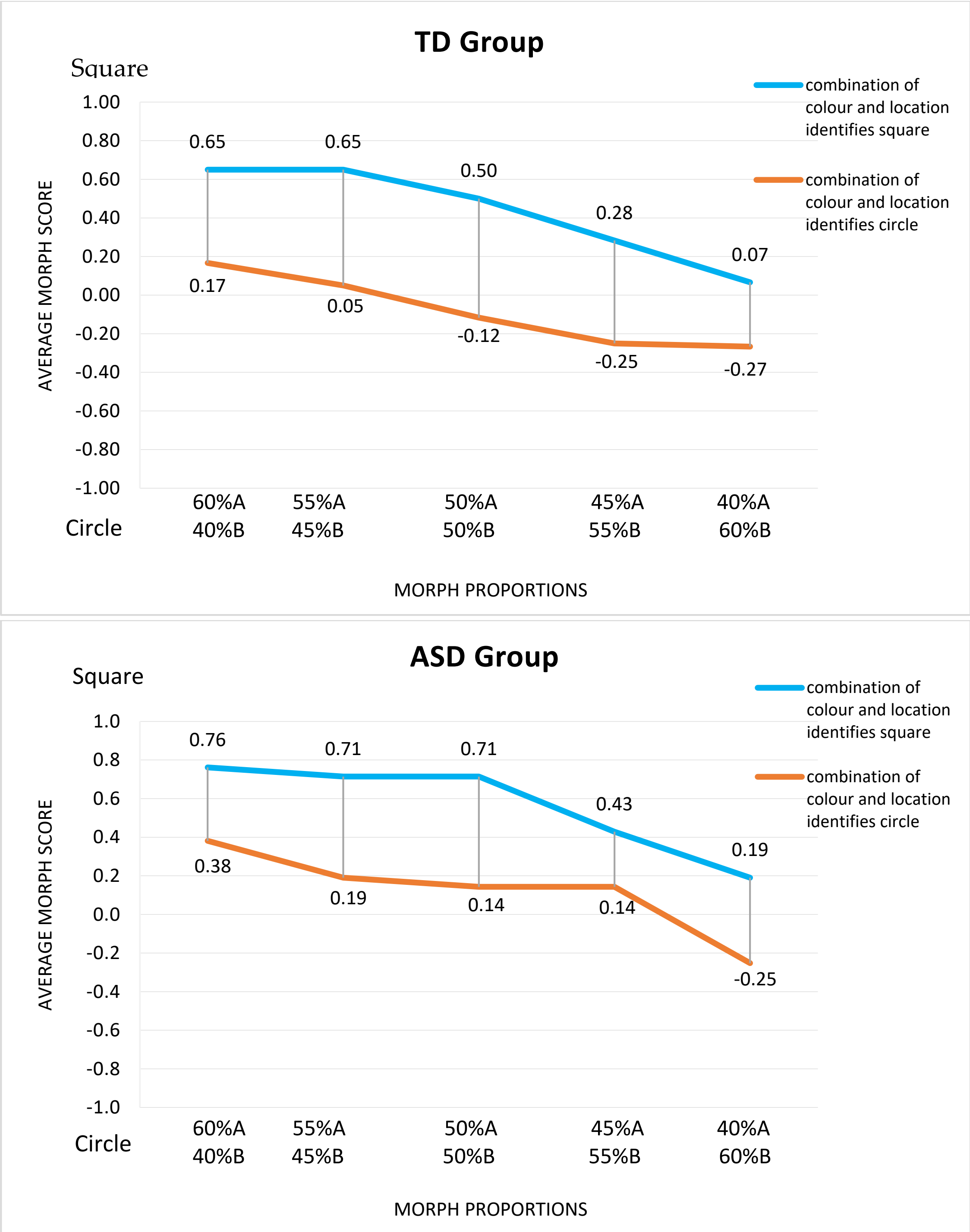


Figure 26 The mean scores across all morph levels - proportions of the two objects: square (A) and circle (B) shown for the TD (top panel) and ASD (bottom panel) groups. The amount of implicit learning is represented by a difference between mean score for morph identifying square and morph identifying circle. Clear implicit learning effect can be observed in both groups.

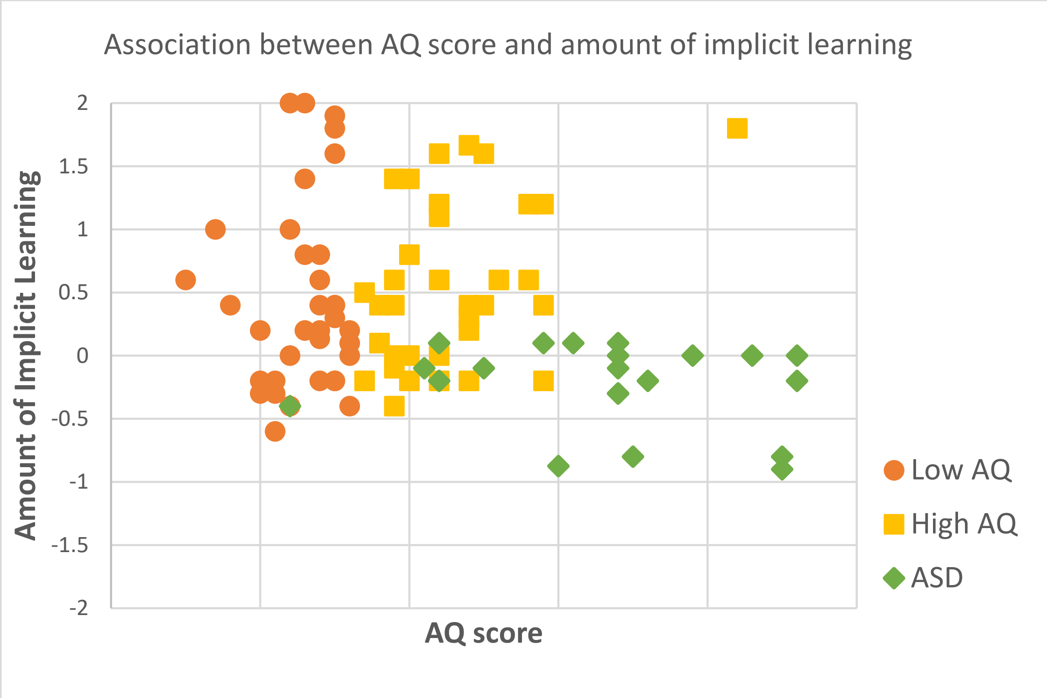


Figure 27 The association between the amount of implicit learning observed and participants' AQ score for Low AQ, High AQ and ASD groups.

<u>Comparison of social and non-social condition</u>

Several participants completed both social and non-social learning tasks, allowing for direct comparison between the two (TD, n = 20; ASD, n = 17). A repeated-measures ANOVA was performed with Task (Social, Non-Social), Morph (A, B), as within-subject factors and Group (TD, ASD) as between-subject factor. The scores for the Morph factor were calculated as an average value across all Morph Levels (proportions) for Morph A and B.

The results revealed a significant main effect of factor Morph ($F_{1,35}$= 28.78, p < .001, ηp2 = .451), confirming that implicit learning has occurred across both conditions. This was qualified by a significant interaction between Morph and Group ($F_{1,35}$= 18.99, p < .001, ηp2 = .352). Follow-up paired-samples t-test showed significant difference between judgement of morphs in TD subjects (t(19) = 6.32, p < .001) but not ASD group (t(16) = .845, p = .411).

There was also a significant main effect of Task ($F_{1,35}$= 7.57, p = .009, ηp2 = .178), qualified by a significant interaction between Task and Morph factors ($F_{1,35}$= 9.12, p = .005, ηp2 = .207). The interaction between Task and Group was not significant ($F_{1,35}$= .234, p = .632, ηp2 = .007). Crucially, a significant three-way interaction between Task, Morph and Group was found ($F_{1,35}$= 6.55, p = .015, ηp2 = .158), indicating differences in implicit learning in social and non-social tasks between the groups. Follow-up t-test were conducted, with the difference between Morph A and Morph B in social and non-social tasks calculated for each participant. The results revealed that there was no difference in the amount of implicit learning between social and non-social task in TD group ($t(19)$ = .301, p = .763). On the contrary, significant difference between the tasks was found in ASD group ($t(16)$ = 4.50, p < .001).

Discussion

This study aimed at exploring implicit learning abilities in ASD set within the non-social domain. In line with the hypothesis, those on the autism spectrum showed perceptual biases in their perception of the morphed figures congruent with the to-be-learned contingencies, similar to the typically developed group. This suggests that they were capable to integrate the cues contained within the videos and more importantly, implicitly learn combinations, in which these cues appeared. These results are in accord with previous research suggesting that individuals with ASD are able to learn implicitly, at least under certain circumstances (Barnes et al., 2008; Brown et al., 2010; Kourkoulou et al., 2013, 2012; Müller et al., 2004; Nemeth et al., 2010; Travers et al., 2010). Intact implicit learning in the non-social domain would argue against a general impairment in the ability to implicitly extract structural regularities or patterns form the environment and to learn them in ASD. Further to this, the results show that the individuals with ASD were capable to implicitly integrate at least a small number of cues, contrary to weak central coherence account (Happé & Frith, 2006). Since social and non-social experiments were structurally similar and contained the same number of cues to be learnt, it is unlikely that individuals with ASD were able to integrate three cues in one task (non-social) but not in the other (social).

Although there seems to be a consensus that individuals with ASD are capable of learning implicitly, the rate at which the learning occurs may differ from typical development. For example, Scott-Van Zeeland et al. (2010) found a deficit in implicit language learning in children with ASD listening to a 2.4-minute speech stream while another study using a 21-minute speech stream reported intact language learning abilities in children with ASD (Mayo & Eigsti, 2012). This indicates that autistic individuals might be slower at implicitly recognising patterns in their environment and may require more exposure to arrive at the same results as their typically developed peers. This could potentially explain why the negative association between the amount of learning and AQ score was found also in non-social condition. While this effect much less pronounced than in the social tasks in Experiment 4 and 5, it could indicate that those with higher AQ scores learnt the contingencies to a lesser extent, even though the differences at the group level were not revealed. It is important to note, however, that the contingencies presented in the current study were relatively simple, with a low number of cues (3) required for learning to occur. It could be the case that more complex patterns that are more difficult to extract and/or fewer repetitions would yield some deficits in implicit learning abilities in ASD. Future studies should explore the rate of implicit learning in ASD in both simple and more complex tasks.

4.4 General Discussion

Studies in this chapter aimed to explore the capacity for implicit learning in individuals with ASD within the social and non-social domain. Social learning inherently relies on associated emotions and affective valences, with abstract concepts such as disposition, attitude and intention being an intrinsic part of what is learned. This led to the proposition that those on the autism spectrum may have a selective impairment in their ability to learn implicitly but limited to the social domain, and possibly caused by a failure to implicitly attribute (or associate) emotional value to social information. Results revealed atypical implicit learning patterns in the ASD group, but exclusively in the social condition. Those on the autism spectrum failed to show biases in their perception of morphed faces in line with social contingencies they were exposed to during the learning phase of the experiments. Surprisingly, they seem to show the implicit associations that were in the opposite direction to those present in the learning phase of the experiment. Further to this, a clear distinction between likability scores for characters with positive and negative dispositions was observed in a typically-developed group, while this was not the case in participants with ASD, who gave similar scores to both characters, regardless of social disposition they displayed. Strikingly, there were no differences between the groups in implicit learning in the non-social task, with the performance of the ASD group comparable to the typically-developed group. This is in line with previous studies finding intact implicit learning performance in ASD on tasks not related to social stimuli (Barnes et al., 2008; Brown et al., 2010; Kourkoulou et al., 2013, 2012; Müller et al., 2004; Nemeth et al., 2010). Taken together these results suggest a domain-specific impairment in implicit learning. Since social implicit learning is considered a building block of social intuition (Lieberman, 2000), inability to learn from social encounters can have far-reaching consequences for social development. This could partially explain the social difficulties observed in ASD.

There are in principle several reasons why social implicit learning might not have happened in those on the autism spectrum even though their capacity for implicit learning may have been intact. These will be now discussed in turn.

Were ASD-individuals able to understand and integrate social cues in the implicit social learning paradigm?

If there would be a specific impairment in the processing of any of the three cues used in the implicit social learning paradigm (facial emotion, eye-gaze direction and identity) *per se*, then implicit learning of the contingencies would not take place, simply because one or more of the cues was not processed or recognised.

Facial expression. Deficits in emotion recognition have previously been found in individuals with ASD. One could argue that difficulties in understanding the facial expression displayed by the characters could explain the responses in the test phase. However, the evidence for emotion recognition deficits in the identification of basic emotions for adults with ASD is inconsistent, while for individuals with high-functioning ASD (as in the current study) the evidence is even less convincing (Evers, Kerkhof, Steyaert, Noens, & Wagemans, 2014; Nuske et al., 2013; Tracy, Robins, Schriber, & Solomon, 2011). Moreover, for basic emotions, individuals with ASD have been commonly found to have difficulties recognizing only the basic emotion of fear (Corden, Chilvers, & Skuse, 2008; Pelphrey et al., 2002). Further to this, all ASD participants were able to correctly identify the emotional expressions of joy and anger used in this study.

Gaze direction. Individuals with ASD show an intact capacity to discriminate gaze directions and can easily tell direct gaze from averted gaze, and accurately discriminate even subtle differences in gaze direction unless presented for a very brief amount of time (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995; Leekam, Baron-Cohen, Perrett, Milders, & Brown, 1997; Wallace, Coleman, Pascalis, & Bailey, 2006). Therefore, current findings cannot be explained by deficits in gaze direction detection or recognition.

Identity. Face identity processing has been found to be impaired in those on the autism spectrum for tasks that require face memory (Behrmann, Thomas, & Humphreys, 2006; Wallace, Coleman, & Bailey, 2008). However, since we used only two different identities per experiment, and all participants indicated correctly in the questioning session that they had seen two different identities, we have to assume that identity processing impairments were not present in the current ASD sample. Moreover, problems with face identity processing typically emerge when a delay intervenes between two presentations of identity (for a review see Weigelt, Koldewyn, & Kanwisher, 2012). In the current study, the morphed faces in the testing phase were presented simultaneously with the neutral faces of both characters, which should have reduced memory demand for this particular task. In fact, based on the catch trials error rates participants with ASD were equally good at discriminating between the two characters, as their typically developed peers.

Cue integration. Even if the understanding of specific social cues in isolation is intact, it might be that the integration of the cues into a meaningful percept was impaired. This view is in line with weak central coherence account (Happé & Frith, 2006). Evidence does indeed suggest that ASD-individuals show enhanced abilities on tasks where local processing is required, such as visual search tasks (Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009; O'Riordan & Plaisted, 2001) or block design completion (Minshew, Goldstein, & Siegel, 1997; Shah & Frith, 1983). However, previous studies have found that the integration of eye gaze and facial attributes (e.g. head movement; Hudson et al. 2011) is evident in those with high-functioning ASD. Further to this, the results from Experiment 6 suggest that the individuals with ASD were capable to implicitly integrate cues employed in the non-social learning paradigm. As the experimental design of social and non-social learning experiments was matched on the number of cues and difficulty, it is unlikely that ASD individuals would be capable of cue integration in one study, but not the other.

<u>Could differences in social memory reflect distinct implicit learning abilities between TD and ASD groups?</u>

Differences in memory for social cue combinations in those on the autism spectrum could potentially explain contrasting learning effects in both groups. The implicit learning effect found in the typically-developed group in the social implicit learning task could have been driven by memory for facial expressions of both characters when they were accompanied by directed gaze (for character A this was the expression of joy, for character B the expression of anger). These respective facial expressions may have been enhanced by the directed gaze, possibly because of directed gaze signals relevance toward the observer (D'Argembeau, Van der Linden, Comblain, & Etienne, 2003). One could also argue that there may be an evolutionary advantage to remembering individuals, who directed their anger toward a person during previous encounters (to avoid negative future consequences). It is, therefore, possible that the angry facial expressions accompanied by direct gaze would be particularly memorable and thus, sufficient to solve the learning task. A directed gaze advantage has been found to enhance memory for face identity in TD individuals (Conty & Grezes, 2012; Mason et al., 2004, Smith et al., 2006), but not in ASD (Zaki & Johnson, 2013). Since individuals with ASD may not preferentially attend to eye region and even avoid eye contact, showing a preference towards averted gaze (Dalton et al., 2005; Kylliäinen et al., 2012; Senju & Johnson, 2009), this may affect their ability to process faces displaying direct gaze similarly to typically-developed individuals. However, as facial expressions were not manipulated in the aforementioned study (Zaki & Johnson, 2013), it is not clear whether emotion displayed by the faces would affect a reduction in direct gaze memory. To explore whether the implicit learning in the social task could have been driven by the facial expression of anger accompanied by directed gaze and whether memory for emotion/gaze combinations differs in ASD, experiments in Chapter 5 evaluate participant's memory for the facial expression of specific identities in typical and autistic individuals.

<u>Can atypical social attention explain the absence/reversal of the response bias in ASD?</u>

While socio-emotional memory in ASD has not been subject to experimental scrutiny, atypical social attention is a hallmark of ASD, with preferential attention toward non-social rather than social stimuli reported fairly consistently (Klin et al., 2002; Kirchner, Hatri, Heekeren, & Dziobek, 2011; Riby and Hancock, 2009a, 2009b; Riby, Hancock, Jones, & Hanley, 2013; Rice, Moriuchi, Jones, & Klin, 2012; Shi et al., 2015; Shic et al., 2011). One could argue that differences in social attention in ASD could lead to aberrant implicit learning specific to the social task. If those with ASD failed to direct their attention toward the content of the videos in social condition, this could have had negative consequences on the implicit learning process. However, atypical attention to social information is typically observed when social content is present in competition with non-social stimuli, which was not the case in the current study. While atypical social attention would be detrimental to the ability to detect social cues in one's environment, based on the answers provided by participants during the questioning session, it is clear that participants with ASD did attend to the social cues displayed by the characters, since they were able to accurately describe the content of the videos. In addition, catch trials were used to identify participants who failed to discriminate between the two identities, and thus lack of attention to social stimuli cannot account for current results.

On the other hand, it could be that those on the autism spectrum paid *less* attention to the critical areas of the face, which could have resulted in decreased exposure time to the stimuli in comparison to the typically developed group, and in turn, influence their ability to learn effectively. Indeed, information processing in ASD appears to be critically affected by the amount of exposure to the relevant stimuli (T. F. Clark, Winkielman, & McIntosh, 2008; Tardif, Lainé, Rodriguez, & Gepner, 2007). However, the results of Experiment 5 revealed the opposite social learning effect, rather than no learning at all.

One interpretation that is in line with hyperarousal model (Corden et al., 2008; Coss, 1978; Dalton et al., 2005; Hutt and Ounsted, 1966; Joseph et al., 2008; Kylliainen and Hietanen, 2006; Richer and Coss, 1976), is that those on the autism spectrum avoided looking at the characters while their gaze was directed at the participants. According to this model for individuals with ASD the eyes of others are strongly aversive stimuli, causing increased physiological arousal, and as a result gaze avoidance behaviour has developed as an adaptive response (e.g. Tanaka & Sung, 2016). Such active gaze avoidance should be more prominent in response to perceived eye contact - direct gaze - rather than averted gaze (Senju & Johnson, 2009). If participants with ASD paid more attention to the faces when averted gaze was present and/or avoided looking at the faces when direct gaze was present, this would explain the opposite learning effect found. The positively-portrayed character, displayed angry facial expression when looking away (so angry would be remembered for that identity) and negatively-portrayed character displayed happy facial expression when looking away (so joy would be remembered for that identity). To date, only a handful of studies explored visual attention to averted gaze in ASD as compared to typically developed individuals (Hernanderz et al., 2009; Kliemann et al., 2010; Tanaka & Sung, 2016) and results so far have been mixed. However, the stimuli used in those studies included only static images. It has been shown that dynamic facial expressions elicit higher emotional arousal than static ones (e.g. Sato and Yoshikawa, 2007), which is of particular importance for the hyperarousal model. Additionally, dynamic facial expressions are more ecologically valid and thus, more salient for emotional communication. A recent eye-tracking study found that individuals with ASD demonstrated reduced looking time at social versus non-social stimuli, but only when the stimuli were moving towards them, rather than past them (Crawford et al., 2016). It could be that individuals with ASD tend to avoid social stimuli that are directed at them and have the potential to require social interaction. To explore whether the direct gaze in social implicit learning task was avoided by participants with ASD, in Chapter 6 visual attention toward faces displaying direct or averted gaze in typical and autistic individuals is compared.

<u>Is it possible for the implicit learning mechanisms to be intact in ASD, while the knowledge derived from implicit learning may not be applied successfully?</u>

Previous studies have demonstrated a dissociation in ability and skill application in ASD (Minshew, Meyer, & Goldstein, 2002; Soulieres et al., 2007) and difficulty in generalizing learned skills across contexts (Lovaas et al. 1973; Ozonoff and Miller 1995). Although these findings are in relation to explicit learning processes, if also applicable to implicit learning they may imply difficulties in everyday abilities associated with the implicit acquisition in ASD, regardless of the learning mechanism itself. The capacity to learn implicitly exists in tandem with an ability to implicitly know when to act on the implicitly acquired knowledge; without the ability to use implicitly learnt information effectively, implicit learning is redundant. The question then becomes what could be the reason behind ASD impairment in the successful application of implicitly acquired information.

<u>Could overreliance on the explicit processing of social information interfere with implicit social learning in ASD?</u>

Implicit impairments in ASD may result from a greater propensity for individuals with ASD to use explicit learning strategies, rather than to rely on implicit strategies (Gidley Larson & Mostofsky, 2006). Consistent with this observation, there is evidence that compared with typically-developed children, children with autism show greater reliance on explicit approaches to learning new information and categories (Klinger & Dawson, 2001) and a pattern of word retrieval consistent with enhanced declarative memory (Walenski, Mostofsky, Gidley Larson, & Ullman, 2008). Similarly, in a social context, individuals with ASD consciously remind themselves to think about the mental states of others in an attempt to compensate for interaction difficulties (Schilbach et al., 2013). Participants with ASD, who discovered hidden contingencies in social experiments (Experiment 4 and Experiment 5), that is, realised that one character displayed positive disposition toward them while the other displayed negative disposition toward them, showed performance on morph perception task that was similar to that of typically-developed controls. This means that once ASD individuals acquired explicit social knowledge, they were able to apply it successfully in the following tests. This was consistent across all five participants with ASD, who were explicitly aware of social contingencies present in the learning phase of the experiment.

Further to this, previous research has shown that overreliance on explicit strategies interferes with normal implicit acquisition of skills (e.g., Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Foerde, Knowlton, & Poldrack, 2006; Gebauer & Mackintosh, 2007; Hoyndorf & Haider, 2008; Lieberman, Chang, Chiao, Bookheimer, & Knowlton, 2004; Lleras & Von Muhlenen, 2004; Poldrack & Rodriguez, 2004). This could be particularly pronounced when engaging in a social interaction, where one needs to keep track of different social information. Using explicit strategies to navigate the social world, would be much effortful and not as efficient as relying on implicit processing mechanisms and may result in cognitive overload and feelings of being overwhelmed. Indeed, autistic individuals describe "being flooded" by information, an "inability to keep up," and "not knowing when and how" to respond to others. This is in line with a number of behavioural and brain imaging studies reporting that less requirement to use executive functions is associated with better implicit learning performance; the more effort a task requires, the less implicit learning takes place (e.g. Nemeth et al., 2013; Virag et al., 2015).

However, it should be noted that the overreliance on explicit information could be a consequence of impaired implicit learning mechanism, rather than a cause. Limited ability to learn implicitly may lead to the development of alternative learning strategies to cope with a complex social environment.

<u>The influence of cognitive load</u>

Implicit learning is often conceptualised as an automatic process, making minimal demands on cognitive/attentional resources and therefore occurring relatively effortlessly. However, studies combining implicit learning paradigms with concomitant tasks indicate that added cognitive load can impair implicit learning (A. Cohen, Ivry, & Keele, 1990; Frensch & Miner, 1994; Shanks & Channon, 2002; Shanks et al., 2005; Stadler, 1995). Although some studies found no interference, which is probably due to the nature of the dual-task (Wierzchon et al., 2012).

It could be that individuals with ASD experience the social condition (but not the non-social condition) as more cognitively demanding, which then in itself could prevent implicit learning from occurring. There is quite some evidence that individuals with ASD are easier 'overloaded' by environmental stimuli, especially in the social domain (Frith, 1995). Various reasons for this have been proposed (e.g. lack of social experience), but recently a new, interesting, perspective was introduced, which holds that there are basically two distinct types of working memory: social and non-social working memory, each with its own neural substrate (the former overlapping with the "mentalizing network"; Meyer et al., 2012; Dumontheil et al., 2014). The social working memory is responsible for the constant, largely automatic, updating of information concerning others, their emotional/mental states and beliefs, during social interactions. Increased cognitive load has been shown to disrupt automatic ToM processing in TD individuals (Schneider et al., 2012).

Future studies should manipulate the cognitive load to see if that would affect implicit social (and non-social) learning. If the absence of cognitive load plays indeed a crucial role in establishing implicit learning, and the ASD individuals have a limited social working memory, then increasing the cognitive load in the social condition should predominantly affect the ASD group, whereas the groups should be equally affected in the non-social condition. However, it is important to note the high cognitive load resulting from social interaction can also be a consequence, rather than the cause of impaired implicit social learning.

<u>Failure to associate affective values to implicitly learned social stimuli: implicit affective tagging hypothesis.</u>

As previously discussed, intuitive judgements are thought to be comprised of both cognitive and affective components, with emotions acting as computational tags that subserve and facilitate cognitive processes. If the cognitive process itself is intact, that is, if the implicit learning mechanism is preserved in ASD, this could suggest deficits in affective components that gave rise to intuition. These would be particularly important for the formation of intuitive thoughts within the social domain, where affective valences are imprinted in the nature of the stimuli. While the inability to automatically attribute affective information to social stimuli could make social interaction problematic, attributing inaccurate emotional tags would be devastating for social development. There is some evidence that individuals with autism may not assign affective values to social cues when these are presented implicitly. In a recent study investigating social perception through the sense of smell, individuals with ASD were equally capable of detecting and perceiving fearful body odours when explicitly requested to do this (Endevelt-Shapira et al., 2017). However, when the smell of fear was present but was undetected, it increased physiological arousal trust only in typically developed individuals but not ASD individuals. What is more, ASD individuals perceived a manikin infused with explicitly undetectable small of fear as more trustworthy than the control manikin with neutral smell whereas the results were in opposite direction for typically developed participants, who as expected, rated the control manikin as more trustworthy. This suggests that while individuals with ASD perceive the smell of fear and are capable of recognising it, they interpret it, and respond to it, differently, sometimes displaying behaviour opposite to that of typically developed individuals. This finding is particularly important, as it suggests that those on the autism spectrum have a propensity not to ignore or dismiss socio-emotional cues, but rather to misread them as having an opposite meaning to that what was intended. This effect seems to emerge if social signals are perceived outside of conscious awareness.

The results from the current study support this notion at least to some extent since the perceptual bias in the judgement of morphed faces in ASD was in the opposite direction to that displayed by typically developed individuals. Although the specific social cues such as facial expressions or gaze direction were explicitly displayed by the characters, the contingencies to be learnt were implicit in nature. The questioning session confirmed that all participants were able to correctly identify social cues displayed by each character. Yet, the combination these cues seemed to implicitly acquire different values for typical and autistic individuals; regardless of their ability to understand and process social information, positive sequences of social cues seem to have acquired negative affective value and at the same time, negative sequences of social cues acquired positive affective value. Implicitly misclassifying a character with a negative disposition as having positive intentions could have far-reaching consequences for social interactions and could explain at least in part the social difficulties seen in ASD. However, it is important to note that the questionnaire data revealed no differences in likability scores for positive-disposition and negative-disposition characters in the ASD group. The disposition of the character did not seem to affect liking judgements of ASD-individuals, who rated both characters similarly, which may suggest that they did not attach emotional value to the characters based on the social cues they displayed. If the social cues were indeed misinterpreted in this population, due to differences in implicit processing of affect, one would expect higher likability scores for the character with a negative disposition toward the observer. Future studies should investigate automatic attribution of emotional value in ASD in social and non-social context.

The social implicit learning ability lies on a population-wide continuum.

Combined with the findings from the previous chapter, where individuals high in autism spectrum traits showed a deficit in their ability to learn social information implicitly, current results suggest a gradient of social implicit learning ability that runs throughout the population. The differences in implicit learning start to emerge even within a typical population. In the social learning condition participant with a high number of autistic traits showed increased liking towards positively portrayed characters when explicitly asked to score the characters on the questionnaires. However, they failed to show biases in their perception when judging the morphs (implicit or indirect measurement), while these biases were evident in low autism traits group. In contrast, social implicit learning effects in ASD individuals were impaired on both, implicit and explicit measures (see Table 6).

Table 6 Implicit learning in social and non-social domains across the population-wide continuum.

	Social Learning Judging Morphs (Implicit Measure)	Social Learning Questionnaires (Explicit Measure)	Non-Social Learning (Implicit Measure)
Low Autism Traits	✓	✓	✓
High Autism Traits	X	✓	✓
Autism Spectrum	X	X	✓

4.5 Conclusion

A set of studies in this chapter provided initial evidence for dissociated implicit learning in the social and non-social domain in ASD. People implicitly learn associations between social cues and use this knowledge to guide their behaviour, even in the absence of explicit knowledge. Impaired ability to acquire implicit associations on the basis of social signals may lead to underdevelopment of social intuition and thus, have far-reaching consequences for social functioning. It has been argued those on the autism spectrum are prone to adopt explicit learning strategies and rely more on explicitly acquired knowledge. While this approach could be to some extent useful for understanding the physical world, the interpretation of social cues using effortful cognitive processes would negatively impact the ability to adjust one's behaviour to a given social context, within the time window available.

One reason why social implicit learning may be particularly problematic in individuals with ASD may be defective affective tagging mechanism that would allow for implicit linking of emotional valence to social information. It is not sufficient to store a set of implicitly learnt patterns, without the information about their (emotional) significance it will not have much relevance for the owner. For example, in case of social intuition, associations between the specific sequence of social cues and their outcomes will not be meaningful without information about emotional salience they carry, such as danger or satisfaction from previous episodes. Impairment in implicit processing of affective valences can reduce the usefulness of implicitly acquired information and as a result, may lead to the overreliance on explicit strategies to understand one's environment. On the other hand, atypical cognitive processes such as a deficit in social memory and aberrant social attention observed in ASD could also affect one's ability to learn implicitly. Therefore, to assess their potential contribution to the implicit social learning in ASD, these processes will be further explored in the next chapters. Chapter 5 will investigate social memory for facial expressions with a direct versus averted gaze, while Chapter 6 will examine social attention in relation to emotion-gaze cue combinations in dynamically changing facial expression sequences.

Chapter 5: Memory for facial expressions in typical development and ASD.

Implicit social learning observed in the set of studies from Chapter 3 has been thought to result from participants' ability to infer another person's disposition toward them based on the specific combination of facial expression and gaze direction. However, the obtained results could originate from memory advantage for a particular emotion-identity combination induced by directed gaze. The aim of the studies in this chapter was to investigate whether certain combinations of social cues are more memorable than others. If found, any potential differences in memory for social information in typical development and ASD could help to explain observed difficulties in implicit social learning in ASD.

<u>The saliency of emotional facial expressions</u>

Facial expressions are probably the most salient aspect of non-verbal communication that may grant immediate insight into others' state of mind (Keltner, Ekman, Gonzaga, & Beer, 2003). People's faces provide adaptive information about the social interactions they offer (Zebrowitz, 2006). In other words, face perception reveals social interaction opportunities and is thereby closely linked to action, with facial expressions conveying information about behavioural motivation (e.g. approach or avoidance) and intentions toward the observer (Mumenthaler & Sander, 2012; N'Diaye, Sander, & Vuilleumier, 2009). Emotional expressions of joy and anger are particularly potent, signalling approval or disapproval of others (D'Argembeau, Van der Linden, Comblain, et al., 2003). From an evolutionary perspective, both positive and negative facial expressions have particular survival value; positive facial expressions communicate cooperative opportunities, while negative facial expressions are important for avoiding potentially threatening situations (Shimamura, Ross, & Bennett, 2006).

There is a debate as to the relative impact of positive versus negative facial expressions on processing other aspects of faces. For example, it has been argued that angry and threatening faces are identified more efficiently in a crowd of distractor faces, a finding known as the 'face in the crowd effect' (Öhman, Lundqvist, & Esteves, 2001). This effect has been explained by attention allocation, with threatening targets orienting attention more quickly than nonthreatening targets, although it is not quite clear whether this is due to the emotionality of these faces, or rather to their low-level characteristics (Shasteen, Sasson, & Pinkham, 2014). However, not all studies support the 'face in the crowd effect' for expressions of anger. There is also ample evidence suggesting that positive emotional expressions can capture attention as effectively as negative ones; with happy faces identified even faster and more accurately than all the other facial expressions (Becker et al. 2011, Calvo & Lundqvist, 2008; Kirita & Endo, 1995; Leppänen & Hietanen, 2004; Svärd, Wiens, & Fischer, 2012).

Memory for facial expressions

In addition to such immediate effects of the other's facial expression on attention and social behaviour, researchers also studied its impact on memory. Especially the influence of facial expressions on the memory for the other's identity has been the subject of a plethora of studies (W. Chen et al., 2015; Conty & Grèzes, 2012; D'argembeau & Van der Linden, 2007; D'Argembeau, Van der Linden, Comblain, et al., 2003; D'Argembeau, Van der Linden, Etienne, & Comblain, 2003; Endo, Endo, Kirita, & Maruyama, 1992; Gallegos & Tranel, 2005; Jackson, 2018; Kaufmann & Schweinberger, 2004; Larøi, D'Argembeau, & Van der Linden, 2006; Liu, Chen, & Ward, 2014; Nakashima, Langton, & Yoshikawa, 2012; Sergerie, Lepage, & Armony, 2005, 2007). Surprisingly, only a few studies focused specifically on memory for facial expressions of certain identities (D'argembeau & Van der Linden, 2007; D'Argembeau, Van der Linden, Comblain, et al., 2003; D'Argembeau, Van der Linden, Etienne, et al., 2003; Shimamura et al., 2006). Unlike the studies of facial identity that rely on discrimination between previously encountered faces and newly presented ones, studies of memory for facial expressions assess memory for social information contained within a face. Such memory has been argued to form only for social cues that are functionally important (Weisbuch, Lamer, & Ford, 2013). While remembering facial identity is undoubtedly of great social value, retrieving emotional connotation associated with the previously encountered face can act to forecast approach-avoidance tendencies and help to adjust one's behaviour to a given social context based on the behavioural expectations (Adams & Kleck, 2005). In that respect, all emotional facial expressions are functional and may enhance memorability. While some studies comparing memory for positive versus negative facial expression support this notion, with expressions of joy and anger, recalled equally well (D'argembeau & Van der Linden, 2007; D'Argembeau, Van der Linden, Etienne, et al., 2003), others have shown memory advantage for the expressions of joy as compared to that of anger (D'Argembeau, Van der Linden, Comblain, et al., 2003; Shimamura et al., 2006), often referred to as the 'happy advantage'. Some authors suggested that these inconsistencies may be at least partially due to individual differences, in particular regarding psychopathological dimensions such as social anxiety and depression (D'Argembeau, Van der Linden, Etienne, et al., 2003; Ridout, Astell, Reid, Glen, & O'Carroll, 2003). For example, clinically depressed patients do not show a memory advantage for happy faces similar to controls, instead, they are better at recognising sad rather than happy faces (Ridout et al., 2003), possibly due to their relevance to their own state of mind. However, these differences emerged when studying memory for facial identity, it is not clear whether memory for facial expressions themselves is also affected.

<u>The role of gaze direction in memory for identity and expression</u>

Faces are dynamic stimuli and require the joint processing of their invariant features for identity recognition, as well as the processing of their changeable features, such as gaze direction or facial expression (Haxby, Hoffman, & Gobbini, 2000). Gaze direction distinguishes between behaviour directed toward the self (the observer) and behaviour directed elsewhere and thus facial expressions differ in meaning depending on the gaze direction, revealing intentions and target of the gazer's emotional display (Adams & Kleck, 2003; Hudson & Jellema, 2011; Mumenthlaler & Sander, 2012; N'Diyae et al., 2009). A smile will be interpreted differently if directed at, rather than away from, the observer. This special binding between facial expression and gaze direction has the capacity to enhance facial processing (Adams & Kleck, 2003; 2005; Sander, Grandjean, Kaiser, Wehrle, & Scherer, 2007; Artuso & Palladino, 2015). Not all emotion-gaze combinations, however, have the same power to influence perception and subsequent memory of the face. Gaze behaviour and emotion have been linked to behavioural tendencies to either approach or avoid (Adams & Kleck, 2003). Specifically, direct gaze enhances the processing of approach-oriented emotions such as happiness and anger, while averted gaze enhances the processing of avoidance-oriented emotions such as fear or sadness (Adams & Kleck, 2005; Milders, Hietanen, Leppänen, & Braun, 2011; Sander et al., 2007). According to the shared signal hypothesis, congruent emotion and gaze combinations, in which gaze direction matches the underlying behavioural intent communicated by a specific emotion (e.g. direct gaze-anger), denote a stronger emotion-gaze binding than incongruent ones (e.g. averted gaze-anger) and therefore enhance perception of that emotion and its memorability (Adams & Kleck, 2003; 2005; Artuso & Palladino, 2015).

Enhanced memory for faces initially encountered with a directed gaze as compared to averted gaze has been supported by a number of studies (Conty & Grèzes, 2012; Mason, Hood, & Macrae, 2004; A. D. Smith, Hood, & Hector, 2006; Weisbuch et al., 2013). A direct gaze has a capacity not only to enhance the memorability of facial identity but also the memory for the gaze itself. In a forced-choice paradigm, Weisbush et al. (2013) found that individuals would be able to recall the gaze direction of previously encountered faces with the direct gaze better than those with averted gaze. Nonetheless, studies reporting the direct gaze advantage effect for the memory of face identity typically employ faces with neutral facial expressions. Despite the combinational nature of social perception, surprisingly little attention has been paid to the combined effects of facial expressions and gaze direction on memory. Based on the studies of memory on recognition of facial *identity*, which typically find memory advantage for faces displaying expressions of happiness or direct gaze, one might expect that happy faces with direct gaze would also be remembered better than any other emotion-gaze combinations. Yet, the only couple of studies that looked at face identity recognition in relation to emotional facial expression and gaze direction failed to support this prediction

(Jackson, 2018; Nakashima et al., 2012). Nakashima and colleagues (2012) found increased recognition rate of angry faces encountered with the direct gaze as compared to angry faces encountered with averted gaze, yet no such direct gaze advantage was found for happy faces. However, due to the design limitations, the study did not examine a direct interaction between emotion and gaze. On the other hand, Jackson (2018) found a memory advantage for happy expressions with averted as compared to direct gaze whereas no such difference has been observed for angry facial expressions. The discrepancy between the two findings can be explained by the type of memory that each study engaged. While the study by Nakashima et al. (2012) investigated long term memory (LTM) for facial identity, the study by Jackson (2018) looked specifically at the influence of gaze on working memory. In the context of findings from implicit learning, it is the influence of gaze on LTM is of particular interest.

<u>Current study</u>

Social implicit learning observed in the set of studies from Chapter 3 has been thought to result from participants' ability to implicitly infer another person's disposition toward them based on the specific combination of facial expression and gaze direction. However, due to the dichotomous nature of the test task used, it could be argued that the obtained differences in implicit learning between the low and high AQ groups (both TD), and between the TD and ASD groups, could, in principle, originate from a memory advantage for a particular emotion-identity combination induced by directed gaze. For example, if during the learning phase, character A expressed joy accompanied by direct gaze, and the directed gaze facilitated the forming of memory for the smile on the face of character A, then observers could have relatively easily solved the test task in the social implicit learning studies. That is, simply observing a smile on the face of the target (i.e. the morph between characters A and B) would be enough for the observer to choose character A as best resembling the target, as character A was remembered as displaying a smile. This result could thus be obtained regardless of whether the knowledge of characters' dispositions had been implicitly acquired or not. The directed gaze ensured that the smile on the face of character A had been imprinted more than all other combinations, giving the appearance of implicit learning of the character's disposition towards the observer, whereas, in fact, all that was learned was the smile on character's A face. The frown on character's A face (during the remaining 50% of the viewing time) had not been imprinted or remembered as well as the smile because during character A's frown the gaze was directed away from the observer. A similar line of reasoning could be applied for a facilitated memory of the frown on the face of character B due to the accompanying directed gaze. Therefore, such results would have direct implications for the findings presented in previous chapters.

As such, studies in this chapter set out to investigate the influence of gaze direction on the memorability of facial expressions of specific agents. Experiment 7 explored memory for facial expressions in the typical population with varying number of autistic traits. A similar study was then conducted with ASD individuals (Experiment 8).

5.1 Experiment 7

This study aimed to investigate the memory for facial expressions of specific agents in relation to the combination of gaze direction (away versus toward) and type of emotion (happy versus angry). Participants repeatedly viewed images of expressions of joy or anger accompanied by gaze directed either at the observer or averted to the right, displayed by different characters. It was hypothesised that when a few minutes later probed with the same characters but now displaying neutral facial expressions (with the eyes covered), participants would be more likely to recall expressions of joy, especially when it had been accompanied by direct gaze. This hypothesis was based on the predominant finding of studies investigating memory for facial identity, but by no means is a settled outcome, as the memory for facial expression is still very much under-researched. A further aim was to examine the influence of repeated encounters on memory formation. Previous studies typically assessed memory for facial expressions based on single presentations (D'argembeau & Van der Linden, 2007; D'Argembeau, Van der Linden, Comblain, et al., 2003; Shimamura et al., 2006). If people automatically encode social cues each time a person is encountered, one might expect these cues to accumulate in memory over time and be stored for future interactions. Indeed, Lieberman (2000) argued that such automatic learning of sequences of social cues forms a basis for the development of social intuition. Therefore, the memory for facial expressions should increase as a function of repeated exposure. Finally, memory for facial expressions in typically developed individuals that vary in autistic traits (as measured by AQ questionnaire) was examined. It was hypothesized that any direct gaze memory advantage would be reduced in individuals with higher AQ scores. It was not clear whether this would be evident for both emotions.

Methods

Participants

A total of 96 undergraduate students at the University of Hull participated in the experiment in return for course credits. After applying data exclusion criteria (see below), 89 participants were included in the analysis (53 women, 36 men). The average age of the included participants was 20.93 (*SD* = 2.67). All participants had a normal or corrected-to-normal vision. None of them reported to be suffering from any psychological or (neuro-)developmental conditions.

Stimuli

Experimental stimuli consisted of 16 images of faces (eight women, eight men) taken from the Warsaw set of Emotional Facial Expressions Pictures (WSEFEP; Olszanowski et al., 2015). Images depicting expressions of joy and anger, and a neutral expression, were selected for each model. The images in the WSEFEP set consisted only of models exhibiting direct gaze, therefore the right-averted gaze images were generated using Paint.Net software.

For the learning phase, four sets of the aforementioned 16 images were prepared for counterbalancing purposes, to remove any effects due to differences in the memorability of the faces of particular models. Each set included eight happy and eight angry faces, each expression was displayed by four men and four women, half of them with averted gaze and the other half with direct gaze.

Counterbalancing across participants ensured that each model was shown an equal number of times within each emotion-gaze category (happy-direct, happy-averted, angry-direct, angry-averted).

For the test phase, the same 16 models that were used in the learning phase were presented once, but all with neutral facial expression. The eyes of the test faces were covered with small blue rectangles, one on top of each eye. This was done to ensure that faces that had been initially presented with direct gaze were not remembered better due to the low-level similarity to test faces.

Procedure

Participants were tested individually. They were seated in front of a PC monitor at approximately 60cm distance. The procedure consisted of two main phases: a learning phase and a test phase, separated by a retention interval.

Learning phase

The faces were sequentially presented in random order on a computer screen in front of the participants. Each face was presented for 1000ms. Half of the participants were assigned to the three-repetitions condition, with each face presented three times (total of 48 trials), the other half was assigned to the eight-repetitions condition, with each face presented eight times (total of 128 trials). Participants were asked to look at the faces carefully as they were told they would be later asked to judge them on trustworthiness. No mention was given of a subsequent memory test, and thus the learning of facial expressions occurred in an incidental manner.

Retention interval

The learning phase was followed by a five-minute retention interval, during which participants did an online 50-piece jigsaw puzzle, depicting a neutral scene.

Test phase

Directly following the retention interval, the surprise test phase began. Test faces were presented with neutral expression and eyes covered, at the centre of the screen. At the start of the test phase, participants were reminded that the faces they had seen earlier had either a happy facial expression or an angry facial expression. For each presented face, participants were asked to recall the emotional facial expression by pressing one of the two keys labelled 'happy' and 'angry'. Each face remained on the screen until the participants indicated their response, however, participants were instructed not to dwell on their responses and make their decision on the basis of an initial impression. Once this response had been given, the next face would be presented.

IQ Test

Following the task participants' intellectual functioning was evaluated using a short version of Wechsler Intelligence Scale, 4th edition (WAIS-IV)

AQ Test

Finally, participants completed an online 50-item Autism Quotient (AQ) test, assessing the extent to which they possessed autistic traits (Baron-Cohen et al., 2001)

Results

Data Reduction

Participants were excluded if they failed to respond at more than 25% of trials (four participants). In addition, one participant was removed as they failed to complete the AQ questionnaire and two participants as they failed to follow test instructions. In total, data from seven participants were excluded from the analysis. Further to this, trials with response times shorter than 150ms and longer than 1000ms were excluded (2% of trials).

Demographics

A median split was performed to assign participants to either low or high AQ group. The AQ scores ranged from 5 to 39, with median of 17, resulting in 45 participants in low AQ group (*M* = 12.58, *SD* = 3.89) and 44 participants in high AQ group (*M* = 22.77, *SD*=5.49). The high and low AQ groups did not differ on age ($t(87) = 1.04$, $p = .303$), nor gender ratio ($X_2(1, N = 89) = 0.08$, $p = .930$).

Data Analysis

The memory for facial expressions was measured in terms of the percentage of accurately recalled facial expressions for each emotion-gaze combination. The overall percentage of correct responses was analysed with a one-sample test against the value of 50%. The results revealed that the average number of correctly remembered facial expressions in three repetitions condition was not above the chance in low AQ group ($t(22) = 1.51$, $p = .145$), who remembered on average 55% of facial expressions. However, this has reached significance in the high AQ group ($t(21) = 2.54$, $p = .019$), with on average 59% of facial expressions remembered correctly. For eight repetitions condition both groups performed significantly above the chance level, with low AQ individuals remembering on average 69% of facial expressions ($t(21) = 4.67$, $p < .001$) and high AQ individuals 67% ($t(21) = 3.58$, $p = .002$).

To analyse memory for specific emotion-gaze combinations, the percentage of correct responses was entered into an ANOVA with Facial Expression (Happy, Angry) and Gaze Direction (Direct, Averted) as within-subject factors and Repetitions (Three, Eight) and AQ Group (Low, High) as between-subject factors. The results can be seen in Figure 28 and 29. A significant main effect of Repetitions was found, $F_{(1, 85)} = 8.15$, $p = .005$, $\eta p2 = .088$, with a higher percentage of correct responses in the Eight-Repetitions condition (*M* = 68.32, *SD* = 19.97) than in the Three-Repetitions condition (*M* = 57.21, *SD* = 16.75).

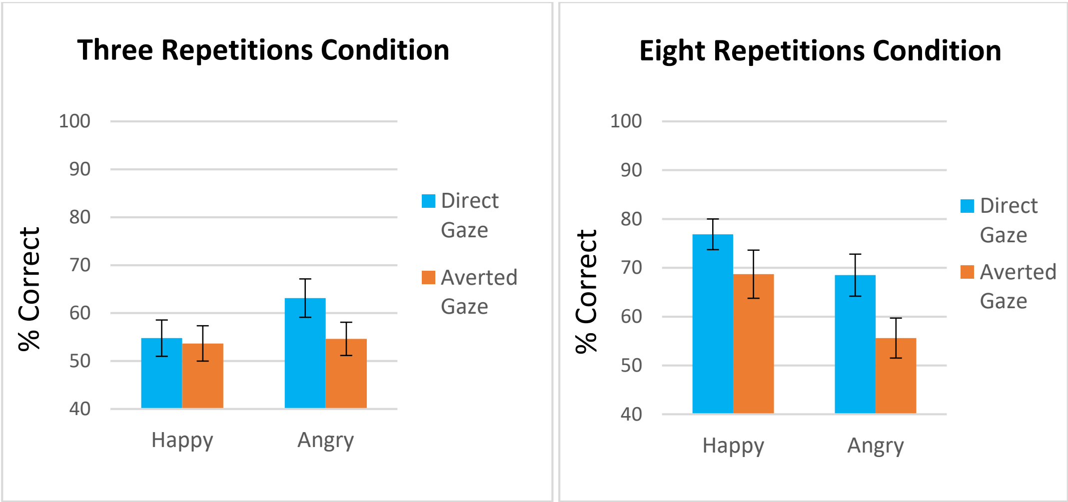


Figure 28 The mean percentage of recall rates for all emotion-gaze combinations for the three-repetitions condition (left) and the eight-repetitions condition (right) for all participants. Error bars represent SE.

Facial expressions were better recalled when encountered during the learning phase with a direct gaze (M = 65.74, SD = 21.62) as compared to an averted gaze (M = 59.73, SD = 23.49), $F_{(1, 85)}$ = 8.35, p = .005, ηp2 = .089. Overall, facial expressions of joy (M = 63.23; SD = 22.24) were not significantly better remembered than expressions of anger (M = 60.49, SD = 20.53), $F_{(1, 85)}$ = 1.95, p = .166, ηp2 = .022. Interestingly, the interaction between the Facial Expression and Gaze Direction factors was also non-significant, $F_{(1, 85)}$ = 1.70, p = .196, ηp2 = .020.

A significant interaction between the factors Repetitions and Facial Expression was found, $F_{(1, 85)}$ = 12.01, p = .001, ηp2 = .128. Follow up paired samples t-tests revealed a memory advantage for expressions of joy (M = 72.78, SD = 21.32) as compared to expressions of anger (M = 62.06, SD = 22.96), emerging after eight repetitions (t(44) = 3.74, p = .001, d = 0.57), no such memory advantage was observed for three repetitions condition (joy: M = 54.22, SD = 19.24; anger: M = 58.88, SD = 17.96; p = .156). All other interactions were non-significant.

Importantly for the interpretation of the implicit learning experiments in Chapter 3, no differences in memory for facial expression between participants with low and high scores on the AQ were found, with the same pattern of results observed in both groups (see: Figure 29). The main effect of AQ Group was non-significant ($F_{(1, 85)}$ = .137, p = .712, ηp2 = .002), reflecting that overall there was no difference in the number of facial expressions recalled accurately. The crucial two-way interaction between AQ group and Gaze Direction was non-significant ($F_{(1, 85)}$ = .084, p = .772, ηp2 = .001), with a direct gaze memory advantage observed in both groups. If a direct gaze memory advantage was significantly more present in the low AQ group compared to the high AQ group then that could in principle explain the differences in implicit learning responses between the low and high AQ groups reported in Chapter 3, but this was clearly not the case. None of the remaining interactions was significant (all p's >.212).

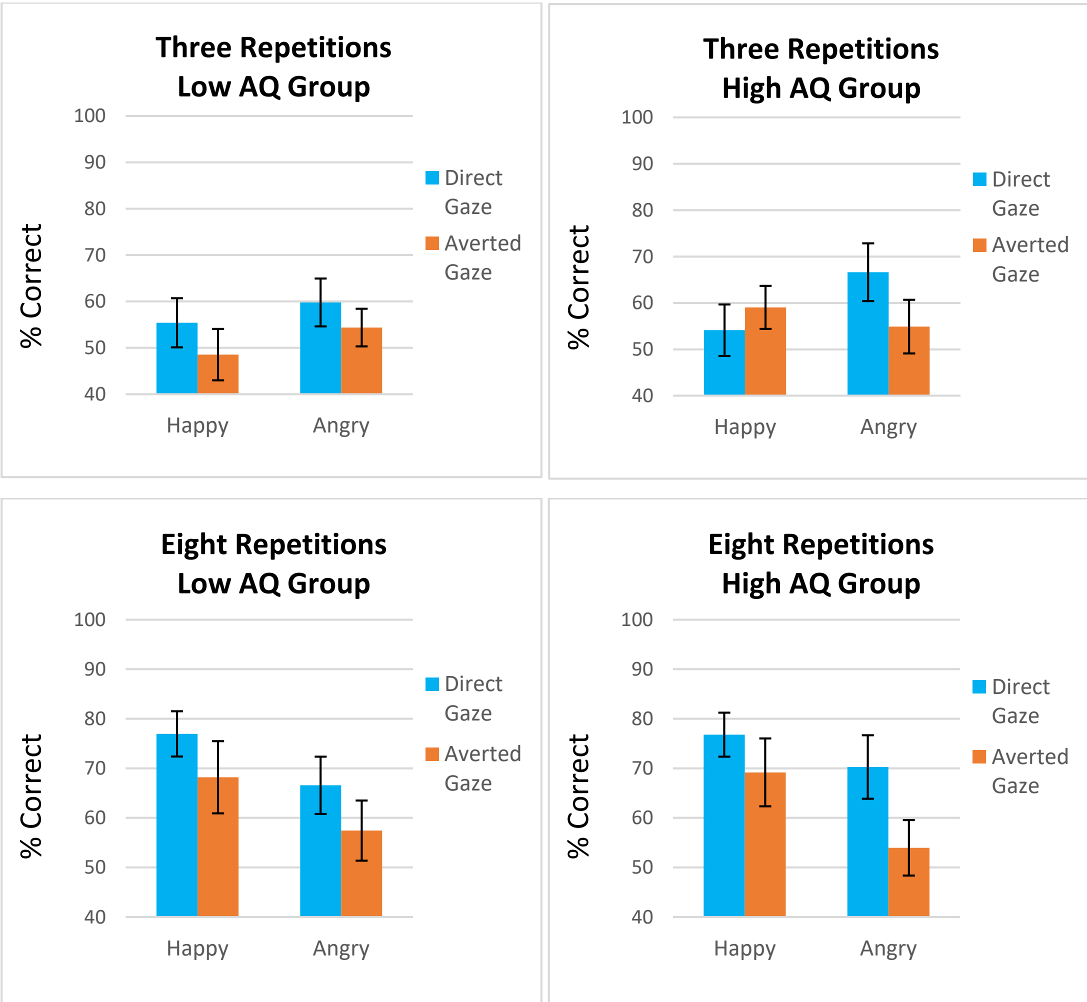


Figure 29 The mean percentage of correctly recalled facial expressions by those low in autism spectrum traits (left) and those high in autism spectrum traits (right) for three condition repetition (top panel) and eight condition repetition (bottom panel). Error bars represent SE.

Discussion

The current study investigated whether memory for facial expressions portrayed earlier by specific agents is influenced by the type of emotion and gaze direction during those earlier encounters. We further examined whether improvement in recall would be seen with increasing number of encounters with the faces. These issues were investigated in typically developed individuals with varying extent of autistic traits. Despite the combinational nature of social perception, this is to our knowledge, the first study that looked at the memory for facial expressions of specific agents in combination with gaze direction. Contrary to expectations, the memory advantage for faces displaying the expression of happiness with direct gaze was not found. While facial expressions accompanied by direct gaze were remembered better than those with gaze directed away from the observer, corroborating previous reports of direct gaze memory advantage, this effect was present in combination with both happy and angry facial expressions. Likewise, memory for facial expressions did not seem to depend on the type of emotion expressed by the character, as both emotions were remembered equally well. As expected, memory for facial expressions increased as a function of a number of repetitions; participants' recall was better for faces encountered eight times in comparison to faces encountered only three times. Finally, there was no evidence suggesting that memory for facial expressions was affected by the level of autistic traits.

Findings from this study imply that memory advantage for a particular emotion-identity combination influenced by direct gaze was unlikely to contribute to the implicit learning effect observed in Chapter 3. If direct gaze influenced memorability of only happy facial expressions, the smile on the face of character A would had been imprinted in memory more than all other expression-gaze combinations, giving the appearance of implicit learning of the character's disposition towards the observer, whereas, in fact, all that was learned was the smile on character's A face. As direct gaze was found to enhance the memorability of both happy and angry facial expressions, it is plausible to assume that it would have equally affected the memory of happy and angry facial expressions. This would not account for the implicit learning results obtained in Chapter 3.

<u>Why does direct gaze enhance memory formation of identity-emotion associations?</u>

The gaze direction of others allows for inferring their focus of attention and for subsequent adaptation of the observer's behavioural response. As directed gaze indicates an intention to communicate (Kampe, Frith, & Frith, 2003), special meaning may be allocated to facial expressions accompanied by direct gaze, which in turns can lead to enhanced memorability (Conty & Grèzes, 2012; Mason et al., 2004). In line with the shared signal hypothesis (Sander et al., 2007), both happy and angry facial expressions combined with direct gaze form strong, congruent emotion-gaze bindings, signalling motivational approach tendencies, which enhance facial processing (Adams & Kleck, 2003; Adams & Kleck, 2005; Artuso & Palladino, 2015). One explanation of the direct gaze advantage with respect to the memory of facial expressions is the emotional arousal elicited by the self-relevance of the other's directed gaze. Emotional arousal following an event can influence the strength of the subsequent memory for that event (McGaugh, 2000). If something in the environment appears to be emotionally charged or arousing, then this indicates that it requires further evaluation. The salience of such a stimulus is influenced not only by its inherent emotional properties but also by its perceived relevance to the observer (Sander et al., 2007). Studies have shown an enhanced amygdala activation during processing of emotional facial expressions directed at the observer compared to directed away (Cristinzio, N'Diaye, Seeck, Vuilleumier, & Sander, 2010; Kawashima et al., 1999; Sato, Kochiyama, Uono, & Yoshikawa, 2010). In line with theories of emotional appraisal, the impact of an emotional event depends on the significance of that event for the self (Sander, Grafman, & Zalla, 2003; Sander et al., 2007). As the amygdala might act as a relevance detector (Cristinzio et al., 2010; Sander et al., 2007), it could activate in response to a variety of emotional (or even neutral faces), depending on the context, because such stimuli potentially convey highly relevant social information for an individual. Research shows that the perception of facial expressions can be modulated by eye-gaze direction (Adams & Kleck, 2003; 2005; George & Conty, 2008; Sander et al., 2007).

It is, however, also possible that the observed direct gaze advantage memory effect is related to attentional bias created by the averted eyes (i.e. gaze following). Gaze averted to the side signals shift of attentional focus, which can drive one's attention toward an external object (Driver et al., 1999; Friesen & Kingstone, 1998; Frischen et al., 2007). This potentially diverts attention outside the face area, which in turn can diminish encoding of other facial features such as facial expressions and face identity (Conty & Grèzes, 2012; George & Conty, 2008). However, it has been shown that a shift of attention in response to averted gaze typically does not last for longer than 200ms (Friesen & Kingstone, 1998). Considering that in the current experiment, faces remained on the screen for 1000ms, this should allow sufficient time for face processing, making this explanation rather unlikely. Future studies employing eye-tracking methodology will be important for understanding if overt attentional shifts could be responsible for the memory advantage of emotional faces directed at the observer (Chapter 6). Potentially, the described mechanisms (self-relevance of directed gaze and attentional shifts of averted gaze) do not need to be mutually exclusive but could operate in tandem, resulting in enhanced processing and subsequent enhanced memorability of emotional displays accompanied by direct gaze, and in reduced processing and subsequent reduced memorability of those faces with the averted gaze.

<u>Memory for facial expressions</u>

Contrary to what is typically observed for the memory of facial identity (e.g. Liu et al., 2014), there was no overall effect of type of emotion on the memory for facial expressions, with expressions of joy and anger recalled equally well. As previously mentioned, the few studies that compared memory for positive versus negative facial expressions produced conflicting findings, with some studies showing a better memory for positive than negative expressions (D'Argembeau, Van der Linden, Comblain, et al., 2003; Shimamura et al., 2006) and other studies finding no difference (D'argembeau & Van der Linden, 2007; D'Argembeau, Van der Linden, Etienne, et al., 2003). It is worth noting that in the current study, the differences in the memorability of emotions emerged as a function of the number of times each face was presented. In the three repetitions condition, the recall rate was similar for both facial expressions, but in the eight repetitions condition expressions of joy were better remembered than those of anger, suggesting that differences in the memorability of happy and angry facial expressions could be due to the exposure time. Previous studies that examined memory for facial expressions of joy and anger typically used a single presentation mode of five seconds, which may be insufficient in producing the effect in some people. On the other hand, Shimamura et al. (2006) found that exposing participants to facial expressions for as little as three seconds led to enhanced memorability of expressions of joy, which is not in agreement with the current result. Although the reasons for these inconsistencies remain to be investigated, methodological differences between the two studies could have accounted for the mixed findings.

There are several theories on why memory may be enhanced for facial expressions of joy. Memory advantage for happy facial expressions could be explained by the self-enhancement bias (D'Argembeau, Van der Linden, Comblain, et al., 2003). Even though facial expressions of joy and anger are both approach-oriented, they differ in the reactions they may elicit in the observer. In the case of joy, the expression conveys both a heightened likelihood of approach as well as a congruent reaction in the observer (Stins et al., 2011). In contrast, for anger, the expression conveys a heightened likelihood of approach, yet tends to elicit avoidance in an observer (A. A. Marsh, Ambady, & Kleck, 2005; Stins et al., 2011). Happy facial expressions offer opportunities for positive social interactions. Interpreting happy facial expressions of others denotes approval and promotes self-esteem, whereas interpretation of anger and hostility directed to oneself denotes disapproval and is likely to lead to lower esteem. Several studies found a self-positivity bias for gaze processing of smiling faces, which were more likely judged as looking at the observer in comparison to other emotional expressions (Lobmaier, Tiddeman, & Perrett, 2008). In the current paradigm, gaze direction displayed by the actors could be easily categorised as either direct or averted. However, it is possible that faces with happy facial expressions were *remembered* as having gaze directed towards the observer (even if the gaze was directed elsewhere). Indeed, Weisbush and colleagues (2013) found that memory for averted gaze was better for faces initially encountered with angry facial expressions than happy facial expressions – error rate increased when judging the gaze of happy faces. Preference for happy facial expressions and their capacity to influence the perception of the gaze direction could potentially explain the memory advantage of happy facial expressions.

Further to this, happy and angry facial expressions have been found to exert an opposite effect on the observer's attentional scope, which could also lead to differences in their memorability. Negative expressions tend to attract attentional resources (Öhman et al., 2001), which can lead to disruption in processing of other facial features due to narrowing of attentional focus, which is directed at the expression itself. Consequently, this may prevent any association to be formed between facial expression and facial identity, resulting in worse memory performance for negative facial expressions (D'argembeau & Van der Linden, 2007). By contrast, positive affect has been found to broaden the attentional scope, promoting global processing of the face, which coupled with the finding that positive facial expressions are processed faster than negative ones could explain the memory advantage for happy faces. All these factors taken together can result in more elaborative encoding of happy versus angry facial expressions, with the deeper level of processing leading to subsequent memorability. This effect could be intensified with repeated exposures to a particular face, which is indeed what was found in this experiment.

<u>Social memory as a function of the number of encounters</u>

In line with our predictions, the results indicated that memory for facial expressions increases as a function of the number of encounters. The limitations of human memory require efficient mechanisms to select only the most relevant information to be represented in memory (Vogel & Machizawa, 2004). The observed facial expressions were encoded, potentially due to their functional importance for navigating social interactions and their role in the retrospective evaluation of social situations (Haxby et al., 2000). Indeed, social intuition has been argued to be formed on the basis of sequences of social cues learnt implicitly during a social encounter and subsequently stored in memory (Lieberman, 2000). For example, when a person is repeatedly viewed with a certain facial expression, an implicit association between the face identity and expression can be formed. The condition with eight repetitions used in this study relates closely to that in the implicit social learning experiments in Chapter 3, where the similar number of receptions was displayed and the implicit learning on the basis of social cues was observed. The associations in the current study were also implicit in nature since participants were not instructed to remember facial expressions displayed by the actors and thus, the assessed memory effect was incidental. This suggests that memory for facial expressions is automatic and no explicit attention needs to be directed towards the expressions for learning to occur. However, this can be also due to the fact that facial expressions automatically capture attention, therefore they are remembered incidentally as a consequence.

Social memory in relation to ASD-traits

The social memory capacity investigated in this study was independent of the number of autism spectrum traits (i.e. scores on the AQ). This is to the best of our knowledge the first study that looked into memory for facial expressions in relation to autistic traits. Low and high AQ groups were equally effective in recalling facial expressions of previously observed individuals. This suggests that individuals high in autistic traits are as competent at remembering facial expressions as those with the low number of autistic traits. Regardless of their emotional connotation, facial expressions with direct gaze were retrieved from memory more effectively than those with gaze averted to the side. This effect did not differ between the low and high AQ groups, which is in contrast with our initial hypothesis. According to our predictions, those with higher AQ scores would not benefit as much from direct gaze as those with low AQ scores when remembering the facial expressions, possibly due to less engagement with others' directed gaze, as reported for individuals with ASD (De Wit, Falck-Ytter, & von Hofsten, 2008; Pelphrey et al., 2002). The importance of these findings for the explanation of the large difference in implicit learning between the low and high AQ groups described in Chapter 3, is that preferential learning of the identity-facial expression links when accompanied by direct gaze by the low AQ group, does not seem to be a likely candidate. This leaves open the possibility that the effects described in Chapter 3 were due to differences in implicit social learning between the low and high AQ groups of the character's disposition towards the observer.

However, this does not exclude the possibility that implicit social learning abilities in those with the clinical diagnosis of ASD may have been affected by aberrant memory for social information, especially that there is evidence that memory for face identity is impaired in this group in some circumstances. Experiment 8 will, therefore, measure memory for emotion-identity combinations with respect to direct and averted gaze in ASD individuals.

5.2 Experiment 8

Individuals with ASD show a number of atypicalities in the processing of social stimuli, which may impact their memory for these stimuli. Face memory in particular seems to be affected in ASD, with studies consistently reporting deficits in memory for face identity (Boucher & Lewis, 1992; De Gelder, Vroomen, & Van der Heide, 1991; Hauck, Fein, Maltby, Waterhouse, & Feinstein, 1998; McPartland, Webb, Keehn, & Dawson, 2011; Tantam, Monaghan, Nicholson, & Stirling, 1989). Such impairments have been argued by some to result from underdeveloped expertise in face processing caused by reduced attention towards facial stimuli (Grelotti, Gauthier, & Schultz, 2002; Schultz, 2005). Infants with autism are typically less attentive to people – especially their faces – and many social cues in their environment (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998). It has been found that ASD individuals show a specific deficit in discriminating facial identity from eyes (Joseph & Tanaka, 2003; Riby, Doherty-Sneddon, & Bruce, 2009; Wolf et al., 2008). The eyes are one of the facial futures that differ greatly between individuals, therefore, issues specific to eye discrimination cause impaired performance on face memory tasks observed in ASD (Weigelt et al., 2012).

There is some evidence to suggest that atypicalities in gaze direction processing may be driving the face recognition deficit in ASD. Zaki and Johnson (2013) found that children and adolescents with high functioning ASD failed to show the direct gaze advantage memory effect as compared to typically matched controls. Since individuals with ASD may not preferentially attend to the eye region and even avoid eye contact, showing preference towards averted gaze (Dalton et al., 2005; Kylliäinen et al., 2012; Senju & Johnson, 2009), this may affect their ability to process faces displaying direct gaze. Some eye-tracking studies indeed suggest that individuals with ASD allocate more attention to the mouth than to the eyes when exploring faces (Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002). Other studies, however, have indicated similar patterns of face viewing behaviour in ASD and typically developing controls (Rutherford & Towns, 2008a; Van Der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2002).

Surprisingly, memory for facial expressions has not yet been studied in ASD. While recognition of basic facial expressions seems to be preserved in high functioning individuals with ASD, especially for emotions high in intensity, it is not clear whether those on the autism spectrum are capable of remembering emotions expressed by an individual. As consistently demonstrated, typically-developed individuals, show memory for facial expressions, which is independent of explicit instruction to learn these expressions. This suggest that memory for facial expressions is functionally important and may help to manage behavioural expectations and inform future encounters. Difficulties in one's ability to associate emotions with those who produce them would have a negative impact on social functioning.

This study aimed to replicate Experiment 7 to investigate memory for facial expressions in ASD, in relation to specific combinations of type of emotion (happy versus angry) and gaze direction (direct versus averted). However, due to the relatively small size of the ASD group available for testing (n = 18), only a condition with eight repetitions was used, as it is more relevant for the implicit learning experiments presented in previous chapters. Since memory deficits in remembering social information have previously been found in ASD, it was hypothesised that those on the spectrum would show a diminished ability to remember facial expressions displayed by specific actors, as compared to the typically developed group. Based on the results from Experiment 7, no particular emotion-gaze combination was expected to be remembered better than others. However, given the aberrant gaze processing in ASD, it was hypothesised that the memory for facial expressions in ASD individuals would not be enhanced gaze direction. As there is the data to support that ASD is often associated with symptoms of social anxiety (Kuusikko et al., 2008), the expectation was that individuals on the autism spectrum would remember less facial expressions of joy compared to the control group (D'Argembeau, Van der Linden, Etienne, et al., 2003).

Methods

Participants

Eighteen undergraduate students with ASD took part in Experiment 8. After applying exclusion criteria none of the participants was excluded from the analysis. The final sample consisted of five women and thirteen men, with a mean age of 19.83 (*SD* = 1.34), a mean total IQ score of 114.17 (*SD* = 9.56) and a mean ADOS score of 9.28 (*SD* = 2.24). The control group consisted of a subset of participants from Experiment 7, matched for age, sex and intellectual abilities. The data of twenty-four participants were included in the analysis (eight women, sixteen men), with a mean age of 20.33 (*SD* = 1.66) and a mean total IQ score of 113.88 (*SD* = 6.16). The ASD and TD groups did not differ significantly in terms of age ($t(40) = 1.05$, $p = .301$), gender ratio ($X_2(1, N = 40) = .149$, $p = .700$) nor IQ ($t(40) = .120$, $p = .905$). The AQ scores were significantly higher in the ASD group than in the TD group ($t(40) = 6.71$, $p < .001$). Participants' characteristics are presented in Table 7.

Table 7 Participants' characteristics.

	AGE	SEX	IQ-total	AQ	ADOS
ASD GROUP (n = 18)	19.83 (1.34)	5 women 15 men	114.17 (9.56)	33.44 (8.20)	9.28 (2.24)
TD GROUP (n = 24)	20.33 (1.66)	8 women 16 men	113.88 (6.16)	18.36 (6.37)	-

Stimuli and procedure

The stimuli and procedure were identical to those of the previously described Experiment 7, therefore it is summarised in this section. Participants viewed randomly presented images of 16 faces, with each face displayed eight times. Participants were asked to carefully look at the faces. This was followed by a 5-minute retention interval, after which participants completed a surprise memory test. For each face stimulus, participants were asked to recall the associated emotional facial expression by pressing one of the two keys labelled 'happy' and 'angry'. Each face remained on the screen until the participants indicated their response, however, participants were instructed not to dwell on their responses and make their decision on the basis of their initial impression.

Results

Data Reduction

Participants were excluded if they failed to respond to at least 25% of trials (none of the participants). Further, trials with response times shorter than 150ms and longer than 1000ms were excluded. This accounted for 2% of trials.

Data Analysis

The overall percentage of correct responses was analysed with a one-sample test against the value of 50%. The results revealed that the average number of correctly remembered facial expressions was significantly above the chance in both TD group ($t(21) = 3.58$, $p = .002$) and ASD group ($t(17) = 30.05$, $p = .007$).

To analyse memory for specific emotion-gaze combinations, the percentage of correct responses was entered into an ANOVA with Facial Expression (Happy, Angry) and Gaze Direction (Direct, Averted) as within-subject factors and Group (TD, ASD) as between-subject factor. The results can be seen in Figure 30.

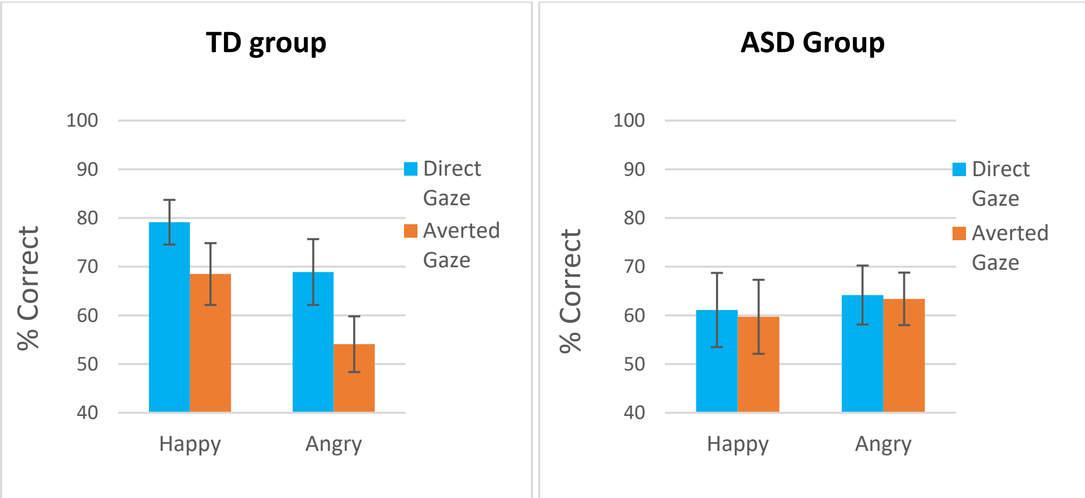


Figure 30 The mean percentage of correctly recalled facial expressions by typically-developed (left) and autistic (right) groups. Error bars represent SE.

Memory for facial expressions was similar across both groups, with TD participants recalling on average 68% of facial expressions and ASD participants 62% (main effect of Group: $F_{(1, 40)} = 1.04$, $p = .313$, ηp2 = .025). Overall, memory for facial expressions of joy ($M = 67.43$, $SD = 23.99$) did not differ from memory for expressions of anger ($M = 62.89$, $SD = 24.44$), $F_{(1, 40)} = 1.10$, $p = .302$, ηp2 = .027. The interaction between Group and Facial Expression was not significant ($F_{(1, 40)} = 3.22$, $p = .079$, ηp2 = .022). There was, however, a trend for the TD group to show enhanced memory for expressions of joy versus anger, while this trend was absent in the ASD group. The main effect of Gaze was significant ($F_{(1, 40)} = 4.53$, $p = .040$, ηp2 = .10), reflecting that overall facial expressions were better recalled when encountered during the learning phase with direct gaze ($M = 68.85$, $SD = 22.49$), as compared to averted gaze ($M = 61.48$, $SD = 22.92$), However, the significant main effect of Gaze was not further qualified by the Group by Gaze Direction interaction ($F_{(1, 40)} = 3.39$, $p = .073$, ηp2 = .078). Regardless of the interaction result, planned comparisons paired samples t-tests were conducted to further investigate the differences in memory for direct and averted gaze in both groups. The results revealed that TD participants recalled facial expressions that had been presented with direct gaze significantly better than those with averted gaze

($t(21) = 3.40$, $p = .002$). This was not the case for the ASD group, who recalled facial expressions with both types of gaze equally ($t(17) = 0.47$, $p = .648$).

Crucially, the three-way interaction between Emotion, Gaze and Group was not significant ($F_{(1, 40)} = 0.33$, $p = .857$, $\eta p2 = .001$). There was no evidence that any particular emotion-gaze combination enhanced memorability of facial expressions, as the two-way interaction between Facial Expression and Gaze Direction was not significant ($F_{(1, 40)} = 0.05$, $p = .946$, $\eta p2 < .001$). All remaining interactions were also not significant (all p's >.05).

Discussion

This study investigated memory for facial expressions in ASD. Contrary to the initial hypothesis, it was found that individuals with ASD were as good as matched controls in remembering facial expressions, with similar numbers of expressions correctly recalled by both groups. There was no evidence found for a memory advantage for a particular emotion-gaze combination. Regardless of the emotional content of the face, facial expressions accompanied by direct gaze were better recalled than those accompanied by gaze averted to the side. Although this effect was only evident in the TD group. Individuals with ASD recalled facial expressions equally well, regardless of the initial gaze direction of the characters. In contrast to the findings from Experiment 7, expressions of joy and anger were recalled equally well in this study.

Contrary to expectations, ASD individuals were capable of correctly recalling facial expressions of previously encountered individuals above chance level and most importantly, their performance did not differ from the TD control group. These results are particularly impressive if one considers that the tasked measured incidental memory, that emerged without any explicit instruction to learn. It suggests that ASD individuals can implicitly and spontaneously pick up social cues from their environment and remember them. However, studies have demonstrated that individuals with ASD can perform similarly to control subjects on behavioural tasks by employing various compensatory mechanisms. The current study consisted of maximally intense emotional expressions of joy and anger and did not require any mentalising abilities to complete the task successfully. Simply associating configurations of facial features with each face identity, without necessarily understanding the underlying emotional value or its behavioural consequences would be sufficient to accurately recall previously observed facial expressions. Future study designs should discern the mechanistic and mentalistic implicit process of memory formation for social information (Jellema et al., 2009).

Memory for face identity in ASD

Studies have consistently shown that individuals with ASD have a poor memory for face identity. In line with these findings, it was expected that those on the autism spectrum would show diminished ability to remember facial expressions. After all, in order to correctly identify previously encountered facial expression displayed by an individual, one needs to associate that expression with the individual's identity. As such, ASD participants in the current study seem to have intact memory for face identity. One reason for this discrepancy could be age-related differences in social memory. Previous studies typically examined memory for face identity in children or adolescents (Boucher & Lewis, 1992; De Gelder et al., 1991; Hauck et al., 1998; McPartland et al., 2011), rather than adults, as was the case in this study. In addition, most of the studies required memory for large sets of faces, typically with 20-30 items to be learnt, as compared to 16 faces presented here. However, it is important to note that in the current study memory for facial expression was measured rather than memory for face identity, and the latter can only be inferred based on participants' accuracy in identifying previously encountered facial expressions.

Direct gaze memory advantage in ASD

In line with Zaki and Johnson (2013), in the current study, only the TD group showed enhanced memory for facial expressions encountered initially with the direct gaze. This was regardless of differences in methodology. Zaki and Johnson's study used an old/new recognition paradigm to obtain measures of memory for face identity. In the current study, the focus was specifically on memory for facial expressions rather than identity, with participants having to recall the emotion portrayed by each individual and not simply discriminate between old/new faces. ASD individuals in this study remembered facial expressions accompanied by each type of gaze equally well. However, as this is a first study to examine memory for facial expressions in ASD, further research is needed to establish whether there are any differences in the way facial expressions influence memory in this group.

Direct gaze advantage memory effect was present regardless of emotional content of the face in TD group, providing some support for the shared signal hypothesis (Sander et al., 2007), which suggest that both expressions of joy and anger combined with direct gaze form strong emotion-gaze bindings, signalling motivational approach tendencies, which enhance facial processing (Adams & Kleck, 2003; Adams & Kleck, 2005; Artuso & Palladino, 2015). In the ASD group, there was also no difference in memory for facial expressions with different emotional content based on gaze, regardless of the fact that direct gaze advantage was not present in this group. In the future, it would be interesting to examine the influence of gaze direction on memory for avoidance-oriented emotions such as fear or sadness.

<u>Memory for the emotion of joy</u>

The current study failed to replicate the memory advantage for facial expressions of joy observed in Experiment 7. Although overall there was a trend for joyful faces to be remembered better than angry faces. When examining the results at the group level, it shows that individuals with ASD were slightly more accurate in recalling angry facial expressions, while the opposite pattern was seen for typically-developed subjects. One explanation for the variation in memorability of facial expressions of joy between the two experiments could be individual differences in anxiety levels. Individuals are more likely to elaborate on positive rather than negative social stimuli in relation to themselves (D'Argembeau, Comblain, & Van der Linden, 2005; Shimamura et al., 2006). This tendency may be reduced in socially anxious individuals because of the negative meaning they tend to ascribe to positive social information. Indeed, D'Argembeau and colleagues (2003) found while those low in anxiety levels showed memory advantage for joyful faces, this effect was absent in high anxiety group. There are some data to support that ASD may be associated with clinically relevant social anxiety symptoms (Kuusikko et al., 2008; S. W. White, Bray, & Ollendick, 2012) and AQ scores have been found to positively correlate with scores on a social anxiety measure (S. W. White, Ollendick, & Bray, 2011). This could potentially explain the lack of a memory advantage for facial expressions of joy in the ASD group. Unfortunately, since the anxiety scores were not measured in the current study, it is difficult to draw any definite conclusions.

In summary, this was the first study to investigate memory for facial expressions in autism. Individuals with ASD were as good as control participants in remembering facial expressions of joy and anger. This effect was independent of social information contained within the face, such as expressed emotion (joy or anger) or gaze direction (direct or away).

5.3 General Discussion

The studies in this chapter aimed to investigate social memory for facial expressions in typically-developed participants with the varying number of autistic traits and in those on the autism spectrum. In line with the studies of memory for facial identity, it was expected that happy facial expressions accompanied by direct gaze would be remembered better than any other emotion-gaze combinations. However, this is not what was found; both happy and angry emotional displays seemed to enhance memory for facial expressions when directed at the self rather than away. This effect was observable both in typical development, regardless of number of autism spectrum traits. In ASD group both happy and angry emotional displays were remembered equally well but this was not enhanced by gaze direction. Further to this, the studies found conflicting results in relation to memorability of emotions of joy and anger, with Experiment 7 reporting enhanced memory for facial expressions of joy and Experiment 8 finding no influence of the emotional content of the face on memory.

Intact social memory for facial expressions in ASD

Deviant memory patterns are likely to contribute to the social difficulties exhibited by ASD individuals due to their importance in learning processes. Having observed aberrant social implicit learning in individuals on the spectrum, the apparent next step was to examine memory for social information in this group. Memory studies consistently show that memory for social information is impaired in ASD, while this is not the case with memory for non-social facts (Brezis, Galili, Wong, & Piggot, 2014; Crane & Goddard, 2008; Lind, 2010; Lombardo, Barnes, Wheelwright, & Baron-Cohen, 2007; Losh & Capps, 2003; Toichi & Kamio, 2002). Further to this, some studies report impairments in the ability to remember social information that is independent of seemingly typical perception. Hauck et al. (1998) demonstrated that those on the autism spectrum showed poorer memory for facial identity as compared to typically matched controls, even though face perception tests using the simultaneous presentation of sample and test stimuli have not revealed differences in performance between participants with ASD and typical individuals. This would suggest that although differences in perception of social stimuli may be apparent on some social tasks, they cannot fully explain social memory deficits observed in ASD. Therefore, it was crucial to examine social memory in this group as difficulties in ability to remember facial expressions and develop associations between the displayed emotion and the person expressing that emotion could potentially explain differences in implicit learning abilities between ASD and typically-developed subjects found in Chapter 4. Contrary to expectations, ASD individuals in the current study showed memory performance comparable to that seen in typical development. This is in unlike the studies reporting impairments in memory for identity in individuals with ASD.

However, given the huge scope of this area of research and the variability in methods and ASD samples, it is not surprising that there are conflicting findings regarding social memory in ASD. First of all, this was a first study looking at expression memory in ASD. Neuroimaging studies suggest that the encoding of facial expressions can to some degree be dissociated from the encoding of facial identity. Face identity recognition involves temporal-occipital regions, such as the fusiform gyrus (Posamentier & Abdi, 2003), whereas the encoding of facial expressions appears to recruit other areas, such as the amygdala, cingulate gyrus, insula, and prefrontal regions (Canli, Sivers, Whitfield, Gotlib, & Gabrieli, 2002). As a result, comparing studies of memory for face identity with studies of memory for facial expressions can be misleading as they involve different processes. Secondly, most of the early studies of social memory typically included children and adolescents on the autism spectrum, while the current study looked at social memory in high-functioning autistic adults, who may have to some extent learned to attend to social stimuli and have better general memory skills. Studies show that social cognitive processes depend on both a general form of memory to support non-social aspects of the task as well as social memory, which are independent (Meyer & Lieberman, 2015; Meyer, Taylor, & Lieberman, 2015).

It is important to note that the task employed in the current study could have been solved without mentalising abilities, by simply by relying on general memory abilities. In everyday life, faces are not static images but rather display a constantly shifting stream of expressions that convey different mental states and behavioural intentions, which need to be tracked in order to adapt to the social environment. Issues of attentional focus and socio-emotional interpretations of expressions may determine the degree to which the affective quality of an event is remembered. Given that high-functioning ASD individuals tend to adopt compensatory strategies to deal with social aspects of their environment, it is not quite clear to what extent their competency on the current task was due to their ability to interpret affective valences contained within the faces or general memory. Further studies should account for this possibility.

Social memory and implicit learning

Studies in this chapter suggest that direct gaze enhances memorability of emotional displays more so than averted gaze. This effect is not exclusive to specific emotional expressions. Rather, gaze directed at the observer positively impacts on one's ability to remember both expressions of joy and anger. These findings have a direct consequence in interpreting the results from implicit learning chapters. They suggest that social implicit learning was not primarily driven by enhanced memorability of expressions of anger accompanied by direct gaze since both expressions exert a similar influence on memory when directed at the observer. Most importantly, the pattern of social memory in the current study was similar across both typically-developed and ASD group, which provides some evidence against direct gaze avoidance hypothesis of autism (Dalton et al., 2005; Kylliäinen et al., 2012; Senju & Johnson, 2009). If those on the autism spectrum paid more attention to the characters while their gaze was averted and actively avoided looking at the characters with direct gaze, this would, in theory, lead to increased memory for facial expressions accompanied by averted gaze, which was not the case. Visual attention toward faces and direct gaze avoidance in ASD are explored further in Chapter 6.

5.4 Conclusion

In conclusion, this study investigated how emotion-gaze combinations impact on the memory for another individual's facial expression. Memory for facial expressions seems to form in an incidental manner, without explicit instruction to pay attention or remember emotional displays of others. The pattern of results suggests that the memory for another individual's facial expression largely depends on the self-relevance of that expression for the observer as conveyed by the character's gaze direction, regardless of its emotional content. Emotions directed at the self rather than away from the observer were more likely to be remembered. This tendency did not seem to be modulated by the autism spectrum traits, however, those with clinical levels of autism may not show direct gaze advantage. The exact mechanism that could drive memory for facial expressions accompanied by direct gaze seems different in atypical and typical development and necessitates further exploration.

Chapter 6: Distribution of visual attention when viewing dynamic emotional faces in typical development and ASD.

Face processing literature shows that individuals with ASD tend to pay less attention to the eye region of the face than control participants and have difficulties in discriminating emotions from the eyes (Chawarska & Shic, 2009; Dalton et al., 2005; Pelphrey et al., 2002; Rutherford, Clements, & Sekuler, 2007; Spezio, Adolphs, Hurley, & Piven, 2007; Wolf et al., 2008). The reduced attention towards the eye region observed in ASD may limit the social and emotional information ASD individuals can gather from faces. The studies in this chapter will investigate social attention to dynamic emotional faces. The results will be linked to the experimental work on social implicit learning presented in Chapters 3 and 4 in order to explore whether potential differences in social attention could contribute to distinct learning patterns observed in TD individuals high in ASD-traits (Experiment 9) and clinically diagnosed ASD individuals (Experiment 10).

<u>Social Attention in Typical Development</u>

Visual social attention refers to the overt attentional bias to orient to and look at other people, notably their face and eyes, as well as to where they direct their attention (Birmingham, Bischof, & Kingstone, 2008). From infancy, typically developed individuals display an attentional bias towards faces, which are preferred over other non-human and inanimate objects (Barrera & Maurer, 1981; Gliga & Csibra, 2007; Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Salva, Farroni, Regolin, Vallortigara, & Johnson, 2011). Several studies have investigated infants' perception of faces using eye movement registration techniques. When infants scan the face of a person, they look at the key features of the face from the first weeks of life onward (Hunnius & Geuze, 2004). Prioritising attention towards social information within one's social environment has been argued to be an innate social mechanism, which is critical for the development of social and communicative skills (Goren et al., 1975; Johnson et al., 1991).

One of the direct measures of visual social attention are patterns of eye movements, which nowadays can be easily collected thanks to advances in eye-tracking technology (Frank, Vul, & Saxe, 2012; Klin et al., 2002). By carefully examining gaze behaviour, it is possible to understand what is being observed. Of particular interest is how individuals orient to and engage attention to faces, as well as how they visually explore faces and whether they make use of the other's gaze information. Eye-tracking allows for detecting and characterising the subtle variations in the spontaneous looking patterns of individuals.

A plethora of studies found that visual exploration of the face is characterised by a triangular fixation pattern on eyes, nose, and mouth, with the majority of attentional resources allocated towards the eyes (Groner, Walder, & Groner, 1984; Walker-Smith, Gale, & Findlay, 1977). Among healthy adults, the behavioural research demonstrates that the eyes are a key area for perceiving social information. When making judgments about face identity, emotion or gender, gaze fixations of typically developed individuals concentrate at the eye region, and this area of fixation has been found the most optimal for recognition of identity or inferring an individual's mental state (Baron-Cohen et al., 1997; Peterson & Eckstein, 2011; Van Belle, Ramon, Lefèvre, & Rossion, 2010).

However, the eyes are not the best diagnostic region of the face for all emotional expressions (Beaudry, Roy-Charland, Perron, Cormier, & Tapp, 2014; Eisenbarth & Alpers, 2011). The eye-tracking research has shown that attention towards specific facial features will vary as a function of the perceived emotion (Åsberg Johnels et al., 2017; Eisenbarth & Alpers, 2011; Schurgin et al., 2014). For example, when viewing the emotion of joy, the majority of attentional resources are allocated to the mouth region of the face, whereas negative emotions such as sadness attract attention toward the upper part of the face (Beaudry et al., 2014; Eisenbarth & Alpers, 2011; Schurgin et al., 2014). The models of attention propose that there is a topographic map of visual salience within the brain that combines bottom-up and top-down influences, such as knowledge and goal of the observer to identify locations in the environment for further processing (Gottlieb, Kusunoki, & Goldberg, 1998; Thompson & Bichot, 2005). It has been argued that the strategic deployment of attention depends on what is the most relevant information for the perceived emotion (Ekman et al., 1980; Kowler, Anderson, Dosher, & Blaser, 1995; M. Smith et al., 2005; Spezio et al., 2007). For example, the orientation of attention towards the mouth for happy faces is possibly driven by the importance of the lips to the smile - the most salient feature of joy (Schurgin et al., 2014).

Social Attention in ASD

Previous research has demonstrated aberrant social attention in autism, which starts to emerge as early as in infancy. Infants with ASD tend to be less attentive to people – especially their faces – and to many other social cues in their environment (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998). The patterns of attention toward social stimuli in infants who go on to develop ASD begin to differ from that of typically developing infants at about 6 months of age (Chawarska, Macari, Powell, DiNicola, & Shic, 2016; Chawarska, Macari, & Shic, 2013; Jones & Klin, 2013; Shic, Macari, & Chawarska, 2014) with continued increasing difficulties such as atypical eye contact, visual tracking and disengagement of visual attention in the first years of life (Elsabbagh et al., 2013, 2011, 2009, Ozonoff et al., 2010, 2008; Rozga et al., 2011; Turner-Brown, Baranek, Reznick, Watson, & Crais, 2013; Zwaigenbaum et al., 2005). These difficulties appear to continue into adulthood, with many studies reporting deficits in social orienting (for a recent meta-analysis see Chita-Tegmark, 2016) and differences in distribution of attention during face viewing, with decreased attention to the eyes and increased attention to the mouth and body compared to TD individuals (Falck-Ytter & von Hofsten, 2011; Guillon et al., 2014). Webb and colleagues examined the nature of face attention, perception and learning in individuals with ASD by reviewing the relevant literature, in which they demonstrated that atypical social attention seems to precede the development of other ASD symptoms (Webb, Neuhaus, & Faja, 2017). They concluded that aberrant attentional skills alter the type of information available to individuals' social learning, resulting in a less efficient, robust, and consistent face processing system, which may then have far-reaching consequences for social abilities (Dawson, Webb, & McPartland, 2005; Elsabbagh et al., 2011; Johnson, 2005; Sasson, 2006; Schultz, 2005). Numerous studies have found that reduced attention to social stimuli is correlated with behavioural measures of autism (Bird, Press, & Richardson, 2011; Chawarska et al., 2013; Klin et al., 2002; Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011).

Face processing literature shows that individuals with ASD tend to pay less attention to the eye region of the face than control participants and have difficulties in discriminating emotions from the eyes (Chawarska & Shic, 2009; Dalton et al., 2005; Pelphrey et al., 2002; Rutherford et al., 2007; Spezio et al., 2007; Wolf et al., 2008). The reduced attention toward the eye region observed in ASD could potentially limit the social and emotional information ASD individuals can gather from faces. Some studies found that those with ASD rely preferentially on mouth information to process faces, suggesting that the encoding of information contained in the mouth is enhanced at the expense of information contained in the eyes (Joseph & Tanaka, 2003; Klin et al., 2002; Neumann, Spezio, Piven, & Adolphs, 2006). However, a recent meta-analysis examining excess mouth viewing hypothesis in ASD found little data to support this claim (Guillon et al., 2014). Further to this, a few studies found that individuals with ASD had the same fixation behaviours as typically developed controls (Bar-Haim, Shulman, Lamy, & Reuveni, 2006; McPartland et al., 2011; Sawyer, Williamson, & Young, 2012; Sepeta et al., 2012; Van Der Geest et al., 2002; Wagner, Hirsch, Vogel-Farley, Redcay, & Nelson, 2013). Åsberg Johnels et al. (2017) suggested that the mixed results can be to some extent explained by the normalisation of the gaze behaviour during adulthood in individuals with ASD. Indeed, in his study examining attention toward different aspects of emotional faces, adults with ASD performed in similar fashion to controls, with gaze behaviour differences observed only between younger control and ASD participants. In another study, Wagner et al. (2013) found no difference in gaze behaviour between ASD and TD participants when viewing emotional facial images but reported that ERP varied with emotional expressions only in the TD group, suggesting lack of neural differentiation between emotion type in ASD. They suggested that adults with ASD may become more socially adept and develop various strategies to compensate for deficits in social functioning and control their visual attention to some extent.

Implicit Learning and Attention

Explicit learning processes require the deliberate involvement of attentional resources. The ability to control the focus of attention and resist distraction has been found to strongly predict academic attainment (Breslau et al., 2009; Duncan et al., 2007), even when variables such as IQ and socioeconomic status are controlled for (Merrell, Sayal, Tymms, & Kasim, 2017). On the contrary, the role of attention in implicit learning is still a subject of debate. The process of implicit learning is thought to occur automatically and outside of one's awareness, and therefore, it has been argued to operate independently of attention (Cleeremans & Jiménez, 1998; Frensch, Lin, & Buchner, 1998; Frensch & Rünger, 2003).

To further explore this notion the role of attention in implicit learning has been studied extensively by either reducing or increasing attentional resources and examining the influence of such manipulation on the ability to learn implicitly. One method for reducing attentional resources are the dual-task paradigms, in which the task that typically leads to the acquisition of implicit knowledge is completed simultaneously with a secondary, attention-demanding task. If implicit learning occurs without the involvement of attention, the process of learning should proceed normally in the presence of the concurrent task. Several studies found that this was actually not the case (A. Cohen, Ivry, & Keele, 1990; Frensch & Miner, 1994; Shanks & Channon, 2002; Shanks et al., 2005; Stadler, 1995). For example, Cohen, Ivry and Keele (1990) found that implicit learning of a sequence of visual locations was disrupted by a tone-counting task, reducing typically observed increases in performance. However, it is difficult to establish to what extent secondary tasks in these studies reduce only the availability of attentional resources and do not interfere with the implicit learning process itself (Frensch et al., 1998; Stadler, 1995). Attention during learning can be also reduced by inducing the state of hypnosis; Nemeth, Janacsek, Polner, and Kovacs (2013) found enhanced implicit learning of visual sequence under hypnosis, as compared to alert state, suggesting that less attention may result in better learning. Implicit learning has also been studied in those with trait mindfulness, i.e., the ability to maintain periods of sustained non-distraction. Increased attentional abilities in mindful individuals were negatively associated with implicit learning, suggesting that enhanced attention can hamper implicit learning (Stillman, Feldman, Wambach, Howard, & Howard, 2014).

The relationship between attention and implicit learning is surely a complex one, with conflicting findings prevalent in the literature. It is important to note that implicit learning tasks can vary greatly in the cognitive processes they engage. As such, Rausei, Makovski and Jiang (2007) suggested that the amount of attentional resources needed for implicit learning to occur may depend on the specific implicit learning task and should be established individually for each implicit learning paradigm. In case of social implicit paradigm introduced in Chapter 3, it is plausible to assume that minimal attentional resources are required for perception of social cues. Although social cues can be processed even subliminally (e.g. Kamio et al., 2006), one needs to attend to the location they are being displayed.

The Current Study

While the eye-tracking literature indicates the importance of eye and mouth region for the perception of the emotional content of the face, there are several factors that can influence the distribution of attention when viewing emotional faces.

Firstly, it is important to differentiate between passive viewing of emotional faces and emotion recognition. A unique attentional strategy may be employed when the individuals are tasked with categorising emotional expressions, as opposed to simply observing them (Hunnius, De Wit, Vrins, & von Hofsten, 2011; Schurgin et al., 2014). There is some evidence that passive viewing of emotional expressions evokes distinct viewing patterns different than those for emotion recognition. Specifically, eye avoidance strategy when observing negative emotional expressions, such as anger or fear has been noted in the past (Hunnius et al., 2011). Studies of emotional face viewing typically employed emotion recognition or rating tasks, which could have affected the natural viewing of the emotional faces (but see: Åsberg Johnels et al., 2017).

Secondly, dynamic emotional expressions can evoke distinctly different viewing patterns in the observer as compared to static images. The static stimuli may not be sensitive enough for revealing subtle differences in gaze orientation toward different regions of the face. The gaze behaviour may be guided by the temporal changes occurring within the face. However, the majority of studies looking at the visual exploration of emotional faces used static images (Corden et al., 2008; De Wit et al., 2008; Pelphrey et al., 2002; Rutherford & Towns, 2008b; Wagner et al., 2013). There was only a couple of studies that looked at the exploration of dynamic facial expressions as a function of emotion (Åsberg Johnels et al., 2017; Bal et al., 2010). However, the gaze data in both studies were averaged over the full duration of the video sequences. This approach, while useful, means that the temporal variations in viewing patterns as the face progressively changes in emotional content remain underexplored.

Thirdly, emotional expressions accompanied by direct gaze can enhance attentional responses. Facial expressions have a different value when directed at or away from the observer. Studies reported that direct gaze is detected faster and attracts longer visual attention than averted gaze or closed eyes (e.g. Senju & Hasegawa, 2005). To our knowledge, the influence of gaze direction on viewing patterns of emotional facial expressions has only been explored in one eye-tracking study, which found reduced eye viewing in response to direct gaze versus averted gaze for facial expressions of anger in the adolescent sample (Sepeta et al., 2012).

The studies in this chapter will investigate social attention to emotional faces accounting for the limitations of previous studies discussed above. The results will be linked to the experimental work on social implicit learning presented in Chapters 3 and 4 in order to explore whether potential differences in social attention could contribute to distinct learning patterns observed in TD individuals with a high number of autistic traits (Experiment 9) and ASD individuals (Experiment 10). More specifically, the rationale for conducting the eye-tracking experiment is the following: if individuals with ASD (or those high in autistic traits) would avoid looking at the eye-region of the characters during the stimulus presentations in the learning phase of the implicit social learning experiment (while TD individuals did look at the eyes), then that could in principle explain the reduced implicit social learning found in the ASD group, as well as in the high AQ group. The eye direction is required to learn the actor's disposition towards the observer (without it the disposition cannot be learned). However, one does not need to look for an extended period of time at the eyes to find out whether they are directed at you or are directed away from you. Therefore, only if the ASD group would not look at the eye region at all, or hardly at all, would it be able to explain the results reported in Chapters 3 and 4.

In addition, we wanted to check whether there was a difference in looking-time at the actor's eye region for the first static frame of the clips (presented for 750 ms) compared to the dynamic part (540ms) and to the last static frame (also presented for 750 ms), as a function of gaze direction and facial expression. It could be that individuals with ASD (or TD individuals with high AQ scores) did look at the actor's eye region, but only when eyes were directed away and would avoid the eyes when directed at them. Such looking behaviour might also in principle be able to explain the results in Chapters 3 and 4. Thus, the main aim of the eye-tracking experiments is to establish whether or not any atypical looking behaviour of the ASD individuals (and high AQ individuals) might have contributed to the results obtained in Chapters 3 and 4.

6.1 Experiment 9

As discussed in previous chapters, the level of autism-spectrum traits vary in the general population and it is this variation that can affect social perception (Chakrabarti et al., 2009; Halliday, MacDonald, Sherf, & Tanaka, 2014; Hudson, Nijboer, et al., 2012; Poljac et al., 2013; Sasson, Nowlin, & Pinkham, 2013). An aberrant fixation behaviour toward faces with direct gaze was observed in those with a high level of autistic traits (Åsberg Johnels et al., 2017; F. S. Chen & Yoon, 2011). For example, Chen and Yoon (2011) found individuals low in ASD traits had longer fixation towards the eye region of the face displaying direct gaze, as compared to individuals with higher ASD traits. In another study by Åsberg Johnels et al. (2017) decreased attention to mouth region for happy faces was found in children/adolescents (but not adults) high in autistic traits and those with a diagnosis of ASD.

There is also some evidence of atypical gaze behaviour in relatives of individuals with ASD. Dalton et al. (2007) used eye-tracking and fMRI measures to explore social attention to faces of unaffected siblings of individuals with ASD. The results found reduced visual attention toward the eye region, as compared to TD controls without ASD family members (Dalton, Nacewicz, Alexander, & Davidson, 2007). Furthermore, the fMRI data revealed lower activation in the fusiform gyrus of siblings of ASD individuals, the area critical for face processing and recognition (Kanwisher, McDermott, & Chun, 1997). The results from the aforementioned studies indicate that aberrant patterns of attention can be observed in the general population, in those high in autistic traits. The diminished exploration of the eye region in those with higher levels of autistic traits mirrors the results typically found in ASD. The eye region contains information important for social cognition, which could be overlooked with infrequent orienting toward the eyes. It is not clear, however, whether attention to different regions of the face is modulated by the emotional expression displayed on the face. Previous research found the avoidance of the eye region in response to negative emotional expression in individuals with ASD (Kliemann, Dziobek, Hatri, Baudewig, & Heekeren, 2012; Kliemann, Dziobek, Hatri, Steimke, & Heekeren, 2010). If the similar pattern of results was observed in those high in ASD traits, then this could be one reason for the implicit learning deficits seen in individuals with a higher level of autistic traits in Chapter 3.

The aim of this study was to explore the distribution of attention toward different facial features in response to expressions of joy and anger under free viewing conditions in TD individuals with a varying level of ASD traits. It was hypothesised that changes in the emotional content of the face will lead to alterations in observers’ gaze behaviour. In particular, longer fixation time on the eye region was expected for angry facial expressions, whereas longer fixation time on the mouth region was expected for expressions of joy (Åsberg Johnels et al., 2017; Eisenbarth & Alpers, 2011; Schurgin et al., 2014). The evidence from ASD would suggest gaze avoidance behaviour in response to the expression of anger due to the eyes being aversive stimuli to those on the spectrum (e.g. Corden et al., 2008). However, the only study that investigated visual attention toward the faces as a function of emotion in those with high ASD traits failed to find this effect (Åsberg Johnels et al., 2017). As previously mentioned, the video data from this study was analysed across the total duration of the video sequence, which could have concealed temporal variations in attention. To explore the temporal changes in gaze behaviour, the dynamic faces where investigated in three sequential steps: the initial emotion, the dynamic change, the final emotion. Additionally, the influence of gaze direction on the fixation patterns was explored. It was expected that changes in the emotion accompanied by the gaze directed at the observer would lead to an increased looking time toward the diagnostic regions of the face (eyes for anger, mouth for joy) in individuals with lower levels of ASD-traits, but possibly not to the same extent in individuals with higher levels of ASD-traits.

Methods

Participants

Forty-four undergraduate Psychology students from the University of Hull participated in the experiment in exchange for course credits. All participants had a normal or corrected-to-normal vision. After applying exclusion criteria (see Data Reduction below for details), the final sample consisted of forty individuals (twenty-five women, fifteen men), with an average age of 19.53 (*SD* = 2.29).

Stimuli

The stimuli were identical to those used in Chapters 3 and 4. In brief, photographs of actors used in this study were taken from the Warsaw set of Emotional Facial Expressions Pictures (WSEFEP; Olszanowski et al., 2015). The selected stimuli consisted of photographs of four models with facial expressions of joy and anger. Two male characters (RA, MK) and two female characters (SS, MS) were used. The models were selected on the basis of high rates of agreement for expressions of joy and anger (as reported in Olszanowski et al., 2015) and the size of their eyes, which would allow for easy manipulation of gaze direction displayed. The photographs of each model were morphed into short videos of two seconds duration to create dynamic stimuli, displaying a natural facial movement (Perrett et al., 1994; Sqirlz Morph software). Two facial features were manipulated: facial expression and gaze direction. Each video started with gaze directed either towards the participant and then gradually averted horizontally until at a 30° angle away from the observer at the end of the clip, or began with a 30° aversion and ended with direct gaze direction (the video played backwards). To manipulate facial expressions, the video began either with a character displaying a joyful expression, which gradually morphed into an angry expression, or began with an angry expression which morphed into a joyful expression (video played backwards). The characters were oriented facing the observer throughout the presentation.

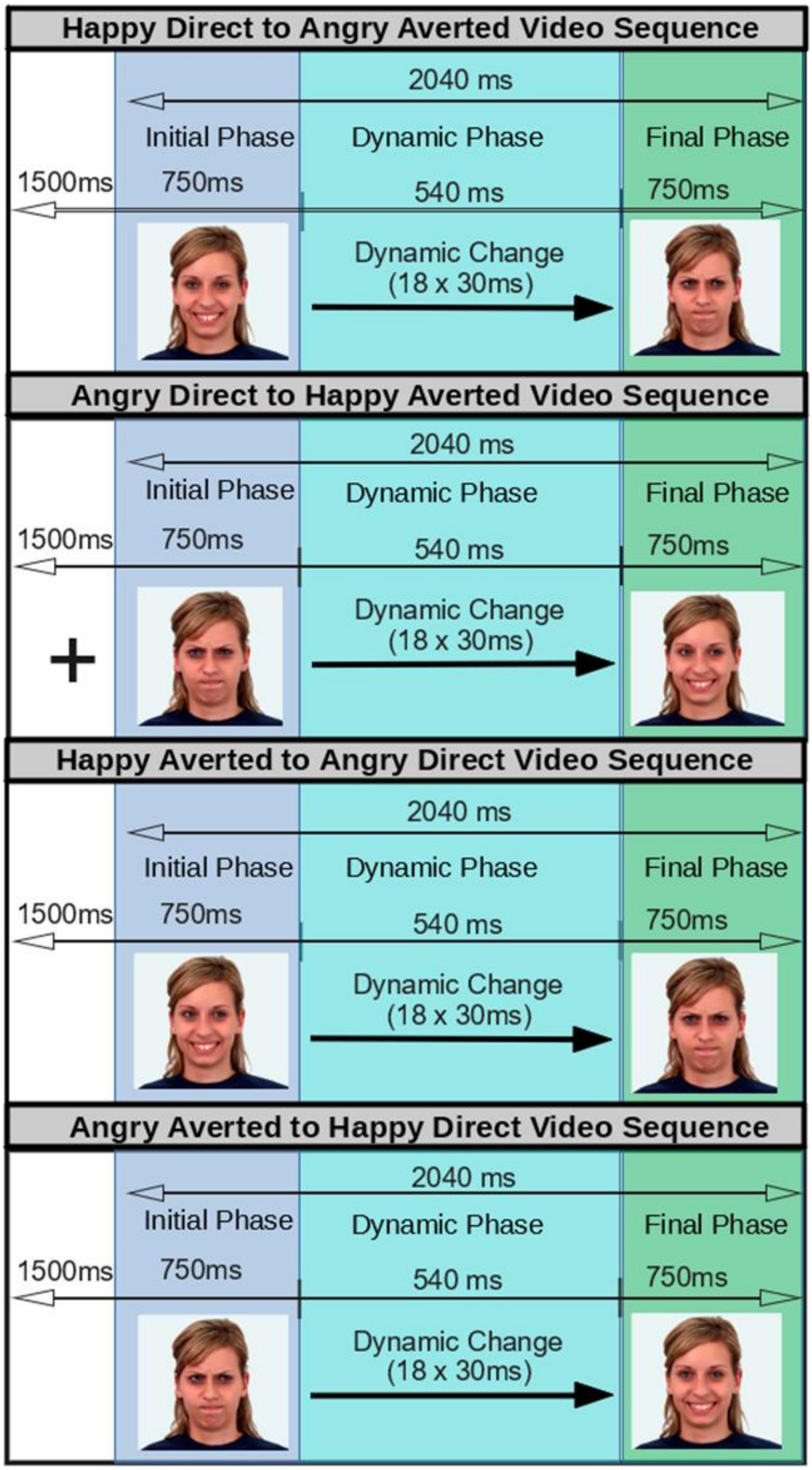


Figure 31 Four types of video sequences used in the eye-tracking experiment.

Procedure

Participants' eye movements were recorded using a head-mounted EyeLink 1000 tracker (SR Research) sampling at 2000 Hz. Viewing was binocular but the camera recorded the eye movements from the right eye. A chin rest was used to stabilize the participant's head and ensure a standard distance (70 cm) between the participant and the monitor displaying the stimuli was maintained.

Participants were seated in front of a computer screen and the eye-tracking camera. Participants were asked to adjust the chin rest to the most comfortable height. Then the lights were turned off so the room was dark with the exception of the light from the computer monitor and a dimmed table lamp placed in the corner of the room. Next, the experimenter located the participant's right eye on the auxiliary eye-tracking monitor. The eye-tracker was then calibrated. Participants were instructed that the aim of the study was to assess their perception of faces and that they should just observe the videos without having to perform any task, which was the same as for the implicit learning studies.

Each trial started with a fixation cross presented at the centre of the screen for 1500ms, after which one of four types of dynamic face videos were shown (see Figure 31). Half of the videos began with a character displaying an expression of joy and the other half with an expression of anger. Gaze direction was manipulated as in the implicit learning experiments: half of the videos for each emotion initially displayed direct gaze and the other half gaze averted to the right. This initial frame remained on the screen for 750ms, after which character's emotion started to naturally morph into the other emotion, which was accompanied by a simultaneous change in the gaze direction (the dynamic part consisted of 18 frames of 30ms each). The final frame remained on the screen for a further 750ms. These trials were identical to those of the implicit learning studies. Participants viewed a total of 64 videos, each of the four types of dynamic face videos was shown four times for each character (4 conditions x 4 repetitions x 4 characters). Once the eye-tracking data collection was completed, participants filled in an online version of the AQ questionnaire.

Results

Data Reduction

The data of the first three participants have been excluded from the analysis due to an error in the E-Prime presentation program. In addition, one participant did not complete the experimental session due to a calibration issue. The data from these four participants were removed from the analysis, resulting in a final sample of 40 participants.

Demographics

A median split was performed to assign participants to either the low or high AQ group. The AQ scores ranged from 6 to 31, with a median of 16, resulting in 22 participants in low AQ group (M = 12.86, SD = 2.71) and 18 participants in high AQ group (M = 21.94, SD = 4.56). The high and low AQ groups did not differ in age ($t(38) = 1.20$, $p = .240$), nor gender ratio ($X_2(1, N = 40) = 0.24$, $p = .622$).

Data Analysis

To quantify visual fixations, for each stimulus, rectangular areas of interests (AOI) covering eyes, mouth, nose and rest of face were defined prior to data collection (see Figure 32). AOIs were equivalent in size across the characters and emotions. The fixation data were analysed using MATLAB with Statistics Toolbox. Missing data points (i.e. blinks, fixation outside of the monitor screen, etc.) were removed from data analysis. Fixations were predefined as consecutive eye gaze positions focused within an area of one visual degree for a period of 100ms or more (Manor & Gordon, 2003); gaze fixations below this threshold were not included in the analysis. It was important to ensure that the AQ groups did not differ in their overall fixation time when saccadic eye movements, fixations shorter than 100ms and off-screen viewing time were removed. To this end, the average of total fixation time on the screen as a function of total stimulus presentation time per trial was calculated for each participant. An independent samples t-test showed no differences in the overall fixation time between the groups ($t(38) = .389$, $p = .699$), with the low AQ group spending on average 83% of the time fixating on the screen, and high AQ group 84%.

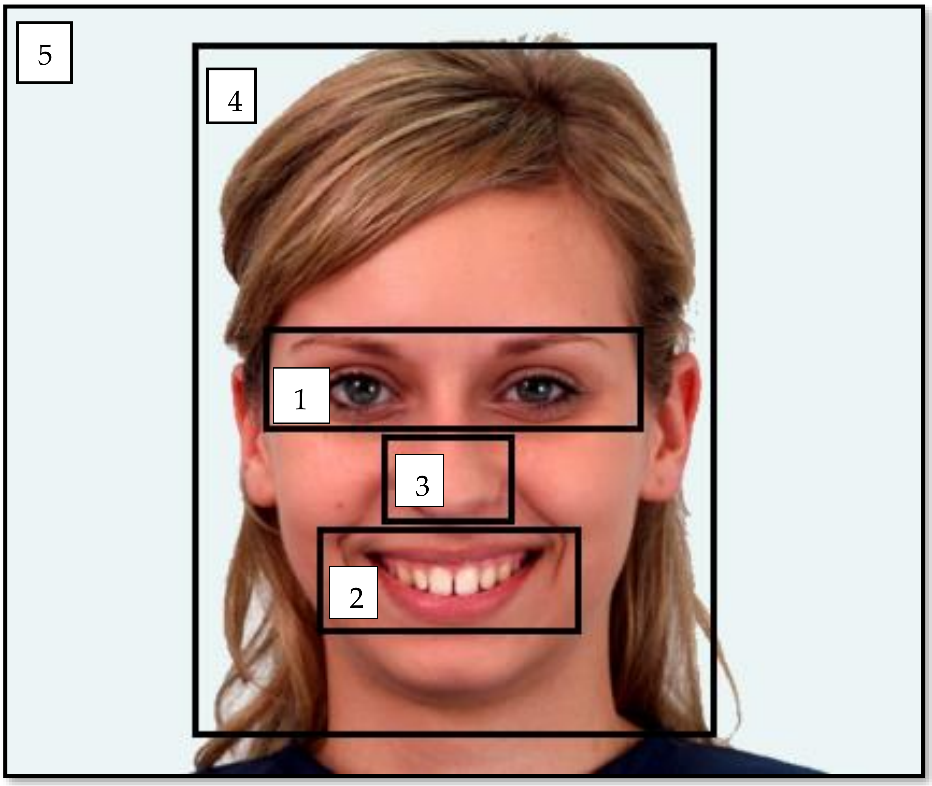


Figure 32 The areas of interest (AOI) used in this study: eyes (1), mouth (2), nose (3), rest of face (4) and background (5).

The total fixation time made to each AOI was calculated for each trial. This was expressed as the average looking time in each AOI per trial as a function of total fixation time on the screen. The first step of the analysis was to compare the overall visual fixation patterns of the low and high AQ groups, regardless of the type of stimuli presented. The data were analysed using a mixed-design ANOVA to examine group differences and interactions for each AOI. The second step of the analysis was to examine fixation patterns across different emotion-gaze combinations in the initial, static frame of the videos (before the change in the emotional state of the character occurs). The final step of the analysis was to explore potential changes in fixation patterns across the dynamic change of the characters' expression. To this end, the videos were split into three parts: initial static frame (750 ms), dynamic change of emotion (540ms) and the final static frame (750ms). For this analysis, only the videos starting with averted gaze gradually changing into a direct gaze were used (see Figure 33). The rationale was that an emotional expression which is gradually directed at the observer will result in a salient attentional response, allowing for better discrimination between the fixation patterns of the two emotions.[4]

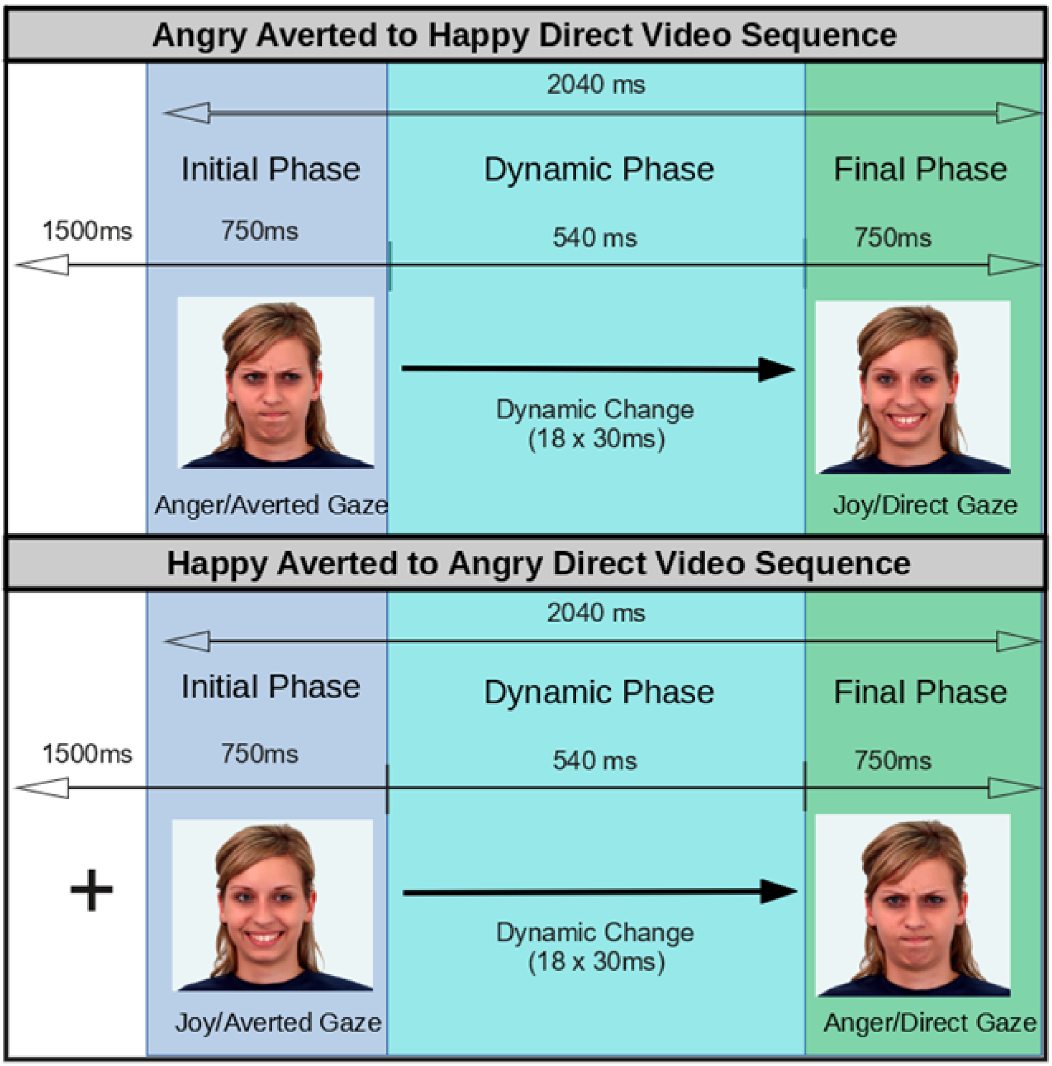


Figure 33 Video sequences used in the analysis of visual attention toward the facial features of the three consecutive phases of the videos.

[4] In addition, the data analysis of videos starting with direct gaze gradually changing to averted gaze revealed a similar pattern of results, with no substantial differences. Therefore, it was decided not to report it here.

Overall viewing patterns of dynamic facial expressions

Averaged fixation times over the entire duration of the video-clips were entered in a mixed-design ANOVA, with AOI (Eyes, Mouth, Nose, Rest of Face, Background) as a within-subjects factor and AQ Group (low AQ, high AQ) as a between-subjects factor. The results are illustrated in Figure 34. Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. There was a main effect of AOI ($F_{1.24,47.15} = 142.34$, $p < .001$, ηp2 = .789), indicating differences in the amount of time spent fixating in each AOI. On average, 66.5% of fixation time was spent on the eyes, 10% on the mouth, 10% on the nose (which seemed to serve as a central fixation point across a face), 13% on the rest of the face and 0.5% on the background. Importantly, there was no interaction between AOI and AQ Group ($F_{1.24,47.15} = 0.97$, $p = .428$), suggesting that both groups deployed their attention in a similar manner across the AOIs. The main effect of Group was non-significant ($p = .349$).

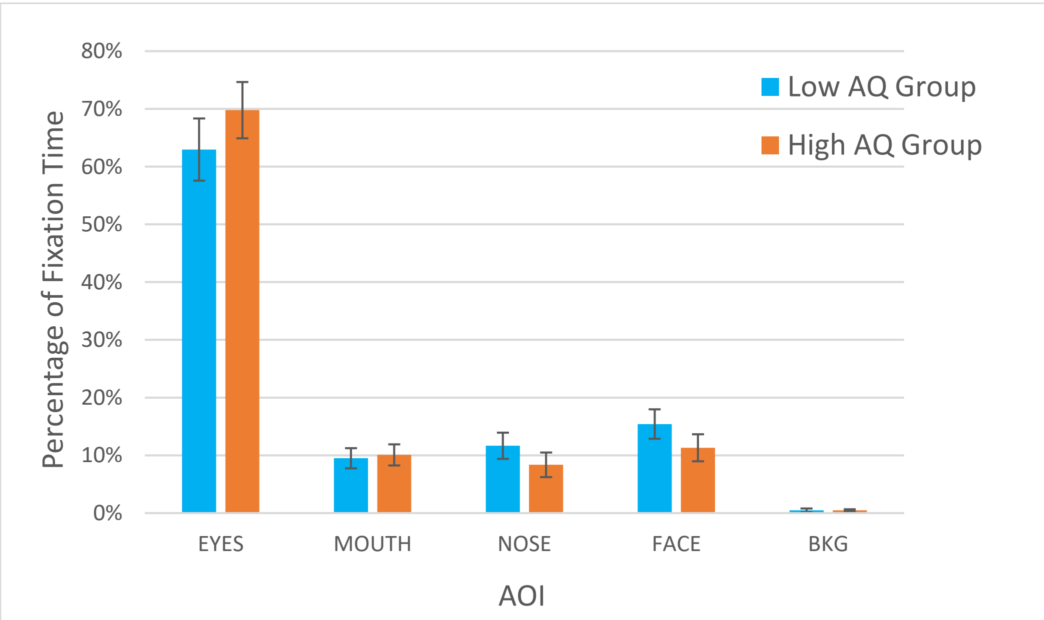


Figure 34 The average percentage of time spent in each AOI as a function of total fixation time displayed for Low and High AQ Groups. BKG = background

Visual attention toward still emotional faces with direct or averted gaze

As most research on visual attention toward emotional faces has been done using static faces, we additionally examined the exploration of static emotional expressions to allow for a direct comparison with previous research. To examine viewing patterns of still emotional expressions, the first part of the videos with characters displaying emotions of joy and anger accompanied by either direct or averted gaze were analysed. A mixed-design ANOVA with Emotion (Happy, Angry), Gaze Direction (Direct, Averted) and AOI (Eyes, Mouth, Nose, Rest of Face, Background) as within-subject factors and AQ Group as between-subject factors was conducted. The results are illustrated in Figure 35. For clarity, separate graphs have been created for each AQ group.

Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. There was a non-significant main effect of Emotion ($F_{1,38}$ = 0.62, p = .435, ηp2 = .016) and a non-significant main effect of Gaze ($F_{1,38}$ = 1.44, p = .237, ηp2 = .037). This indicates that overall participants spent similar amounts of time observing expressions of joy and anger, as well as looking at faces with a direct and averted gaze. There was a significant main effect of AOI ($F_{1.12,42.61}$ = 158.00, p < .001, ηp2 = .806). Pairwise comparisons revealed significantly longer looking time at the eye region, as compared to all other AOIs (all p's < .001). Participants also spent less time looking at the mouth region in comparison to Nose (p = .009) and Rest of Face Regions (p < .001). The viewing time of Nose and Rest of Face regions attracted similar amounts of looking time (p = .878). The Background was the region least attended to, significantly different from any other face region (all p's < .001).

There was also a significant AOI x Emotion interaction, ($F_{2.25,8.53}$ = 3.40, p = .033, ηp2 = .082), indicating that the amount of time spent within AOIs differed as a function of emotion. Bonferroni corrected follow up tests revealed that this was driven by a significant difference in looking times spent on the Mouth region, with the fixation time more than twice as long when the expression of joy was displayed, as compared to the expression of anger (t(39) = 4.36, p < .001). No further differences between the AOIs as a function of emotion were found (see Figure 36).

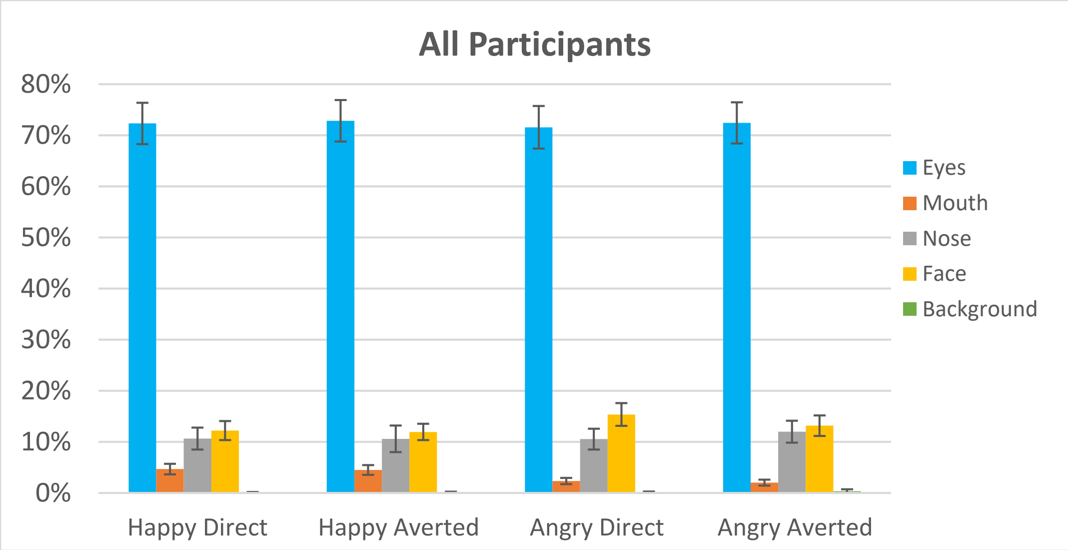
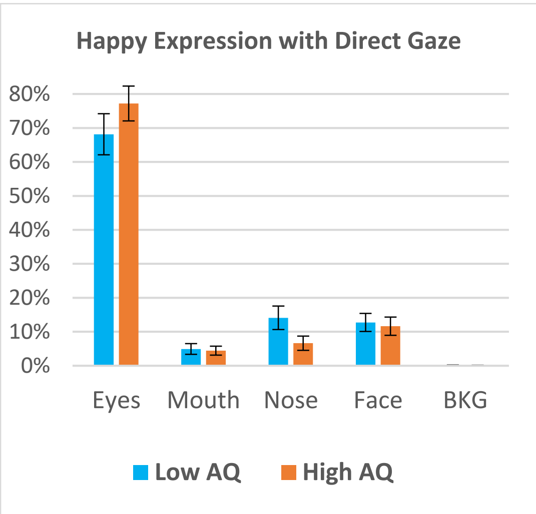
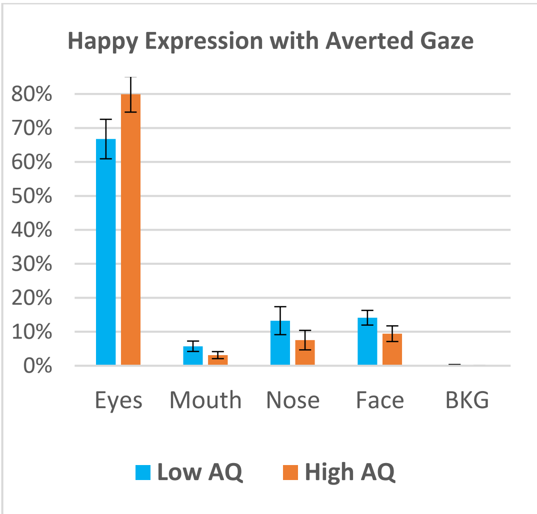


Figure 35 The average percentage of time fixating in each AOI for each emotion-gaze combination in the initial frames of the videos – all participants.

The high and low AQ groups displayed similar visual inspection patterns, with non-significant main effect of Group ($F_{1,38} = 0.47$, $p = .490$, $\eta p2 = .012$) and non-significant interactions with AQ group (all p's > .197).





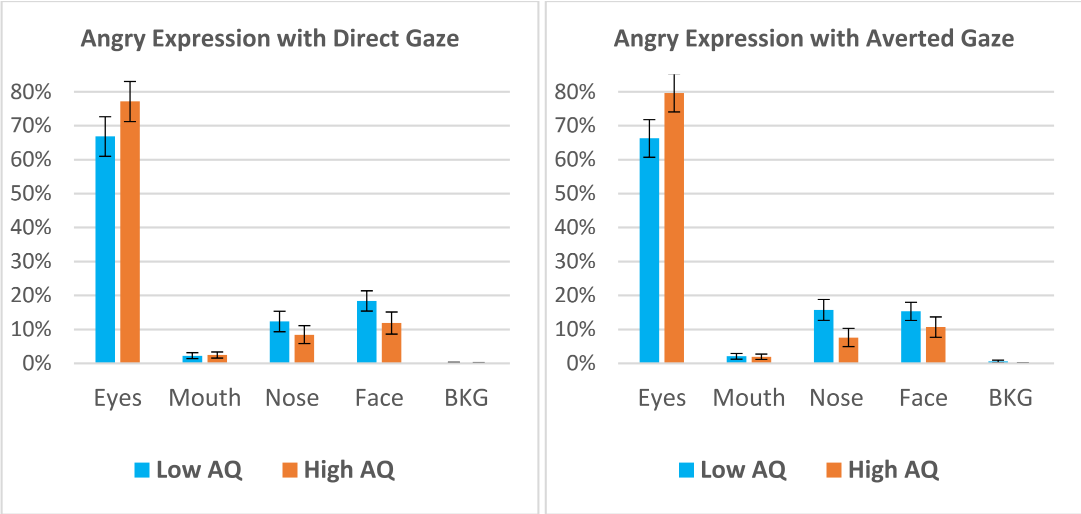


Figure 36 The average percentage of time fixating in each AOI for each emotion-gaze combination for initial frames of the videos – happy facial expression (top panel) and angry facial expression (bottom panel).

<u>Visual fixation patterns of the three consecutive phases of the video sequences</u>

This analysis aimed to find out, in particular, whether fixation times at the eye region would decrease when the actor's eyes started in averted position and subsequently were dynamically directed toward the observer. The main question was: would the high AQ group, more than the low AQ group, avoid the eye region once it changed from averted to directed. The data was analysed with a mixed-design ANOVA with within-subject factors Emotional sequence (Happy to Angry, Angry to Happy), Phase (Initial static, Dynamic, Final static) and AOI (Eye, Mouth, Nose, Rest of Face) and between-subject factor AQ group (Low, High). The results for each emotion are presented in Figure 37.

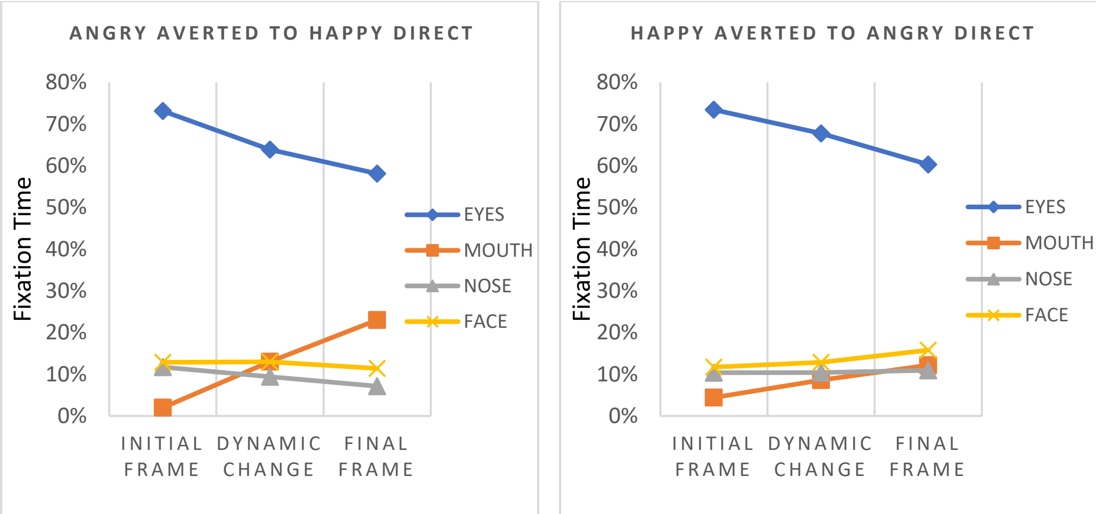
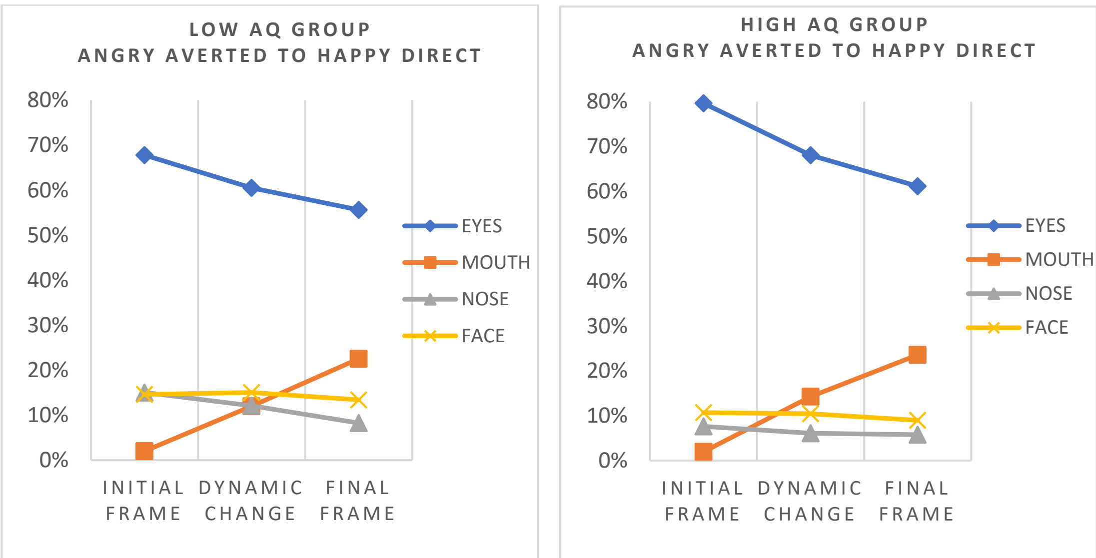
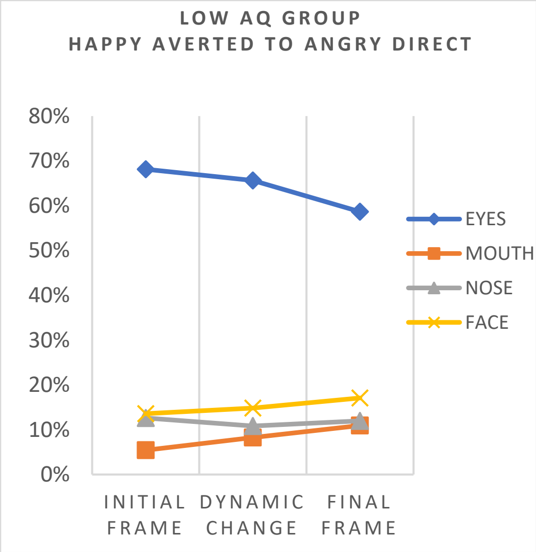


Figure 37 The average percentage of time fixating in each AOI as the emotional expression of the faces changed from a happy expression with averted gaze to an angry expression with direct gaze (left panel) and from an angry expression with averted gaze to the happy expression with direct gaze (right panel).

There was a significant main effect of AOI ($F_{1.30,49.41} = 115.62$, $p < .001$, ηp2 = .753). Bonferroni corrected post-hoc tests showed that the amount of time spent fixating on Eye region was significantly longer than for any other AOI (all p's < .001), but the time spent on Mouth region did not differ from time spent on the Nose nor Rest of Face (p's > .05). Additionally, time spent fixating on the Nose region was significantly higher than the time spent on the Rest of Face (p = .028). The main effect of AOI was qualified by a significant AOI X Emotional sequence interaction ($F_{2.41,91.68} = 5.05$, $p = .005$, ηp2 = .117). Follow up t-tests revealed that Mouth region was fixated for significantly longer when the emotion was changing from anger to joy ($p < .001$). There was also a significant interaction between AOI and Phase ($F_{3.43,130.49} = 21.61$, $p < .001$, ηp2 = .362), i.e. the part of the video (initial, dynamic change, final). Overall, the amount of time spent looking at the Mouth region increased as the video progressed, while the amount of time looking at Eye region decreased. The analysis also revealed a significant AOI x Phase x Emotion sequence interaction ($F_{14.15,157.61} = 6.35$, $p < .001$, ηp2 = .143). For the emotion changing from anger to joy, the amount of time spent looking at the Mouth region increased as the video progressed ($p < .001$), starting at 2% in the initial frame, increasing to 13% during the dynamic change and then increasing even further to 23% in the final frame where the full-blown expression of joy was shown. Conversely, the amount of time looking at the Eye region decreased (p = .029), with the significant difference observed between the initial (73%) and the final frame (58%). For the emotion changing from joy to anger a significant increase was also seen in fixation time towards the mouth region (p = .001), however, this was not as pronounced as for the full-blown expression of joy (with 4% looking time in the initial frame to 12% in the final frame). There was a trend for the amount of time looking at Eye region to decrease from the initial 73% to 60% in the final frame but this did not reach significance (p = .051).

The average fixation time did not differ between low and high AQ groups, main effect of AQ Group ($F_{1,38}$= 0.012, p =.913, ηp2 = .000). Surprisingly, high AQ group was found to have a slightly higher average fixation time toward the eye region than those low in the Low AQ group, however, the AOI by AQ Group interaction was not significant (p = .638). Both AQ groups displayed similar patterns of social attention, regardless of the emotional content of the face (see Figure 38), with none of the interactions involving the AQ Group factor showing significant results (all p's >.074).





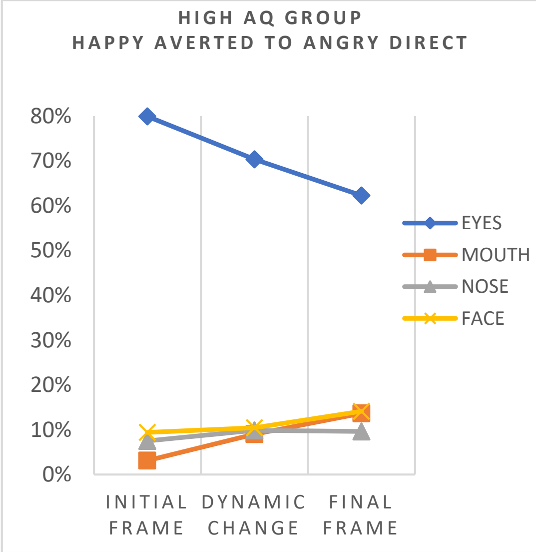


Figure 38 The average fixation time spent in all AOIs for the low and high AQ groups as the emotional content of the faces changed from a happy face with averted gaze to angry face with direct gaze (top panel) and from an angry face with averted gaze to the happy face with direct gaze (bottom panel).

Correlational Analyses Visual Attention toward the eyes and Autism Traits

For exploratory purposes, the associations between the extent of autistic traits (AQ score) and fixation times towards the eye and mouth region of the face as a function of emotion (happy and angry) were examined. None of these correlations was significant (all *p*'s > .17).

Discussion

This experiment explored the distribution of attention toward the faces as a function of the emotional content of the face (joy versus anger) and gaze direction (toward versus away) in TD individuals with a varying level of autism-spectrum traits. The results revealed similar viewing patterns in both high and low AQ groups, with most visual attention directed toward the eye region of the face, independent of the emotional content of the face. The analysis of fixations in the initial phase of the videos (static image presented for 750 ms) showed that viewing times toward the mouth region was twice as high when the expression of joy was displayed, as compared to the expression of anger. This increase was observed regardless of gaze manipulation. Surprisingly, gaze direction did not seem to affect facial viewing patterns in any way. Furthermore, the analysis of the entire dynamic videos revealed that the amount of time spent fixating on the mouth region increased when as the emotional content of the face changed from anger to joy. This was accompanied by a reduction in perceptual orienting toward the eyes. While the similar pattern of results was observed for facial expressions morphing from joy to anger, the latter results were not as pronounced. Importantly, the level of autism-spectrum traits was not found to influence the distribution of attention towards emotional faces, with both low and high AQ group showing similar patterns of fixations, regardless of emotion, gaze or AOI.

<u>Importance of the eyes</u>

The results from this study suggest that the eyes attract most attentional resources, compared with other facial regions. This effect is present independent of the emotional content of the face, with on average over 65% of fixation time spent attending the eyes. This is in line with previous studies, reporting that eyes are fixated at more often and for longer durations than any other region of the face (Eisenbarth & Alpers, 2011; Spezio et al., 2007). Interestingly, a marked reduction in viewing time toward the eyes was observed as the videos progressed, independent of the change in emotion displayed. It seems that once facial information from the eyes has been gathered, more attention is given to other regions of the face. It has been argued that the eye region carries the most information about the emotion, gender and face identity (Peterson & Eckstein, 2011). Therefore, it may be beneficial to explore this region soon after exposure to the face and only then pay more attention to the rest of the face.

<u>Viewing behaviour as a function of emotion</u>

Despite clear dominance of the eye region in perceptual orienting, it was found that the distribution of fixations varied as a function of emotional content of the face, supporting previous findings (Eisenbarth & Alpers, 2011; Schurgin et al., 2014; M. Smith et al., 2005; Spezio et al., 2007). In particular, an increased attention toward the mouth was observed for expressions of joy. This effect was observed both in static face presentations and in video sequence presentations. A similar advantage of the attention to the mouth region for the perception of joy has been noted in previous research (Eisenbarth & Alpers, 2011; Schurgin et al., 2014). This is presumably due to the importance of the smile in the identification of the emotion, as any variation in attention orienting is argued to correspond with the most characteristic configurations of facial muscle movements that provide the perceptual basis for emotion recognition (Schurgin et al., 2014). Studies, where the emotional content of the face needs to be defined just from looking either at the eye or mouth region, seem to support this claim. For example, Schurgin et al. (2014) found the impaired judgement of emotions from the eye region, for which the mouth was the most diagnostic, such as joy or disgust. Conversely, covering the eye region seems to interfere with recognition of anger, for which eyes have been found to be particularly important (Schurgin et al., 2014; M. Smith et al., 2005).

However, previous findings with regard to the fixation patterns of angry faces have been rather mixed. While some studies reported increased viewing time towards the eye region, as compared to other emotions (Schurgin et al., 2014; M. Smith et al., 2005), others failed to record any marked increases in orienting toward the eye for the expression of anger or noted the opposite pattern (De Wit et al., 2008; Eisenbarth & Alpers, 2011; Green, Williams, & Davidson, 2003; Hunnius et al., 2011). In one study, adults displayed avoidant looking behaviour in response to threat-related emotional expressions, such as anger, compared to non-threat related emotions, as demonstrated by the reduced duration and relatively fewer fixations to the inner features of the face, including the eyes (Hunnius et al., 2011). However, it is not clear to what extent these results were driven by the decrease in attention toward specifically the eye region, as this was not examined. In the current study, the eyes of faces expressing anger attracted a similar amount of attention as eyes of faces with an expression of joy. However, while the fixation time toward the eye region of joyful faces decreased significantly as the video progressed, this was not observed to such an extent for expressions of anger.

Some differences between the studies exploring visual fixation patterns of emotional faces may be explained by the viewing instructions that are given to the participants. Studies that failed to demonstrate increased looking time toward the eye region for angry faces typically employed free-viewing paradigms, unencumbered by the concurrent emotion recognition task (De Wit et al., 2008; Eisenbarth & Alpers, 2011; Hunnius et al., 2011). Conversely, such tasks were used in the studies where increased attention to eyes as compared to other emotional expressions was reported (Schurgin et al., 2014; M. Smith et al., 2005). There is evidence to suggest visual exploration of the face is strongly affected by the goal of the observer (Schurgin et al., 2014), therefore differences in methodology could potentially account for observed mixed results.

<u>Are low and high AQ scores related to differences in the viewing patterns of faces?</u>

Important for the studies reported in Chapters 3 and 4, the current findings failed to find any evidence for different viewing patterns between the low and high AQ groups. Therefore, the stark differences in implicit social learning between individuals low and high in ASD traits reported in Chapter 3 cannot be explained by differences in viewing behaviour. These findings do not corroborate some previous studies that did find such differences between low and high AQ groups (F. S. Chen & Yoon, 2011; Freeth et al., 2013; Vabalas & Freeth, 2016). The reduced looking time at the eye region, in particular, was a common theme across these studies. Instead, we found that individuals with more autistic traits focus on diagnostic areas of the face (including the eyes) just as much as individuals with fewer autistic traits, providing the opportunity to effectively process any social cues displayed by the characters. Similar results were obtained in the recent study by Åsberg Johnels et al. (2017) on adults with low and high AQ scores. Although the study did report atypical orienting in children and adolescents with high autism spectrum traits, this was not evident in the adult sample. This may suggest the use of some compensatory strategies in adults or a late maturation of the social attention skills in the adult group.

Experiment 10 will examine the face viewing patterns of individuals diagnosed with ASD, to see whether atypical distribution of attention toward the faces may have implications for the interpretation of the results obtained in Chapter

4. If individuals with ASD would avoid looking at the eye-region of the characters during the stimulus presentations in the learning phase of the implicit social learning experiments (while TD individuals did look at the eyes), then that could to some extent explain the reduced implicit social learning found in the ASD group as the eye direction is crucial to learn the actor's disposition towards the observer.

6.2 Experiment 10

<u>Hyperarousal model</u>

It has been argued that ASD is characterised by a reflexive eye-avoidance behaviour caused by perception of the eyes as threatening and over-arousing (Corden et al., 2008; Dalton et al., 2005; Kliemann et al., 2012, 2010; Kylliäinen & Hietanen, 2006; Tanaka & Sung, 2016; Zürcher et al., 2013). According to the hyperarousal model, in typical development repeated occurrences of eye contact paired with positive experiences resulting from social interaction, lead to a positive value being attached to the direct gaze (Senju & Johnson, 2009). In other words, the mutual gaze is intrinsically rewarding for typically-developed individuals, which is supported by the neuroimaging data showing that reward circuity such as ventral striatum is activated when looking at other's faces is modulated by the direct gaze (Kampe et al., 2003). On the contrary, ASD individuals may fail to form associations between a positive value and eye contact, or may even develop a negative response towards direct gaze, possibly due to overly high physiological arousal. For example, in a series of studies by Kliemann et al. (2010, 2012), participants were asked to fixate on a point that appeared either in the eye or mouth region of the face, displaying either happy or fearful emotions. When cued to the eye region, individuals in the ASD group made more and faster saccades away from the eyes than when cued to the mouth. When cued to the mouth, typically-developed participants automatically shifted their gaze away from the mouth and towards the eyes whereas participants in the ASD group were less inclined to fixate on the eyes. Further to this, although overall fixations towards the eye region were lower in those with ASD, fixations were further reduced when expressions of fear were displayed, as compared to expressions of joy. In addition, those with ASD showed abnormally increased amygdala response compared to controls, when the initial fixation was in the eye region of the face, with the heightened amygdala activation possibly signalling negative arousal (LeDoux, 1996).

Consistent with the hyperarousal model, eye-tracking studies that have explored visual fixations of faces displaying direct gaze found reduced attention towards the eye region in ASD (Chawarska & Shic, 2009; Dalton et al., 2005; Jones, Carr, & Klin, 2008; Klin et al., 2002; Nuske, Vivanti, & Dissanayake, 2014; Pelphrey et al., 2002; Rutherford et al., 2007; Spezio et al., 2007; Wolf et al., 2008). Others reported no differences in eye viewing between typical and ASD individuals (Bar-Haim et al., 2006; Elsabbagh et al., 2009; McPartland et al., 2011; Sawyer et al., 2012; Sepeta et al., 2012; Van Der Geest et al., 2002; Wagner et al., 2013). However, due to a lack of control group in the form of stimuli depicting averted gaze, it is unclear whether these results are related in particular to direct gaze avoidance or general aberrant fixation patterns in ASD. Surprisingly, only a handful of studies directly compared the distribution of attention toward faces with direct versus averted gaze in ASD, yielding mixed findings. In two studies, increased looking time towards direct gaze in comparison to averted or closed eyes have been found in *both* TD and ASD individuals (Louwerse et al., 2013; Vivanti et al., 2011). Some studies found no difference between viewing time of eye region between direct and averted gaze in *neither* of groups (Hernandez et al., 2009; Kaartinen et al., 2012; Nuske, Vivanti, & Dissanayake, 2015; Sepeta et al., 2012). Finally, in line with direct gaze avoidance hypothesis, one study found that longer duration towards direct versus averted gaze in the TD group, but not in ASD (Vivanti & Dissanayake, 2014). Taken together, these findings suggest that there is no clear pattern in response to direct versus averted gaze in ASD.

Other evidence for hyperarousal model comes from overall patterns of emotional arousal in response to direct gaze, as measured by (1) brain activity or (2) physiological responses such as skin conductance responses (SCR), heart rate or pupil dilation. Several neuroimaging studies found differential brain responses to direct versus averted gaze between TD and ASD individuals (Dalton et al., 2005; Kliemann et al., 2012; Pitskel et al., 2011; Von Dem Hagen, Stoyanova, Rowe, Baron-

Cohen, & Calder, 2014). For example, those with ASD showed an abnormally increased amygdala response compared to controls in repose to direct gaze fixation (Dalton et al., 2005; Kliemann et al., 2012). Further to this, Grice et al. (2005) found abnormal processing of direct versus averted gaze in children with ASD, with direct gaze eliciting lager event-related potentials (ERP) over posterior regions than averted gaze, while no such difference has been found in TD group (Grice et al., 2005).

A couple of studies recording skin conductance in relation to direct versus averted gaze reported increased SCRs responses in relation to direct gaze in ASD individuals, but not TD (Kylliäinen & Hietanen, 2006; Kylliäinen et al., 2012). One study found a positive correlation between social skill impairment in ASD and SCRs in response to direct gaze (Kaartinen et al., 2012). However, one study found increased SCR in response to *both* direct and averted gaze in ASD (Joseph, Ehrman, McNally, & Keehn, 2008). Studies using pupillometry typically failed to find an increase in pupil size in relation to direct gaze in ASD (Nuske et al., 2015; Sepeta et al., 2012). A similar pattern of results was observed in studies using heart rate measurements as an index of arousal, with no increase in heart rate recorded in response to direct gaze (Helminen et al., 2017; Louwerse et al., 2013).

In summary, there is mixed support for the hyperarousal model from both eye-tracking and arousal measures. The picture is even less clear for adults with ASD, as the overwhelming majority of studies focused on children or adolescent samples. Therefore, findings from the previous studies cannot rule out the possibility of atypical attention in response to direct gaze in adult participants with ASD, which may potentially be due to the aversion towards the eyes observed in this group.

<u>Hyperarousal model and implicit learning</u>

The results from the social implicit learning studies in Chapter 4 revealed that individuals with ASD did not implicitly learn the dispositions of the characters, which was interpreted as their inability to learn specifically social information, as they did as well as the TD group in the non-social implicit learning task. However, a closer look at the data suggests that learning has occurred to some extent, but in the opposite direction. That is, the character which possessed a positive disposition towards the observer in the learning phase was fairly consistently associated with a negative facial expression (frown) in the test phase, and similarly, the character which possessed a negative disposition towards the observer in the learning phase was fairly consistently associated with a positive facial expression (smile) in the test phase. If participants with ASD exclusively (or to a very large extent) paid attention to the eyes only when gaze was averted and/or avoided looking at the eyes when direct gaze was present, this could in principle explain the reverse learning effect found, as the positive-disposition character displayed an angry facial expression when looking away, while the negative-disposition character displayed a happy facial expression when looking away.

A recent eye-tracking study found that individuals with ASD demonstrated reduced looking time at social versus non-social stimuli, but only when the social stimuli were moving towards them, and not when moving past them (Crawford et al., 2016). It could be that individuals with ASD tend to avoid social stimuli that are directed at them, which have the potential to require social interaction. While avoiding the eyes could be an adaptive strategy, this approach most likely interferes with the ability to process facial cues of identity, expressions and intentions, exacerbating the social challenges for persons with ASD (Tanaka & Sung, 2016).

Given the implications the aberrant viewing behaviour towards the eyes could have on the implicit social learning deficits observed in Experiment 3, the aim of this study was to explore face viewing as a function of the emotional content and gaze direction in individuals with ASD. As inconsistencies in visual attention toward faces in ASD observed in the literature may result from the differences in stimuli characteristics and/or task demands (Senju & Johnson, 2009), the social videos in this experiment were created identically to the videos used in Chapters 3 and 4. In addition, we wanted to check whether there was a difference in looking-time at the actor's eye region for the first static frame of the clips (presented for 750 ms) compared to the dynamic part (540ms) and to the last static frame (also presented for 750 ms), as a function of gaze direction and facial expression. It could be that individuals with ASD (or TD individuals with high AQ scores) did look at the actor's eye region, but only when eyes were directed away and would avoid the eyes when directed at them. Such looking behaviour might also in principle be able to explain the results in Chapters 3 and 4. Thus, the main aim of the eye-tracking experiments is to establish whether or not any atypical looking behaviour of the ASD individuals might have contributed to the results obtained in Chapters 3 and 4.

We predicted that individuals with ASD will show reduced viewing time of the eye region, especially in the context of (1) emotionally arousing direct gaze and (2) threatening emotion of anger. Finally, there were no particular expectations towards the outcome of correlational analyses of the amount of implicit learning observed in Chapter 4 and fixation time toward the eye and mouth. On one hand, the increase in exploration of these face regions could be related to better implicit social learning. However, as social cues tend to be perceived in an automatic manner, the amount of attention towards these regions may not have any substantial effect on learning.

Methods

Participants

Eighteen undergraduate students with ASD took part in Experiment 10. After applying exclusion criteria one participant was excluded from the analysis (see below). The final sample consisted of 17 participants (four women, thirteen men), with a mean age of 19.35 (SD = 0.86), a mean total IQ score of 113.62 (SD = 7.88) and a mean ADOS score of 9.65 (SD = 2.15). The control group consisted of a subset of participants from Experiment 9, matched for age, sex and intellectual abilities (these were not tested again in Experiment 10). The data of 24 participants were included in the analysis (eight women, sixteen men), with a mean age of 19.42 (SD = 1.77) and a mean total IQ score of 114.52 (SD = 6.38). The ASD and TD groups did not differ significantly in terms of age ($t(39) = .137$, $p = .892$, gender ratio ($X_2(1, N =41) = .897$, $p = .344$) nor IQ ($t(39) = .358$, $p = .722$). The AQ scores were significantly higher in the

ASD group than in the TD group ($t(39) = 8.94$, $p < .001$). Participants' characteristics are presented in Table 8.

Table 8 Participants' characteristics

	AGE	SEX	IQ-total	AQ	ADOS
ASD GROUP (n = 17)	19.35 (0.86)	4 women 13 men	113.62 (7.88)	34.18 (7.83)	9.65 (2.15)
TD GROUP (n = 23)	19.42 (1.77)	8 women 15 men	114.52 (6.38)	16.13 (5.12)	-

Stimuli and Procedure

The stimuli and procedure were identical to those of the previously described Experiment 9. Therefore, it is only summarised in this section. The eye-tracker was calibrated in order to measure the positions of the participant's eye on the screen. Dynamic face stimuli were presented on the screen while eye movements were recorded. Participants were told the aim of the study was to assess their perception of faces. Participants freely looked at the videos and did not have to perform any task. The instructions given to the participants were to simply look at the faces, as for implicit learning studies. Half of the videos began with a character displaying an expression of joy and the other half with an expression of anger. The gaze direction was also manipulated in that half of the videos for each emotion initially displayed direct gaze and the other half gaze averted to the right. The initial frame remained on the screen for 750ms, after which the character's emotion started to naturally morph into the other emotion, which was accompanied by a simultaneous change in the gaze direction (18 frames x 30ms = 540ms). The final frame remained on the screen for a further 750ms. The trials thus followed the procedure of implicit learning studies.

Results

Data Reduction

The data of the one ASD participant, who did not complete the experimental session due to a calibration issue was removed.

Data Analysis

As in Experiment 9, to quantify visual fixations, for each stimulus, rectangular AOI reflecting eyes, mouth, nose and rest of face, were defined prior to data collection. Missing data points (i.e. blinks, fixation outside the field of view, etc.) were removed from data analysis. The average of total fixation time on the screen was calculated for each participant as a percentage of total presentation time. Though the TD group spend on average 84% of the time fixating on the screen as compared to 81% for the ASD group, an independent samples t-test was not significant ($t(39) = 1.53$, $p = .133$).

The total fixation time made to each AOI was calculated for each trial. This was expressed as the average of looking time in each AOI as a function of total fixation time on the screen. The first step of the analysis was to compare overall visual fixation patterns of TD and ASD groups. The second step of the analysis was to examine fixation patterns across different emotion-gaze combinations in the initial, static frame of the videos. The third step of the analysis was to explore potential changes in fixation patterns across the dynamic change of the characters' expression (throughout the entire trial duration). Finally, two sets of correlations were run: one to examine fixation patterns in relation to ASD symptom severity, and the second to investigate the association between viewing patterns and implicit learning observed in Experiment 3.

Overall Viewing Patterns of Dynamic Facial Expressions

A mixed-design ANOVA was conducted with AOI (Eyes, Mouth, Nose, Rest of Face, Background) as a within-subject factor and Group (TD, ASD) as a between-subject factor. The results are illustrated in Figure 39. Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. There was a main effect of AOI ($F_{1.34,50.80} = 97.74$, $p < .001$, $\eta p2 = .720$), indicating differences in the amount of time spent fixating in each AOI. Fixation time towards the Eye region was significantly longer than to any other AOIs (all p's < .001). Conversely, the time spent on the Background region was significantly shorter than on any other region (all p's < .001). There were no significant differences in the looking time towards the Mouth and Nose (p = .10), nor Mouth and Rest of Face (p = .085). However, the fixation time on the Nose was significantly shorter than on the Rest of Face (p = .002).

The main effect of AOI was qualified by a significant interaction between AOI and Group ($F_{1.33,50.80} = 5.85$, p = .012, ηp2 =.133), suggesting that the groups displayed different fixations patterns. A follow up one-way ANOVA revealed a significant difference in the amount of time each group fixated at the eye region (p = .014), with the ASD group spending on average 19% less time looking at the eyes, as compared to the TD group. Conversely, the ASD group spent significantly more time than the TD group fixating on the Nose region (p = .032) and Rest of Face region (p = .008). There were no differences in the average fixation time toward the Mouth region nor Background. The main effect of Group was non-significant (p = .120).

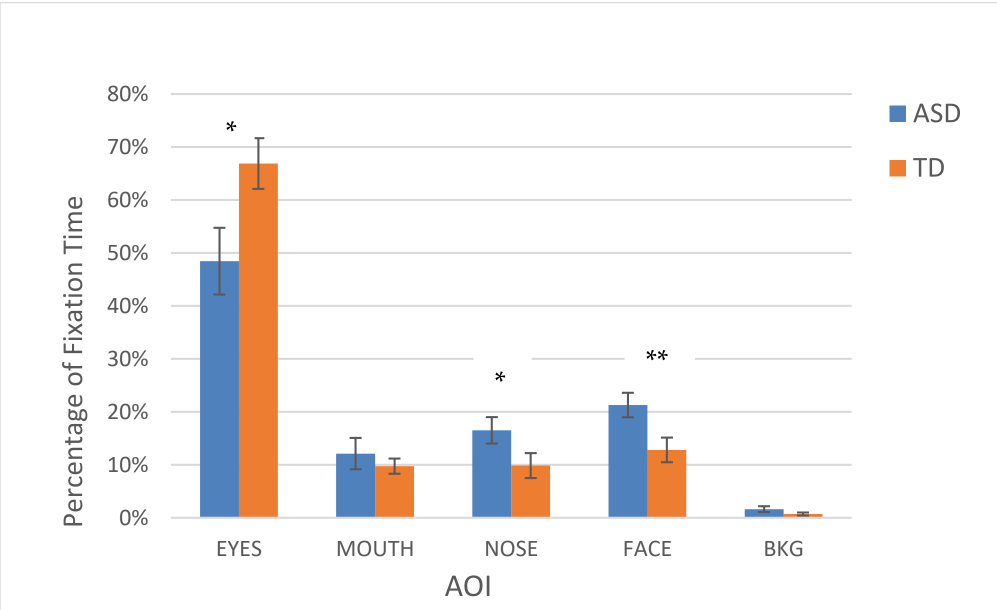


Figure 39 The average percentage of time spent in each AOI as a function of total fixation time for the TD and ASD Group.

Visual Attention Toward Still Emotional Faces with eyes directed either toward or away.

To examine viewing patterns of still emotional expressions, the first part of the videos with characters displaying initial emotions of joy and anger, accompanied by either direct or averted gaze, were analysed. A mixed-design ANOVA with Emotion (Happy, Angry), Gaze Direction (Direct, Averted) and AOI (Eyes, Mouth, Nose, Rest of Face, Background) as within-subject factors and Group as between-subject factors was conducted. The results can be seen in Figure 40. For clarity, separate graphs have been created for each group.

Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. There was a non-significant main effect of Emotion ($F_{1,38} = 0.36$, $p = .553$, $\eta p2 = .009$) and a non-significant main effect of Gaze ($F_{1,38} = 2.20$, $p = .146$, $\eta p2 = .055$). This suggests that overall participants spent similar amounts of time observing faces displaying expressions of joy and anger, as well as looking at faces with a direct and averted gaze. There was a significant main effect of AOI ($F_{1.21,46.03} = 120.77$, $p < .001$, $\eta p2 = .761$). Pairwise comparisons revealed that the amount of time spent on the Eye Region was significantly higher than on any other AOI (all p's < .001). Fixation time on the Mouth region was significantly lower than on the Nose ($p < .001$) and Rest of Face ($p < .001$) Regions, but significantly higher than time spent on the Background ($p = .001$). There was no difference in the viewing of Nose and Rest of Face regions ($p = .100$). The Background was the least attended region of all (all p's < .002). This was qualified by a significant interaction between AOI and Group ($F_{1.21,46.03} = 6.88$, $p < .001$, $\eta p2 = .153$), suggesting that the amount of time spent looking at AOIs differed between the groups.

Similarly, as reported for the overall viewing patterns, the TD group on average looked longer at the Eye region, as compared to ASD group, while increased fixation time toward the Nose and Rest of the Face regions was observed in ASD group compared to the TD group. The interaction between Emotion and Group was not significant ($F_{1,38} = 0.36$, $p = .553$, $\eta p2 = .009$). However, there was a significant three-way interaction between Emotion, Group and AOI ($F_{2.35,89.10} = 3.01$,

p = .020, ηp2 = .073). The Bonferroni corrected follow up tests revealed that for expressions of joy, individuals with ASD spent more time fixating on the Nose region than TD group (p = .040). No other differences in fixation time to other AOIs for facial expression of joy were found. Similarly, the increase in Nose region fixation time in the ASD group was also observed for expressions of anger (p = .005). At the same time, a significant reduction in Eye region fixation time in the ASD group was observed (p = .045), as compared to TD controls. There was also a trend towards increased attention to the Mouth region in the ASD group (p = .050).

The four-way interaction between Emotion, Gaze, AOI and Group was also significant ($F_{2.46,93.61}$ = 3.51, p = .025, ηp2 = .084). To further explore the interaction, a separate three-way ANOVA was run for each group. For TD group, a significant interaction between Emotion, Gaze and AOI was found ($F_{2.26, 49.77}$ = 3.19, p = .017, ηp2 = .126). Bonferroni corrected follow up t-tests revealed that TD participants looked significantly more at the Rest of Face Region of joyful faces when the gaze was averted, as compared to direct gaze (p = .005). There were no other differences in viewing patterns between direct and averted gaze in facial expressions of joy. For facial expressions of anger, a significant difference was observed only in the fixation time in the Mouth region, with TD participants fixating at the Mouth more when the gaze was direct than when it was averted (p = .005). For the ASD group, there was only a trend towards significance for the three-way Emotion, Gaze and AOI interaction ($F_{2.49, 39.79}$ = 2.32, p = .067, ηp2 = .126), therefore, no follow up t-test were performed.

Figure 40 The average percentage of time fixating in each AOI for each emotion-gaze combination for initial frames of the videos in TD and ASD group.

<u>Visual Attention toward facial features of the three consecutive phases of the video sequences</u>[5]

The data was analysed with a mixed-design 2x3x4x2 ANOVA with within-subject factors Emotion sequence (Happy to Angry, Angry to Happy), Phase (Initial, Dynamic, Final) and AOI (Eye, Mouth, Nose, Rest of Face) and between-subject factor Group (TD, ASD). The results are presented in Figure 41.

[5] As for Experiment 9, the data analysis of videos starting with direct gaze gradually changing to averted gaze revealed a similar pattern of results, with no substantial differences. Therefore, it was decided not to report it here.

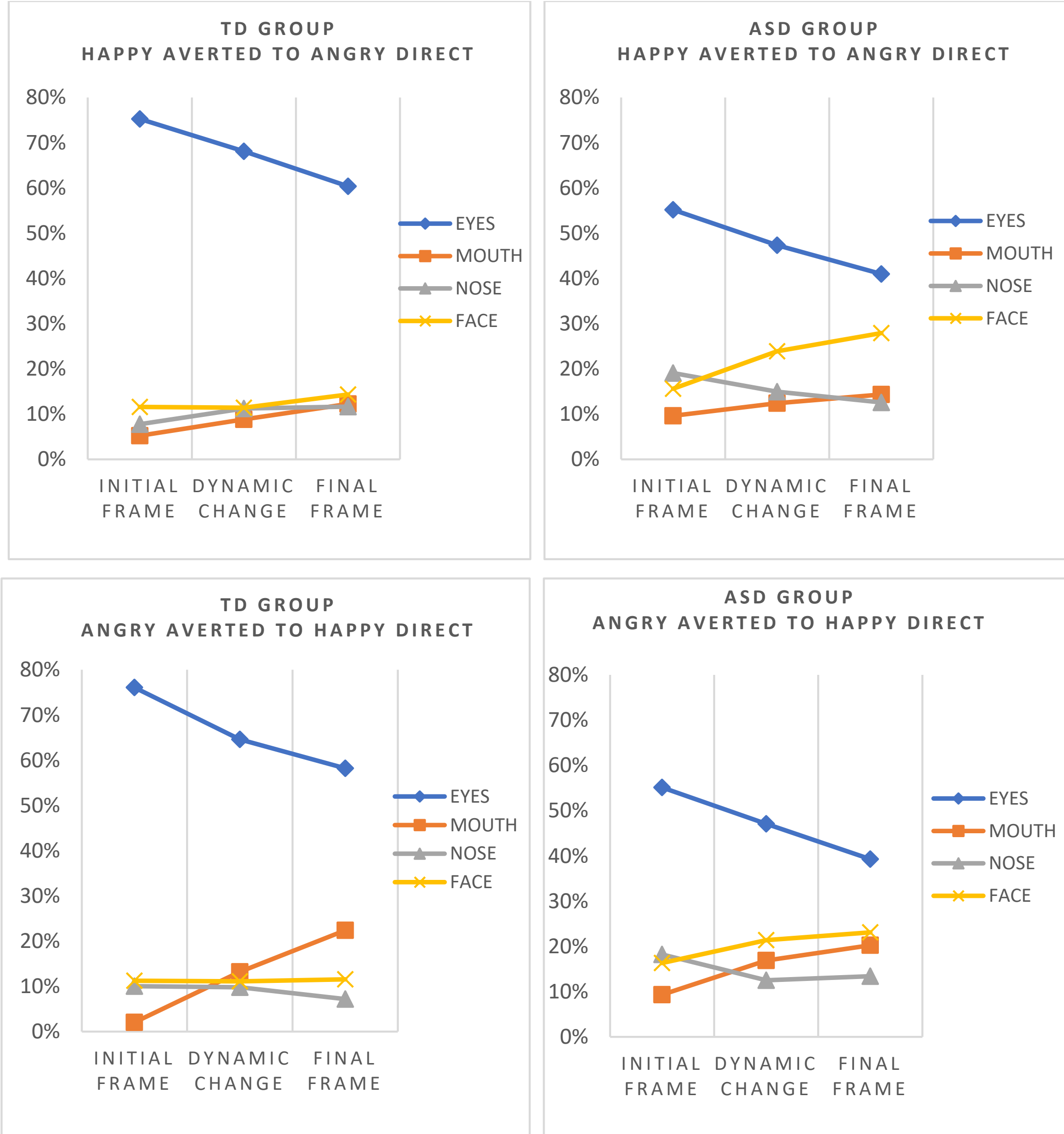


Figure 41 The average fixation time spent in all AOI for TD and ASD groups as the emotional content of the faces changed from a happy face with averted gaze to angry face with direct gaze (top panel) and from an angry face with averted gaze to the happy face with direct gaze (bottom panel).

There was a significant main effect of AOI ($F_{1.33,50.59} = 73.95$, $p < .001$, ηp2 = .661). Bonferroni corrected follow up t-tests showed that the amount of time spent fixating on the Eye region was significantly longer than for any other AOI (all *p*'s < .001) but the time spent on Mouth region did not differ from time spent on the Nose nor Rest of Face (*p*'s > .05). Additionally, time spent fixating on the Nose region was significantly higher than the time spent on the Rest of Face ($p = .009$). Importantly, the main effect was qualified by a significant AOI x Group interaction ($F_{1.33,50.59} = 6.61$, $p < .001$, ηp2 = .148). Follow up t-tests revealed a significant difference in the amount of time spent on the Eye region between the groups, with the ASD group looking less at the eyes than the TD group (p = .016). Conversely, increased viewing time of Rest of Face region was recorded for ASD Group (p = .003). There was also a significant interaction between AOI and Frame ($F_{3.71,141.14}$ = 16.71, p < .001, ηp2 = .305). Follow-up tests demonstrated that the amount of time looking at Eye region decreased as the video progressed (p = .025), while the time spent looking at the Mouth region increased (p < .001), regardless of the emotional content of the face.

A significant interaction was also revealed between AOI and Emotion ($F_{3,114}$ = 2.90, p = .038, ηp2 = .071). However, after Bonferroni corrections, all the follow-up tests were not significant. The analysis also revealed a significant three-way AOI x Phase x Emotion sequence interaction ($F_{3.39,\ 128.691}$ = 2.65, p = .017, ηp2 = .065). For the emotion changing from anger to joy, the amount of time spent looking at the Mouth region increased as the video progressed, starting at 5% in the initial frame, then increasing significantly to 15% during the dynamic change (p =.018) and then increasing even further to 22% in the final frame where the full-blown expression of joy was shown (p < .001). Conversely, the amount of time looking at the Eye region decreased (p = .023), with a significant difference observed between the initial (67%) and the final frame (50%). For the emotion changing from joy to anger, a significant increase was also seen in fixation time towards the mouth region (p = .042), however, this was not as pronounced as for the full-blown expression of joy (with 7% looking time in the initial frame to 13% in the final frame). There was also a significant increase in viewing time of Rest of the Face as the video progressed (p = .047). At the same time, the amount of time looking at Eye region decreased significantly from initial 67% to 52% in the final frame (p = .046).

The AOI x Phase x Group interaction was especially interesting, as it would show whether the ASD group, more than the TD group, look away from the eyes once they began to move in the direction of the observer. This should be reflected by a significant drop in looking-time at the eye region from the initial phase (eyes averted) to the final phase (eyes directed) in the ASD group. However, the AOI x Phase x Group interaction was non-significant ($F_{3.71,\ 141.14}$ = 1.70, p = .159, ηp2 = .043).

Both groups showed a drop in looking-time at the eye region towards the latter part of the video sequences. All remaining interactions were also non-significant (all *p*'s > .188).

Correlational Analyses of Attention to Eyes and Mouth and Symptom Severity

For exploratory purposes, the associations between ASD symptom severity, as measured by the ADOS, and average fixation times towards the eye and mouth region of the face as a function of emotion (happy and angry) were examined. None of the correlations was significant (all *p*'s > .17).

Correlational Analyses of Visual attention to eye/mouth region and Implicit Learning

A subsample of ASD participants in this experiment had also previously taken part in Experiment 3 exploring social implicit learning abilities (N = 16). Therefore, it was possible to correlate the amount of implicit learning observed in Experiment 3, with the looking patterns observed in this study. The observed learning was quantified as the difference between an average rating of character with a positive disposition and an average rating of the character with a negative disposition toward the observer. This value was then correlated with the average fixation times towards the eye and mouth region of the face as a function of emotion (happy and angry). The results did not reveal any significant correlations (all *p*'s > .38).

Discussion

The aim of Experiment 10 was to discover whether looking behaviour at emotional facial expressions would differ in ASD compared to TD, as predicted by the hyperarousal model. We found that individuals with ASD consistently showed reduced orienting towards the eye region, which was typically 'compensated' by increased looking time towards the nose or the non-critical regions of the face. While fixation time toward the eyes seems to decrease more for facial expressions of anger than joy in ASD individuals, this effect was rather small and only observed in the initial still frame of the videos, and disappeared when the full duration of the videos was considered. Interestingly, the fixation patterns of emotional faces were not associated with ASD symptom severity, as measured by the ADOS score. And finally, the amount of implicit social learning observed in Chapter 4 was not related to the amount of attention directed toward the eyes or the mouth.

Avoiding the eye region in ASD

Reduced attention towards the eyes in ASD has been observed in previous studies (Chawarska & Shic, 2009; Dalton et al., 2005; Pelphrey et al., 2002; Rutherford et al., 2007; Spezio et al., 2007; Wolf et al., 2008). However, several studies failed to find reduced eye viewing in ASD (Bar-Haim et al., 2006; McPartland et al., 2011; Sawyer et al., 2012; Sepeta et al., 2012; Van Der Geest et al., 2002; Wagner et al., 2013). This indicates the role of social attention is ASD is complicated and may vary depending on the context. Eyes contain important social cues about the face identity, gender and emotional content of the face, especially in case of negative emotional expressions such as fear, sadness or anger. Avoiding the eye region could potentially affect the amount of social information that is available to navigate the social world, resulting in social difficulties observed in ASD. The results from the current study revealed increased eye avoidance in ASD towards the faces displaying emotions of anger but not the emotions of joy. Surprisingly, there was no difference in looking time toward the faces displaying direct and averted gaze in either TD and ASD individuals, which is in contrast to hyperarousal model, which would predict reduced fixation time spent in the eye region in ASD, specifically in relation to direct gaze. In particular, it was expected that the use of more ecologically valid, naturally changing facial expressions would enhance any potential differences in viewing patterns between the groups. For example, modulation of arousal in response to direct gaze found in ASD (Joseph et al., 2008; Kylliäinen et al., 2012) should lead to a further reduction in eye viewing in response to direct gaze in this group, which was not the case here. In particular, a lack of decrease in looking-time at the eye region in response to video sequences starting from eyes averted and gradually changing to the eyes directed in the ASD group, argues against the hyperarousal model. These findings corroborate some of the previous studies examining direct versus averted gaze eye viewing in ASD, which failed to find difference in viewing patterns of direct versus averted gaze, not only in ASD but also TD group (Hernandez et al., 2009; Kaartinen et al., 2012; Nuske et al., 2015; Sepeta et al., 2012).

Hyperarousal model posits that reduced attention toward the eyes in ASD stems from a failure to form positive associations between the mutual gaze and social interaction caused by sustained states of negative arousal. However, a failure to attach positive reward value to the direct gaze may also result from deficits in social motivation (Senju & Johnson, 2009; Sepeta et al., 2012). Individuals with ASD miss the significance of the information contained in the eyes due to the reduced sensitivity to the reward value of social stimuli. One study looking at pupillary responses in ASD found that TD participants showed pupillary dilation in response to happy facial expressions looking directly at the observer in comparison to happy faces with averted gaze (Sepeta et al., 2012). No such effect was found in ASD individuals. Happy faces activate reward circuitry in the ventral striatum in TD individuals, which is further modulated by direct gaze (Kampe et al., 2003). Therefore, a lack of physiological response to smiling faces in ASD may indicate an impairment in the processing of social reward (Sepeta et al., 2012). ASD individuals may fail to appreciate the reward value associated with social cues, in line with the social motivation hypothesis (Chevallier et al., 2012).

One of the other causes for diminished attention towards the eye in ASD may be inflexibility in looking behaviour. Looking at the nose in the initial phase of the videos may indicate issues with the disengagement of attention, which could potentially be related to inflexible viewing patterns that have been observed in ASD in the past (Elison, Sasson, Turner-Brown, Dichter, & Bodfish, 2012; Elsabbagh et al., 2013, 2009; Sabatos-DeVito, Schipul, Bulluck, Belger, & Baranek, 2016; Sasson, Turner-Brown, Holtzclaw, Lam, & Bodfish, 2008). The fixation point, directly preceding the onset of the clips, was placed in the middle of the screen, which was typically where the nose region of the face was displayed. Although this was not measured in the current study, it could be that individuals with ASD, because of this initial fixation, did not explore the face to the same extent as TD controls.

Previous studies found that ASD individuals tend to exhibit reduced visual exploration by making smaller and less frequent saccades (Elison et al., 2012; Sasson et al., 2008). In a study with TD individuals, emotion recognition accuracy was 28% higher when participants were allowed to move their eyes freely during learning than when they were required to hold fixation steady (Henderson, Williams, & Falk, 2005). This suggests that either detail of specific features of the face are important for achieving high-level recognition performance, or that initial encoding of the relation between facial features benefits from eye explorations, or both. If inflexible viewing patterns were employed in the current study by the ASD group, they could have affected the amount of social information gathered from the faces.

Comorbid conditions such as anxiety and alexithymia could also contribute to the reduced viewing time of the eye region observed in ASD group. Indeed, there is some evidence to suggest that visual attention toward the eyes tend to be affected by anxiety (e.g. Garner, Mogg, & Bradley, 2006) and alexithymia (Bird et al., 2011). For example, in the study by Bird et al. (2011), it was alexithymia, and not autism symptom severity, that predicted the eye fixation. Alexithymia has been described as a subclinical phenomenon marked by difficulties in identifying and describing feelings and difficulties in distinguishing feelings from the bodily sensations of emotional arousal (Nemiah, 1976). As alexithymia is frequently comorbid with ASD, it could potentially explain some of the mixed findings on social attention in ASD reported in the literature. Similarly, anxiety has been found to affect visual attention toward the eyes, especially in relation to negative facial expressions. In the current study, neither anxiety nor alexithymia was measured, therefore, it could be the case that aberrant social attention toward the eyes was to some extent modulated by one or both of those traits.

<u>Are differences in social attention in ASD related to social functioning?</u>

Regardless of the exact reason behind the atypical social attention in ASD, it is not quite clear to what extent differences in social attention interfere with social functioning. Even when individuals with ASD show no difference in time spent on the eye region compared to TD, behavioural differences may still be observed

(Sawyer et al., 2012). Similarly, aberrant patterns of social attention may not necessarily explain behavioural differences between the groups. For example, although in the current study overall eye viewing time was reduced in the ASD group, no relationship between looking patterns and the ability to learn implicitly examined in the earlier studies has been found. While the ASD individuals tend to display abnormal gaze behaviours, these cannot fully explain social deficits associated with the disorder, especially since those ASD individuals that exhibit typical social orienting, still show marked deficits in social functioning.

Further to this, it is important to note that the current results revealed that the eyes were still the most attended region of the face in individuals with ASD and that the amount of time viewing the eye region accounted for about half of the overall fixation time in those with ASD. Although in comparison to the typically-developed subjects this reflected a reduced looking time towards the eyes, it could have been sufficiently long for all the relevant social cues to be extracted from the eyes. It has been found that face recognition can be achieved almost immediately, after only one or two eye movements (Hsiao & Cottrell, 2008). Although more time may be required for the perception of emotional expressions, emotion recognition can typically be completed in a short amount of time, even by high-functioning ASD individuals when only basic emotions are involved. It is a question for future research to determine the amount of social attention (i.e. fixation time) required for various social processes and efficient social functioning in general.

6.3 General discussion

The aim of the studies in this chapter was to explore social attention toward different parts of faces with varying emotional content and varying gaze direction, measured by the time spent viewing predetermined facial regions, in individuals with ASD and TD (with varying autistic traits). The main findings can be summarised as follows: (1) In both the TD and ASD groups, eyes are the most attended feature of the face, regardless of the displayed emotion or gaze direction. (2) In both the TD and ASD groups, observing expressions of joy results in increased orienting towards the mouth. (3) There is no difference in looking time at diagnostic areas of the face between individuals with few and many autistic traits. (4) Individuals with ASD tend to show reduced attention toward the eye region compared to TD, which is more pronounced for the expressions of anger. (5) Aberrant viewing patterns in ASD are not necessarily related to symptom severity. (6) Reduced looking at the eye region in ASD is not related to the ability to implicitly learn social information.

Gaze behaviour and implicit learning

The key motivation of the studies presented in this chapter was to further inform the social implicit learning results obtained in Chapters 3 and 4, with both individuals high in autistic traits and ASD individuals showing a diminished ability to implicitly acquire social information. Although the correlational studies, between the time spent fixating on the eye region and social implicit learning abilities, measure obtained in the earlier experiment, was only possible for a subset of ASD participants, the general pattern of results in TD individuals with varying numbers of autism-spectrum traits may shed light on this question. This is because (1) the exact same dynamic videos with changing emotional content of the face were used in both studies, (2) the task instructions were kept constant between the studies and (3) the samples of typically-developed individuals were drawn from the same student population at the same university.

The results revealed that there was no difference between visual attention toward faces between individuals low and high in autistic traits. The most informative regions of the face were looked at to the same extent by those high in ASD-traits, regardless of the emotional content of the face or gaze direction. These findings are similar to those reported by Åsberg Johnels et al. (2017), where although atypical orienting was observed in children and adolescent group with high autism spectrum traits, there were no differences found in visual fixation patterns in adults with a high level of autistic traits. This suggests that any developmental differences in social attention in individuals high in ASD traits may normalise with age. One possibility worth examining is that adults high in autistic traits may explicitly learn to attend to the diagnostic regions of the face such as eyes and mouth, even though their automatic orienting may be somewhat faulty. However, it seems that the visual attention toward faces is similar in adults with a varying level of ASD traits. These results when extrapolated to the sample of individuals high in autistic traits from Chapter 3, suggests strongly that aberrant attention to social information cannot explain the social implicit learning deficits observed in this group.

As hypothesised, in the current study ASD individuals showed atypical viewing patterns of emotional facial expressions marked by decreased attention (looking time) toward the eyes. However, even though information processing in ASD appears to be critically affected by the amount of exposure to the relevant stimuli (T. F. Clark et al., 2008; Tardif et al., 2007), reduced attention may not necessarily indicate that attention was insufficient for the task at hand. The emotional expressions used in the current studies included only basic emotions of joy and anger displayed with full intensity. Similarly, changes in the gaze direction of the characters were clearly discernible. All ASD individuals in the current study successfully reported the content of the videos in debriefs and were capable of recognising the displayed emotions, as well as the direction of the gaze. This may suggest that they invested sufficient attentional resources required for emotion and gaze perception. Therefore, they should have had enough perceptual information needed to implicitly learn social contingencies. Indeed, the results revealed that the visual fixation patterns toward the faces were not related to the amount of implicit social learning observed in Chapter 4 in the subset of 16 ASD participants for which data were available from both tasks. Although further research into this topic is warranted due to the relatively small sample size, it seems that the social implicit learning results cannot be explained by the aberrant attention toward the eyes or other regions of the face.

The apparent limitation of the studies presented in this chapter is that the eye-tracking behaviour was not assessed at the same time as the implicit learning and for ASD individuals there was a period of about one year between the two studies. While care was taken to ensure the experiments were as equivalent as possible, it may be more informative to record the looking behaviour while participants are completing the implicit social learning task. This would allow to better understand the deployment of attentional resources as the learning is taking place and possibly assess the minimum attentional requirements for the learning to occur.

6.4 Conclusion

The studies in this chapter investigated the distribution of attention toward different facial features during free viewing of emotional faces in TD individuals with a varying number of autistic traits and in ASD individuals. The results revealed that individuals with more autistic traits focused on different regions of the face as much as individuals with fewer traits, providing the opportunity to effectively process any social cues displayed by the characters. This pattern was somewhat different for the ASD group, where atypical social attention toward the emotional faces was found. As no apparent difference was found between visual exploration of the eyes of faces with a direct versus averted gaze, the current results are against the hyperarousal hypothesis and seem to fit better with diminished social motivation theory of ASD. Importantly, the difference in visual fixation patterns in ASD did not seem to explain the deficits in social implicit learning observed in Chapter 4, as still more than 50% of the viewing time in the ASD group was devoted to the eye region and no association between the amount of implicit learning and the viewing time toward the eyes was found.

Chapter 7: Implicit affective tagging in typical development and ASD.

One possibility as to why the individuals with ASD did not implicitly learn the social dispositions of the characters (discussed in Chapter 4) is that the affective valence related to the positive or negative characters' dispositions did not implicitly get attached to the identity of the particular character displaying that disposition. If the affective valence does not get linked to the identity, the participant will not show a response bias in the test phase, which then will lead us to conclude that the participant had not implicitly learned the character's disposition. Thus, it is possible that the participant with ASD had implicitly learned the contingency between the three social cues, but either no affective valences were evoked, or affective valences were evoked but were not implicitly attached to the respective identities. To look further into any possible differences that may exist between TD and ASD individuals with respect to their ability to be implicitly influenced by affective valences evoked by emotionally-charged stimuli, the experiments in this chapter employed an affective priming paradigm.

<u>Implicit Learning in Typical Development</u>

The ability to adequately process emotional information from our environment is of vital importance. The affective primacy hypothesis assumes that humans are endowed with an implicit evaluative decision-making mechanism allowing them to automatically evaluate affective information (Kamio, Wolf, & Fein, 2006; Klauer & Musch, 2003; LeDoux, 1996; R. B. Zajonc, 1980, 2000; Robert B Zajonc, 1984).

Affective information about a stimulus is among the first types of knowledge that are activated upon the initial perception of that stimulus (Bargh, Chaiken, Govender, & Pratto, 1992; Fazio, Sanbonmatsu, Powell, & Kardes, 1986). That is, one's evaluation of a stimulus as 'good' or 'bad' becomes available immediately upon the mere perception of the stimulus without requiring intention, awareness, effort or control (for a review see Klauer & Musch, 2003). Studies demonstrate that emotionally significant stimuli are first automatically processed outside of awareness before being integrated with slower and more elaborative processing (De Gelder, Vroomen, Pourtois, & Weiskrantz, 1999; Liddell et al., 2005; Morris, Öhman, & Dolan, 1998, 1999; Troiani & Schultz, 2013; Whalen et al., 1998). The automatic processing alerts the observer to the presence of objects that have the potential for hedonic or threatening consequences and promotes meaningful categorisations of such objects (Fazio, 2001). People are likely to automatically notice those objects that can lead to rewarding experiences, those that have been defined as likeable and worth approaching. Likewise, people are likely to automatically notice those objects towards which they have developed negative attitudes, objects that should be avoided. Once the affective significance of the object is automatically processed, an individual can either approach or avoid the object, based on its valence.

The activation of positive or negative affect has been argued to be a central process by which affective information influences behaviour. The extent to which the affective stimulus is automatically processed seems to determine the strength that it exerts on one's information processing, judgements and behaviour (for reviews see Fazio, 2001). According to the Motivation and Opportunity Determinants (MODE) model (Fazio & Towles-Schwen, 1999), automatic evaluation of affective stimuli can guide behaviour in a relatively spontaneous manner, i.e. without one's consideration of the evaluative processing and even without awareness of the existence of the implicit evaluation or of its influence. Instead, the automatic evaluation will impact on one's perception of the object and this spontaneous appraisal will affect the person's behavioural response (Ferguson & Bargh, 2004). The development of affective evaluations may constitute one of the means by which individuals can structure the multitude of objects, people and issues they encounter daily. By forming and storing these evaluations, individuals structure their environment into classes of objects that merit their approach or avoidance behaviour (Chen & Bargh, 1999; Fazio, Jackson, Dunton, & Williams, 1995; Fazio, 2001; Ferguson, Bargh, & Nayak, 2005; McConnell & Leibold, 2001). This is especially important for social judgements. People exchange large numbers of nonverbal cues, which are typically interpreted in a seemingly effortless manner. The ability to encode and decode social information is crucial to successfully navigate the social world. However, social stimuli are often inherently ambiguous in that they are easily fitted in multiple categories and social behaviours can be interpreted in multiple ways. The extent to which the affective information about specific social cues is readily accessible from memory and capable of being automatically invoked can provide more effective tools for situational appraisal and free the individual from some of the impinging demands and stresses of the social environment.

Emotion Recognition in ASD

Despite extensive research effort, the status of emotion recognition abilities in ASD is still unclear. On one hand, some studies reveal deficits in emotional processing in ASD (Celani, Battacchi, & Arcidiacono, 1999; Grossman, Klin, Carter, & Volkmar, 2003; Hobson, 1986b, 1986a; Hobson, Ouston, & Lee, 1988; K. Humphreys, Minshew, Leonard, & Behrmann, 2007; Kennedy & Adolphs, 2012; Law Smith, Montagne, Perrett, Gill, & Gallagher, 2010; Lindner & Rosén, 2006; O'Connor, Hamm, & Kirk, 2005; Tantam et al., 1989; Teunisse & De Gelder, 2001), while others found that ASD individuals show similar performance in processing of emotional facial expressions to typically-developed individuals (Adolphs, Sears, & Piven, 2001; Baron-Cohen et al., 1997; Castelli, 2005; Evers et al., 2014; Neumann et al., 2006; Rutherford & Towns, 2008a; Tracy et al., 2011). A recent meta-analysis of 48 studies concluded that there is an emotion recognition difficulty in ASD, however, it is not a global impairment and typically depends on the type of emotion in question, employed methodology, participants' age and ASD symptom severity (Uljarevic & Hamilton, 2013). It has been suggested that there is only a subset of ASD individuals, who experience difficulty with emotion recognition (Nuske et al., 2013), or rather there is only a subset of ASD individuals who show behavioural atypicalities in experimental settings.

High-functioning ASD individuals were postulated to use compensatory strategies to understand emotions, which may remedy observable behavioural differences (Harms et al., 2010). This possibility is supported by neuroimaging data, with atypical neural activity during emotion recognition found in ASD, even if accompanied by intact emotion recognition performance in behavioural tasks. A number of studies across developmental trajectory reported that while brain activity was modulated by emotion in TD individuals, this modulation was absent in ASD samples. This suggests that while TD display differentiated neural activity based on the emotional content of faces, individuals with ASD may not display the same differentiation. There is also some evidence that ASD individuals do not seem to recruit the fusiform gyrus, the region activated in normal individuals for face processing (Critchley et al., 2000; Pierce, 2001; Schultz, Gauthier, Klin, & Al, 2000) but instead recruit the area typically activated in object processing (Schultz et al., 2000) suggesting that faces in ASD may be processed in a similar manner as other non-social objects.

Facially expressed emotions are conveyed by characteristic configurations of facial muscle movements that provide the perceptual basis for discriminating between distinct types of emotions, implicated in internal emotional and mental states (Ekman et al., 1980; Ekman & Oster, 1979). The emotional information contained within a face can be typically detected almost instantaneously, without explicit intention or effort. The ability to immediately understand others' mental states has been referred to as a low-level mindreading (Goldman, 2006), which is typically employed automatically and implicitly, as opposed to the deliberate and effortful use of cognitive resources to explicitly infer emotional states of others. It could be the case that low-level mindreading ability is dysfunctional in ASD individuals, resulting in challenges in social functioning (Jellema et al., 2009; Palumbo et al., 2015).

<u>Automatic processing of Emotional Information in ASD</u>

There is a growing body of evidence that the implicit, involuntary or spontaneous ability for reading others' emotional or mental states are compromised in ASD (Callenmark et al., 2014; Hudson, Liu, et al., 2009; Hudson, Nijboer, et al., 2012; Jellema et al., 2009; Schneider et al., 2013; Senju et al., 2009). For example, a couple of studies found a peculiar dissociation between the implicit and explicit theory of mind; while the performance of individuals with ASD on an implicit theory of mind task revealed intriguing difference from that of controls, they showed intact explicit theory of mind (Schneider et al., 2013; Senju et al., 2009). Namely, individuals with ASD failed to show spontaneous looking to the correct location of the object in a false belief task, even though they were able to pass the task with ease (Senju et al., 2009). Learning processes do not seem to alleviate this impairment across the presentation of multiple trials (Schneider et al., 2013). In another study, Callenmark et al., 2013 reported a similar dissociation between explicit (i.e. prompted) and implicit (i.e. spontaneous) variants of social cognition task, with the ASD group performing more poorly than controls only on implicit social cognition task in terms of spontaneous perspective taking and social awareness. Together these findings suggest that individuals with ASD may specifically be impaired in the implicit processing of social information.

The stark contrast between implicit and explicit mindreading abilities in ASD may suggest that individuals with ASD use alternative strategies to explicitly understand others' minds, which involve deliberate reasoning about emotional or mental states. This is supported by the fact that social difficulties associated with ASD can improve to some degree with age, especially in those individuals with average or above-average IQ. However, fundamental impairments of social communication persist into adulthood. It may be that cognitive understanding about others' minds can be learnt to some extent through explicit instruction, yet the automatic processing of emotional significance of incoming social stimuli remains dysfunctional in ASD. The interpretation of social cues using effortful cognitive processes would be much slower and possibly less accurate than in involuntary processing, which may be the primary reason for difficulties in social interactions found in ASD. Moreover, it is still unclear whether the ability of individuals with ASD to incorporate the affective valence into the cognitive processing of the social cues is intact or impaired. An impaired ability to automatically incorporate, and be guided by, the affective valence will significantly add to the difficulties of adjusting behaviour to the demands of social situations.

Affective Priming

To investigate the automatic processing of facial expressions, a suitable task needs to be employed. A priming paradigm seems to be an appropriate tool that can tap into the automatic aspect of processing stimuli. Priming refers to an implicit 'memory' effect, in which affective meaning of an antecedent stimulus influences the processing of a stimulus that succeeds it. Fazio and colleagues introduced the first affective priming paradigm, in which the affective/evaluative relation of the prime-target pairs was manipulated (Fazio et al., 1986). The idea was that a presentation of an affectively evaluative stimulus as a prime should activate any associated affective evaluations of objects with similar valence, and hence, facilitate a related judgement of the target word. The target word presented on each trial is an evaluative adjective, with participants instructed to indicate as quickly as possible whether the words contained positive or negative connotation. The focus is on the latency with which this judgement is made and, in particular, the extent to which it is facilitated by the presentation of a prime. Priming studies show that responding is typically faster on trials for which the participant's evaluations of the prime are congruent with the connotation of the targets than on trials for which they are incongruent. For example, 'spider' presented as a prime leads to negative evaluation and so, the presentation of a target adjective which is also negative (e.g. the word 'disgusting') should result in a faster response than the presentation of the target which is positive (e.g. 'appealing'). Likewise, the positive prime elicits faster responses if paired with positive rather than negative target words. Thus, an interaction between the valence of the prime and the valence of the target is the hallmark of the affective priming effect. Affective priming effects can only be explained if one assumes that the affective valence of the prime is automatically processed, even though this is not necessary for the task at hand (the prime is task-irrelevant). The automatic character of this effect is supported by several lines of research, of which subliminal presentation studies (Draine & Greenwald, 1998), in which participants are not aware of the presented primes yet their responses are still influenced by them, most clearly demonstrate this point.

Affective priming effects have been found for a variety of affective prime stimuli, such as words, pictures, prosody, music and odours. Two main mechanisms have been proposed to explain the affective priming phenomenon. (1) The spreading of activation theory posits that the activation level of the associated affective evaluation of stimuli with similar valence was presumed to be temporarily enhanced by the presentation of the prime. As a result, less additional activation would be needed for the target stimuli to be identified, resulting in increased speed of responses to similarly versus dissimilarly valenced prime/target pairs (Bargh et al., 1992; Fazio et al., 1986). (2) The response competition account suggests that an affective prime automatically triggers a response tendency that corresponds to its valence (Klauer & Musch, 2003; Wentura, 1999). If the subsequent target is congruent with the prime, responding is facilitated because the response pathway already received some initiation. On the other hand, if the target is evaluatively incongruent, then the response suggested by the evaluation of the prime must be inhibited in order to respond accurately to the target. In other words, the affective evaluation of the prime and the target may complement or conflict with one another and thus, facilitate or interfere with the response (stroop-like inference process). Importantly, both accounts have a similar initial step. The evaluation associated with the primed target is activated automatically once the prime is presented. In both cases, such an evaluation then facilitates the encoding of affectively congruent targets. The difference lies in what follows automatic activation of the affective value. However, both mechanisms may contribute to the effects observed in the priming paradigm and need not be mutually exclusive.

The priming paradigm provides excellent control over the effects individual stimuli may have on cognitive processing and associated behaviour because the same target stimuli can be presented with different primes. Therefore, any differences in performance must be attributed to the effect of the prime on the processing of the target stimulus.

The Current Study

Priming studies in the typical population showed that individuals are capable of processing the affective valence of incoming stimuli and that this processing subsequently affects their cognitive appraisal of the information that follows (Bargh & Williams, 2006). An impaired ability to automatically incorporate the affective valence of social cues when processing and interpreting them is likely to result in difficulty adjusting behaviour to the demands of social situations in an implicit manner. The impairment to implicitly incorporate the affective valence could in principle be due to (1) a failure to detect and/or process the affective valence itself, or to (2) a failure to integrate it with the cognitive processing while affective valence detection/processing itself is intact.

The aim of the studies presented in this chapter was to investigate the automatic processing of emotional information contained within a dynamic video sequence portraying facial expressions and the extent to which this information influence the subsequent evaluation of emotionally-charged words. To this aim, affective priming paradigm introduced by Jellema and colleagues was employed (Jellema, Pecchinenda, Palumbo, & Tan, 2011), in which prime stimuli constitute dynamic sequences of facial expressions and the targets of emotional words. The video sequences were made such that they induced perceptual extrapolations (i.e. visual illusions) relating to the last frame of the videos, induced by the immediate perceptual history within the video clip (Jellema et al., 2011). Experiment 11 explored whether individuals with ASD are capable to automatically incorporate emotional information into their cognitive processing, using the dynamic video sequences of facial expressions morphing from Neutral to Joy or Neutral to Anger. In Jellema et al. (2011), these sequences produced clear affective congruence effects in typically developed individuals. In Experiment 12, the reverse video sequences were used (Joy-to-Neutral and Anger-to-Neutral) to investigate which aspect of the prime was the most effective (1) the literal value of the face or (2) the changes in the underlying emotional state of mind. These sequences have been shown to induce perceptual distortion effects in which the identical neutral expression is judged as either slightly happy or slightly angry, depending on the preceding perceptual history and produce affective congruence effects in opposite direction (Jellema et al., 2011).

7.1 Experiment 11

The aim of this study was to see whether typically-developed and ASD individuals differ in the extent to which their cognitive evaluations are affected by involuntary emotional processing. To this end, the affective priming paradigm was employed. The presentation of dynamic facial expressions was chosen as the prime as these are natural and powerful cues in real-life social interactions (even more so than static facial expressions). Several behavioural studies have indicated that dynamic facial expressions induce more pronounced behavioural reactions than static ones (Sato, 2014; Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004). It was hypothesised that affective priming is reduced in ASD compared to TD individuals.

Methods

Participants

Nineteen undergraduate students with ASD took part in Experiment 11. After applying exclusion criteria one participant was excluded from the analysis (see below). The final sample consisted of four women and fourteen men, with a mean age of 19.67 (SD = 1.24), a mean total IQ score of 115.39 (*SD* = 9.74) and a mean ADOS score of 8.95 (*SD* = 2.04).

The control group consisted of twenty-six participants, matched for age, sex and intellectual abilities. After applying exclusion criteria, the data of twenty-five participants were included in the analysis (eleven women, fourteen men), with a mean age of 20.36 (*SD* = 2.29) and a mean total IQ score of 114.40 (*SD* = 6.06). The ASD and TD groups did not differ significantly in terms of age ($t(41) = 1.66$, $p = .250$, gender ratio ($X_2(1, N = 43) = 2.98$, $p = .084$ nor IQ ($t(26.33) = .381$, $p = .706$). The AQ scores were significantly higher in the ASD group than in the TD group ($t(25.86) = 6.88$, $p < .001$). Participants' characteristics are presented in Table 9.

Table 9 Participants' characteristics

	AGE	SEX	IQ-total	AQ	ADOS
ASD GROUP (n = 18)	19.67 (1.24)	4 women 14 men	115.39 (9.74)	32.11 (8.79)	8.61 (1.46)
TD GROUP (n = 25)	20.36 (2.29)	11 women 14 men	114.40 (6.06)	16.08 (5.31)	-

<u>Stimuli</u>

The prime stimuli in the social condition consisted of short dynamic videos clips (425ms), which were made by morphing photographs of faces displaying emotional and neutral expressions using Sqirlz Morph software (Xiberpix). Hereto pictures of 4 women and 4 men were selected from the Warsaw set of Emotional Facial Expressions Pictures (WSEFEP; Olszanowski et al., 2015), The videos, consisting of 11 frames in total, started with the neutral facial expression (first frame), gradually changing to either maximally happy or maximally angry in the final frame (see Figure 42). We will refer to these conditions as the happy onset and angry onset conditions, respectively.

The target stimuli consisted of positive and negative words selected on the basis of their valence, arousal and frequency ((Bradley, Lang, Bradley, & Lang, 1999). The valence, arousal and frequency of the words were matched between the two conditions (happy onset and angry onset; Jellema et al., 2011). There were 32 positive and 32 negative words. In one version of the experiments, half of the words were preceded by a congruent prime and the other half by the incongruent prime. In the second version of the experiment, the words were swapped, in such a way that half of the words previously preceded by a congruent prime were now preceded by an incongruent prime and vice versa. Half of the participants completed the first version of the experiment and the other half completed the second version of the experiment.

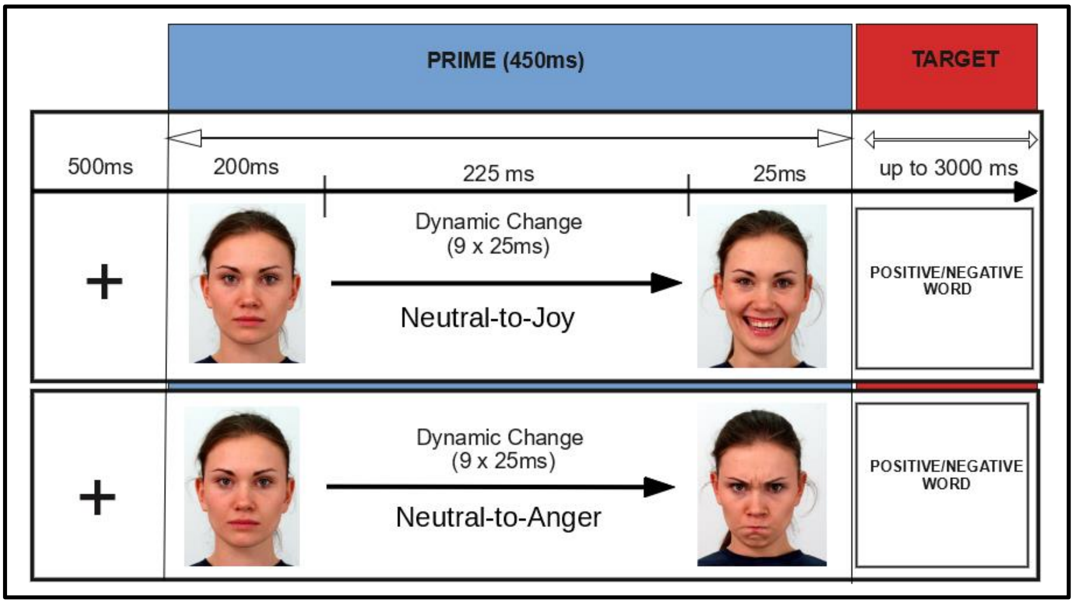


Figure 42 Illustration of the stimulus presentations in Experiment 11. Following a fixation cross for 500ms, video sequences started with a neutral expression, which gradually morphed into a facial expression of intense joy – Neutral-to-Joy trials (top panel) or intense anger – Neutral-to-Anger trials (bottom panel). Video sequences were then followed by a word, which either matched the final expression in terms of valence (congruent trials) or mismatched the final expression (incongruent trials).

<u>Procedure</u>

Each trial began with the presentation of a fixation cross at the centre of the computer screen for 500ms. Next, the primes (videos) were presented for 450ms. Immediately after the presentation of the prime, the target word was shown at the centre of the computer screen and remained on the screen until the response was given, or up to a maximum of 3000ms. The targets could affectively match with the prime: positive prime/positive target, negative prime/negative target (congruent trials) or affectively mismatch with the prime: positive prime/negative target, negative prime/positive target - incongruent trials (see Figure 42). Participants were instructed to respond as fast as possible by evaluating the target words as either positive or negative (using two keys on the keyboard labelled 'positive' and 'negative').

Post-study session: After the main study task, participants completed a short session, in which they were shown five emotional faces selected randomly from the prime stimuli and had to verbally indicate what emotion the face displayed.

Results

Data Reduction

The dependent variable in the current study was the reaction time (RT) to the target words. A +/- 2.5 SD rule was applied to the mean RT per participant, with trials outside of this range considered outliers and were removed from the analysis (ASD, 5%; TD, 7% of trials). The data of any participants with an error rate of more than 30% were also excluded (ASD, n=1; TD, n=1). As revealed in the post-study session, all participants were able to correctly identify and name emotions displayed by the characters.

Data Analysis

The data were analysed using a mixed 2x2x2 ANOVA with Facial Expression Prime (Joy onset and Anger onset) and Target Word (Positive and Negative) as within-subject factors and Group as a between-subject factor (TD and ASD). The results are presented in Figure 43.

The main effect of Facial Expression Prime was not significant ($F_{1,41} = 3.02$, $p = .090$, ηp2 = .069). Similarly, the main effect of Target Word was also not significant ($F_{1,41} = 2.73$, $p = .106$, ηp2 = .062). However, a significant interaction between Facial Expression Prime and Target Word was found ($F_{1,41} = 10.39$, $p =.002$, $\eta p^2 = .202$), indicating that priming has occurred. Follow-up t-test revealed that negative words were evaluated faster when they were preceded by Neutral-to-Anger emotional sequence (*M*=610.60; *SD*=110.11), than when they were preceded by Neutral-to-Joy sequence (*M*=645.88, *SD*=120.92), $t(42) = 3.60$, $p = .002$, $d = 0.55$). The opposite trend was observed for positive words, which were evaluated faster when preceded by a Neutral-to-Joy sequence (*M*=631.56, *SD*=136.04), than when they were preceded by Neutral-to-Anger emotional sequence (*M*=647.86; *SD*=127.02),

$t(42) = 1.98$, $p = .055$, $d = 0.30$. However, the Bonferroni adjustment meant this effect was no longer significant.

Most importantly, the three-way interaction between Facial Expression Prime, Target Word and Group was not significant ($F_{1,41} = 1.21$, $p = .279$, ηp2 = .189), suggesting that both groups exhibited similar priming effects. There was a trend for ASD individuals to exhibit overall longer RTs ($M = 673.81$, $SD = 139.58$) than typically-developed individuals ($M = 605.30$, $SD = 89.71$) but the main effect of Group did not reach significance ($F_{1,41} = 3.84$, $p = .057$, ηp2 = .086). All remaining interactions were also non-significant (all p's >.074).

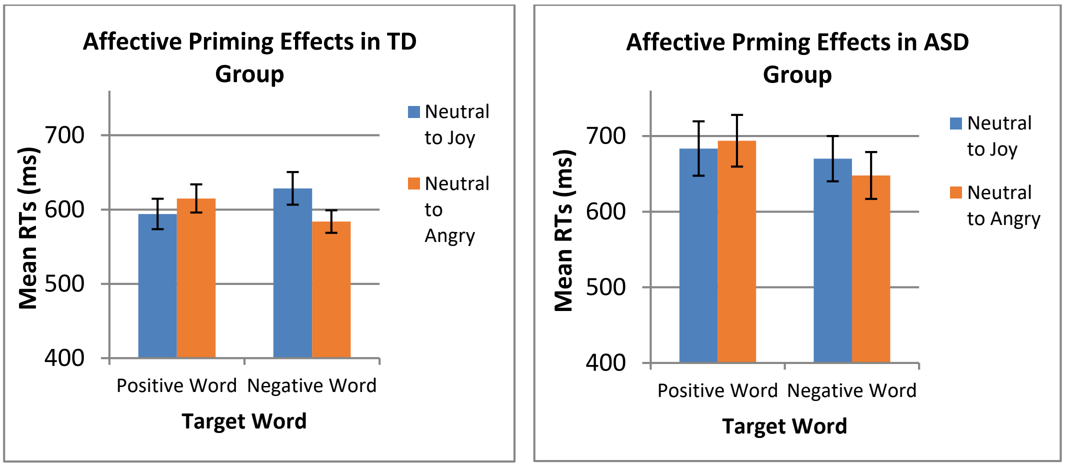


Figure 43 The mean RTs for each Prime/Target combination in TD Group (left panel) and ASD group (right panel). Positive words were consistently evaluated faster when preceded by Neutral-to-Joy sequences than when preceded by Neutral-to-Anger sequences. The opposite pattern is observed for Negative words. Error bars represent SE.

Analysis of Errors

Examination of the errors made in evaluating the word valences showed that the most errors were made in response to the positive words preceded by Neutral-to-Angry video sequences (on average 2.4% of trials). There were no significant differences in the accuracy between the TD (7.3% of trial errors) and ASD group (6.2% of trial errors; $t(41) = .71$, $p = .484$). However, there was a trend in TD group to produce more errors in response to incongruent as compared to congruent trials

($t(24) = 1.99$, $p = .059$, $d = 0.40$). This was not observed in ASD group ($t(17) = .78$, $p = .447$, $d = 0.18$; see Figure 44).

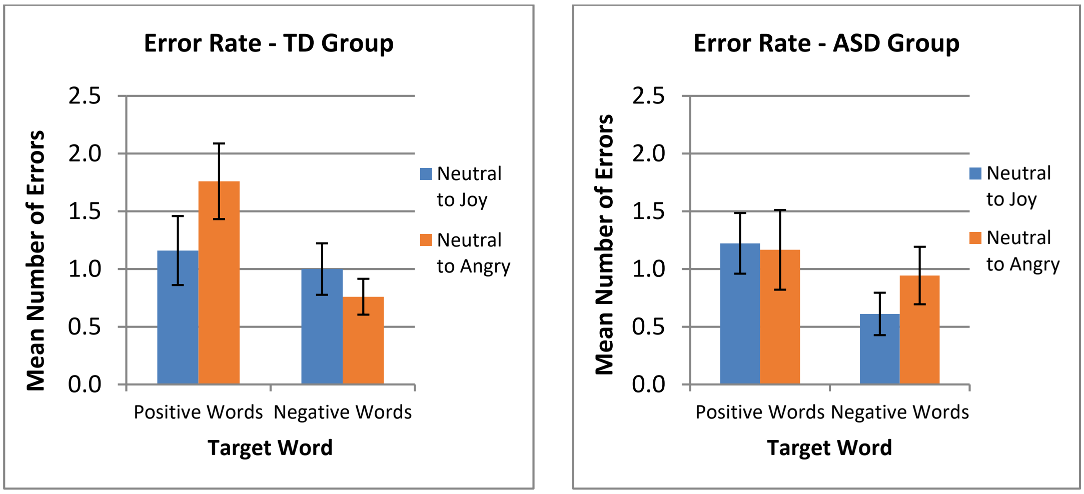


Figure 44 The mean number of errors for each Prime/Target combination in TD Group (left panel) and ASD group (right panel).

Discussion

The aim of this study was to investigate the automatic processing of emotional information contained within a dynamic video sequence of facial expressions and the extent to which this influences the subsequent evaluation of emotionally-charged words. The results revealed that in typically developed participants, dynamic sequences of emotional facial expressions implicitly influenced subsequent cognitive information processing. This was illustrated by the increased reaction times to the incongruent trials, suggesting that dynamic facial expressions interfered with the evaluation of the target words if the valence of the prime/target pairs was conflicting and/or facilitated the evaluation when there was no conflict. Surprisingly, a very similar pattern of results was observed in the ASD group. This contradicts our hypothesis and suggests that ASD individuals may be capable to automatically incorporate the affective valence of emotional facial expression. Alternatively, it could mean that they used a different strategy that led to the same response outcome.

Faster and more accurate evaluations of the target words when the affective valence of the facial expressions matched the emotional connotation of the words suggest that the affective information contained within the faces has been processed, despite the fact that they were not relevant to the task at hand. This finding further supports the claim that facial expressions are processed automatically in ASD, without the need for deliberate cognitive processing (e.g. Kamio et al., 2006). It suggests that automatically extracted valence has a capacity to alter cognitive processing in both TD and ASD, at least during the short period immediately following the prime.

Contrary to our predictions, affective priming was also found in the ASD group. This finding seems to contradict the notion of impairment in automatic processing of social cues in ASD (Jellema et al., 2009; Kamio et al., 2006; Schneider et al., 2013; Senju et al., 2009). The affective priming effect observed in individuals with ASD suggests that not only were they able to automatically process emotional information but also to incorporate it into their cognitive processing in a similar manner as seen in typically-developed individuals. However, it is also possible that an alternate strategy employed by ASD individuals could explain the obtained results.

<u>Perceptual Processing of Facial Expressions in ASD</u>

It has been argued that individuals with ASD may adopt systemizing mechanisms to understand other people's behaviour relying on low-level visual characteristics, rather than emotional attributions (Baron-Cohen, 2002; Hudson, Burnett, et al., 2012). Social cues can be processed perceptually on the basis of the dynamic mechanistic descriptions they offer, such as physical or geometrical features (Jellema & Perrett, 2006). In typical development, the low-level perceptual processing then triggers inferences about emotional states of others. In could be that ASD individuals rely on a bottom-up perception of social cues and infer emotional states of others on the basis of physical characteristics (i.e. the bottom-up route), in the same manner as they would process non-social objects (Baron-Cohen, 2002; Jellema & Perrett, 2006).

It has been found that dynamic sequences of facial expressions are capable of inducing perceptual distortions, which can be either a result of bottom-up processes in the perception of social cues (Yoshikawa & Sato, 2008), or of top-down processes, in which attribution of other's mental states influence low-level perception

(Hudson, Liu, et al., 2009; Jellema et al., 2011; Palumbo et al., 2015, 2018; Palumbo & Jellema, 2013; Teufel et al., 2009). Yoshikawa and Sato (2008) found that video sequences of facial expressions morphing from a neutral expression to emotion changed the perception of the final emotional frame of the video to a more exaggerated form. Participants consistently overestimated the emotional expression, in the direction of the emotional change. For example, in the neutral to joy sequences, agent's facial expression in the final frame was perceived as more intensely joyful than was actually the case, as indicated by participants' responses on an interactive slider. Further to this, the size of the overestimation of the final emotional expression was proportional to the video morphing speed. The effect was interpreted as a low-level visual mechanism called representational momentum (RM), a phenomenon in which the final position of moving object shifts in the perceiver's mind in the direction of the observed movement (Freyd & Finke, 1984). In a replication of Yokashiwa and Sato's study (2008), Uono et al. (2010) found that individuals with the perversive developmental disorder are equally susceptible to this perceptual distortion (Uono, Sato, & Toichi, 2010). It is possible that the low-level perception of the literal value of the faces interfered with the cognitive appraisal of subsequent emotional words, resulting in affective priming effects observed in this study. The next experiment will investigate this possibility.

7.2 Experiment 12

One way to explain the response biases found in the ASD group in Experiment 11 is to assume a mechanistic or literal processing mode in individuals with ASD. That is, a low-level visual perception of the facial stimuli could have been sufficient to produce affective priming effects, without the need to infer anything concerning the agent's emotional state of mind and keep track of changes in the agent's emotional state. To disentangle the effects of perceptual processing of social cues and the automatic attribution of emotional states, this study employed a paradigm first introduced by Jellema et al. (2011), in which a perceptual distortion of neutral facial expressions is induced by the immediately preceding perceptual history.

In this paradigm, the video sequences display an intense emotional expression (joy or anger) gradually morphing into a neutral facial expression. Interestingly, when asked to judge the final frame of the video sequences, participants consistently judged the identical neutral expressions as slightly angry when they were immediately preceded by video-sequences in which the expression morphed from joy-to-neutral and as slightly happy when the expression morphed from anger to neutral (Jellema et al., 2011). That is, the same neutral expression was perceived differently based on the immediately preceding perceptual history. This effect was referred to as the 'overshoot bias' and interpreted as a result of emotional anticipation, in which an observer is keeping track of any changes in the agent's emotional state of mind and continually updates their prediction of the most likely next emotional state of mind. It seems that the observers made an implicit assumption that in the joy-to-neutral sequence emotional state is moving towards a negative state. Likewise, in the anger-to-neutral sequence emotional state is moving towards a positive state.

Even though Joy-to-Neutral sequences were found to induce the perception of slight anger, it is important to note that they do not contain any angry values at any point of the sequence, therefore the physical properties of angry faces are absent from the videos. Similarly, in Anger-to-Neutral sequences, which seem to induce perceptual distortion of joy, the actual emotional expression of joy is not shown at any point. Therefore, for the 'overshoot' priming effect to occur (Jellema et al., 2011) processing of the agent's emotional state of mind is required and relying on just the physical properties of the facial stimuli is not enough. Thus Experiment 12 investigated which aspect of the prime stimuli in Experiment 11 was the most effective: (1) the literal face value of the stimuli (joy = positive, anger = negative, similar to an emoticon) or (2) the underlying emotional state of mind.

It was hypothesised that typically-developed individuals will continue to show affective priming effects with the reversed video sequences as primes, as they will automatically grasp the underlying emotional state of the actors (Jellema et al., 2011), what one could call a kind of low-level mindreading (Goldman, 2006). In contrast, it was hypothesised that this effect will be reduced, or even removed completely, in ASD individuals, as they will not engage in the low-level mindreading process and instead will rely on the physical facial features (which, if anything, indicate positivity for a joy offset, and negativity for an anger offset).

Methods

Participants

A total of 56 undergraduate students took part in Experiment 12. Twenty-four ASD individuals were recruited through Disability Services at Hull University. After applying exclusion criteria, one ASD participant was excluded from the analysis (see below). The final ASD sample consisted of eight women and fifteen men, with a mean age of 19.78 (SD = 1.24), a mean total IQ score of 116.26 (SD = 9.10) and a mean ADOS score of 8.57 (SD = 1.70).

The control group consisted of 32 participants, matched for age, sex and intellectual abilities. After applying exclusion criteria (see below), the data of thirty-one participants were included in the analysis (eighteen women, thirteen men), with a mean age of 20.51 (SD = 2.42) and a mean total IQ score of 115.26 (SD = 6.89). The ASD and TD groups did not differ significantly in terms of age ($t(52) = 1.33$, $p = .190$), gender ratio ($X_2(1, N =54) = 2.87$, $p = .090$) nor IQ ($t(52) = .467$, $p = .320$). The AQ scores were significantly higher in the ASD group than in the TD group ($t(34.97) = 8.43$, $p < .001$). Participants' characteristics are presented in Table 10.

Table 10 Participants' characteristics.

	AGE	SEX	IQ-total	AQ	ADOS
ASD GROUP (n = 23)	19.78 (1.24)	8 women 15 men	116.26 (9.10)	32.09 (7.92)	8.57 (1.70)
TD GROUP (n = 31)	20.51 (2.42)	18 women 13 men	115.26 (6.89)	16.19 (5.06)	-

Stimuli and procedure

The video sequences in Experiment 12 were similar to those presented in Experiment 11 but shown in reverse order. The videos started with a maximally joyful or maximally angry expression presented for 200ms, followed by the morphing sequence (nine frames of 25ms each), ending in a neutral facial expression, which remained on the screen until a response was made, but for no longer than 3000ms (see Figure 45). All further details of the face and prime stimuli remained the same as in Experiment 11.

Post-study session: After the main study task, participants completed a short session, in which they were shown five emotional faces selected randomly from the prime stimuli and had to verbally indicate what emotion the face displayed.

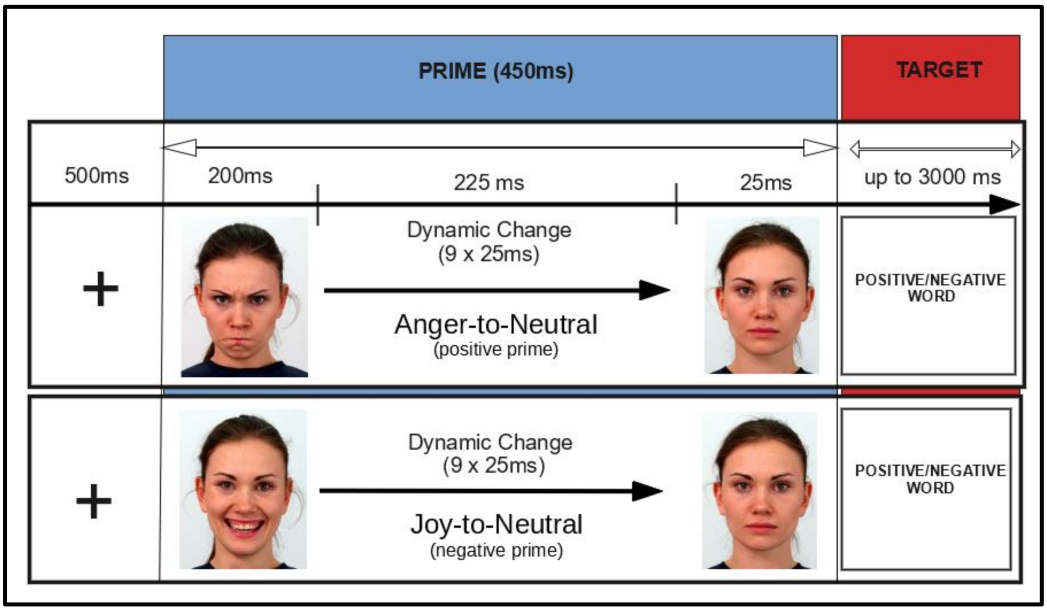


Figure 45 Illustration of the stimulus presentations in Experiment 12. Anger-to-Neutral video sequences started with a facial expression of intense joy, which gradually morphed into a neutral expression (top panel). Joy-to-Neutral videos started with a facial expression of intense anger, which gradually morphed into a neutral expression (bottom panel). As in Experiment 11, video sequences were followed by a word, which either matched the final expression in terms of valence (congruent trials) or mismatched the final expression (incongruent trials).

Results

Data Reduction

The dependent variable in the current study was the reaction time (RT) to the target words. A +/- 2.5 SD rule was applied to the mean RT per participant, with trials outside of this range considered outliers and were removed from the analysis (ASD, 5%; TD, 5%). The data of any participants with an error rate of more than 30% were also excluded (ASD, n=1; TD, n=1). As revealed in the post-study session, all participants were able to correctly identify and name emotions displayed by the characters.

Data Analysis

The data were analysed using a mixed 2x2x2 ANOVA Facial Expression Prime (Anger-offset and Joy-offset) and Target Word (Positive and Negative) as within-subject factors and Group as a between-subject factor (TD and ASD). The results are presented in Figure 46.

The main effect of Facial Expression Prime was not significant ($F_{1,52}$ = .360, p =.551, ηp^2 = .007). However, there was a significant main effect of Target Word, with negative words evaluated faster overall (M = 674.18, SD = 120.03) than positive words (M= 695.32, SD = 150.98), $F_{1,52}$ = 8.16, p = .006, ηp2 = .136. The interaction between Facial Expression Prime and Target Word was not significant ($F_{1,52}$ = 2.41, p =.125, ηp^2 = .045).

However, a significant 3-way interaction between Facial Expression Prime, Target Word and Group was found ($F_{1,52}$ = 5.67, p =.021, ηp2 = .098). Therefore, the two groups were analysed separately using 2x2 ANOVAs.

TD group: The main effect of Facial Expression Prime was not significant ($F_{1,30}$ = .07, p = .937, ηp2 = .001). Similarly, the main effect of Target Word was also not significant ($F_{1,30}$ = .658, p = .424, ηp2 = .021). However, the results revealed a significant interaction between the two factors ($F_{1,30}$ = 10.54, p = .003, ηp2 = .258). Follow-up t-test revealed that the typically-developed group evaluated positive words faster when they were preceded by Anger-offset (*M*=646.8; *SD*=111.3), than when they were preceded by Joy-offset (*M*=669.68, *SD*=116.35), $t(30)$ = 2.95, p = .012, d = 0.53. The opposite trend was observed for negative words, which were evaluated faster when preceded by a Joy-offset (*M*=638.71, *SD*=92.65), than when they were preceded by an Anger-offset (*M*=662.56; *SD*=107.31), but this effect was no longer significant after applying Bonferroni corrections ($t(30)$ = 2.19, p = .072, d = 0.39).

ASD group: The main effect of Facial Expression Prime was not significant ($F_{1,22}$ = .54, p = .470, ηp2 = .024). However, there was a significant main effect of Target Word ($F_{1,22}$ = 8.87, p = .007, ηp2 = .287). Importantly, the priming effects were absent in ASD individuals, as demonstrated by the non-significant interaction between Facial Expression Prime and Target Word ($F_{1,22}$ = .25, p = .622, ηp2 = .011). ASD group evaluated positive words in a similar timeframe, regardless of whether they were preceded by Anger-to-Neutral emotional sequence (*M*=731.35; *SD*=193.57), or by Joy-to-Neutral sequence (*M*=733.43, *SD*=185.60), $t(22)$ = .147, p = .885. A similar pattern was observed for negative words, with ASD individuals evaluating negative words even marginally faster when preceded by an Anger-offset (*M*=691.83, *SD*=139.60) compared to joy-offset (*M*=703.65; *SD*=156.21). However, this effect was non-significant ($t(22)$ = .917, p = .369). The main effect of the group and remaining interactions were all non-significant (p's > .073).

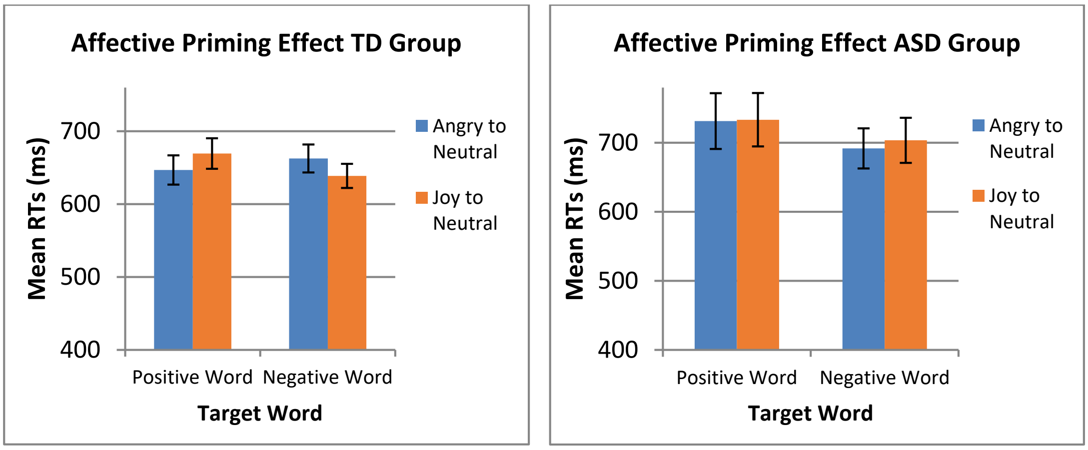


Figure 46 The mean RTs for each Prime/Target combinations in TD Group (left panel) and ASD group (right panel). Positive words are consistently evaluated faster when preceded by Anger-to-Neutral sequences than when preceded by Joy-to-Neutral sequences. The opposite pattern is observed for Negative words. Error bars represent SE.

Analysis of Errors

Examination of the errors made in evaluating the word valences showed that most errors were made in response to the positive words preceded by Joy-to-Neutral video sequences (on average 2.5% of trials). There were no significant differences in the accuracy between the TD (7.5% of errors) and ASD group (7.5% of errors; $t(47)$ =

.00, p = .998, d = 0.00). Both groups produced slightly more errors in response incongruent trials than congruent trials, however these differences were not significant (TD: $t(30)$ = 1.08, p = .290, d = 0.19; ASD: $t(17)$ = 1.46, p = .163, d = 0.34; see Figure 47).

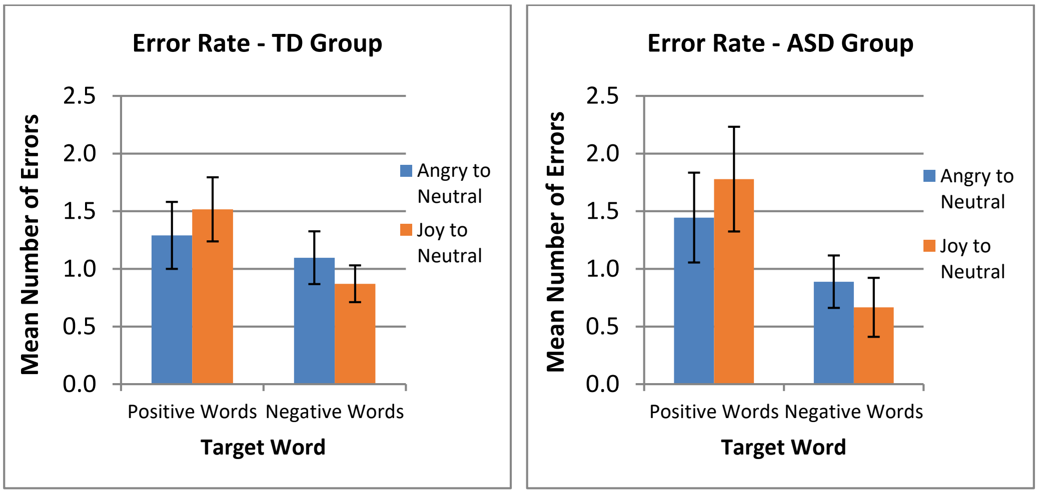


Figure 47 The mean number of errors for each Prime/Target combination in TD Group (left panel) and ASD group (right panel).

Discussion

This study compared automatic emotional processing between ASD and typically developed individuals as they evaluated emotionally-valenced words following the exposure to dynamic sequences of facial expressions morphing from intense emotion (joy or anger) to a neutral expression, which were essentially the reverse of the video sequences used in Experiment 11. typically-developed individuals exhibited a priming effect, especially when evaluating positive target words. However, the priming effect was removed in ASD individuals, even though it was observed in the previous experiment.

Emotional Anticipation

The facilitation of the evaluation of positively-charged words when preceded by anger offsets, and the facilitation of the evaluation of negatively-charged words, when preceded by joy offsets, could reflect an emotional anticipation (Jellema et al., 2011; Palumbo et al., 2015, 2018; Palumbo & Jellema, 2013). That is, it seems that participants anticipated a continuation in the change in the emotion of the observed faces based on the perceptual history, which resulted in the affective priming effects.

However, it could be argued that the affective priming effect may be caused by low-level visual mechanisms such as sequential contrast effects, representational momentum and adaptation, rather than a high-level emotional anticipation effect. In a series of studies, Palumbo and colleagues investigated the possibility of the potential contributions these mechanisms to the distortions in the perception of neutral facial expressions at the endpoint of joy-to-neutral and anger-to-neutral sequences (Palumbo et al., 2015, 2018; Palumbo & Jellema, 2013). These studies consistently reported the 'overshoot bias' in response to the video sequences in the original task and by applying different manipulations to the original task concluded that the low-level visual mechanisms do not sufficiently explain the observed response biases. The results supported the emotional anticipation of the most likely future emotional state, based on immediate perceptual history (low-level mindreading), as the most plausible explanation. It seems that the process of involuntary emotional anticipation affects the evaluation of the final neutral expressions, such that joy offsets lead to the anticipation of the continuation of the emotional state into a negative emotional state. Emotional anticipation can be seen as low-level mindreading, which may reflect involuntary simulation processes (Goldman, 2006), enabling intuitive understanding of another's the emotional state of mind.

Lack of Priming Effect in ASD

The most important finding of Experiment 12 is that no priming effects have been found in the ASD group. This may be due to (1) participants did not keep track of the changes in the emotion of the observed agents and did not implicitly assume the agent's mood to continue along the observed trajectory (into negativity for joy-offsets and into positivity for anger-offsets) (2) the affective evaluation of emotional faces was somehow ignored and did therefore not interfere with the subsequent cognitive processing of the affective target words. However, given that in Experiment 11 the ASD group did show an affective priming effect, which means that they did not ignore the facial prime stimuli, it is highly likely they also did not ignore the primes in Experiment 12.

Interestingly, prior studies using joy and anger offsets showed that the ASD individuals are prone to an overshoot bias to the same extent as typically developed controls when asked to visually evaluate the last, neutral, frame of the clips on a scale running from slightly happy to slightly angry (Palumbo et al., 2015; Palumbo et al., 2018). However, rather than being linked to the attribution of emotional states to others, the overshoot bias in ASD was argued to result from sequential contrast effects (Palumbo et al., 2015; Palumbo et al., 2018). It was found that a change of the identity in the final frame of the video sequences removed the overshoot bias in the TD group, but not in the ASD group (Palumbo et al., 2015). Similarly, further experimentation revealed that the overshoot bias in ASD participants could not be explained by a representational momentum effect nor by pattern extrapolation. This left the contrast effect, i.e. the contrast between the first and final frame of the videos, which were both shown for a relatively long time (400ms), as the most plausible explanation for the observed overshoot effect in the ASD group (Palumbo et al., 2018).

It is remarkable that even though the ASD individuals report an 'overshoot' effect when visually evaluating the last frames of these emotion-offset clips (Palumbo et al., 2015), they do not show an affective priming effect in response to the same clips presented in Experiment 12. Thus, even though the individuals with ASD verbally reported seeing an 'overshoot', i.e. perceiving the neutral expression in the Joy-offsets as slightly angry, this illusionary perception did not affect their responses in the affective priming study. Possibly these perceptual overshoot effects were too weak to influence the priming process. Clearly, in the joy and anger onset videos, the perception of the full-blown emotion at the end of the clip is very intense, which may have ensured a priming effect occurs in the ASD group in that condition (Experiment 11).

One explanation for the response behaviour of the ASD individuals in the affective priming studies is that they processed the prime stimuli literally, meaning that their responses were limited to the physical features of the expressed emotions, without taking into account what this meant for the emotional state of mind of the agent (they didn't automatically/implicitly go beyond the facial expression per se). Furthermore, their priming responses may have particularly be determined by the later part of the prime sequence, the part that immediately preceded the target word. This would explain the presence of an affective priming effect in Experiment 11, as for that effect to happen changes in the agent's emotional state of mind do *not* have to be taken into account. That is, the prime stimulus can be seen as a kind of emoticon, simply representing either a positive or negative value. It would also explain the absence in the ASD group of a priming effect in Experiment 12 because there the emoticon approach would not work, as the last part of the prime consisted of a neutral expression (neutral would not produce any priming effects). If anything, an emoticon approach might even have led to priming effects in Experiment 12 that are congruent with the overall (mean) emotion literally displayed in the clip, which is mildly positive for the joy-offset and mildly negative for the anger-offset clips. The only way to achieve the affective priming effect in Experiment 12 (as seen in the TD group) is to keep track of the changes in the agent's emotional state of mind (i.e. low-level mindreading) and interpret the clip accordingly. That is, to interpret the joy-offset clips as a negative social signal (the agent's emotional state of mind is heading towards a negative state) and to interpret the anger-offset clips as a positive social signal (the agent's emotional state of mind is heading towards a positive state). If this capacity is compromised in ASD then no affective priming effect should be observed, which is what we found.

All in all, the results from Experiment 12 suggest that ASD individuals may not be automatically affected by the emotional significance of the observed facial expressions. However, atypicalities in social functioning are well established in ASD, and therefore the study results might have been contaminated by other aspects of the social perception that interfered with emotional processing, such as diminished social motivation or attention. Therefore, a more fruitful approach would be to examine emotional processing outside of the social context, which will be attempted in Experiment 13.

7.3 Experiment 13

Affective responses that accompany salient events in one's environment influence learning about the hedonic significance of these events and may lead to the development of approach/avoidance tendencies. Disruption of emotional processes would, therefore, have far-reaching consequences, of which atypicalities in social cognition observed in ASD could be a mere example. Yet, there have been only a handful of studies that examined emotional processes in ASD outside of a social context.

One example of stimuli capable of inducing affective responses that are not specifically tied to the social domain is music. Evidence suggests that ASD individuals enjoy listening to music for the same reasons as typically—developed individuals and report reach emotional experiences in response to music (Allen, Hill, & Heaton, 2009a). Behavioural studies further support that ASD process contour and intervals in music just as well as typically-developed individuals (Heaton, 2005) and have often been found to display heightened perception of musical stimuli compared to their TD peers and superior pitch processing (Bonnel et al., 2003; Caria, Venuti, & De Falco, 2011; Heaton, 2005; Heaton, Pring, & Hermelin, 1999; Mottron, Peretz, & Menard, 2000; Stanutz, Wapnick, & Burack, 2012; Witt et al., 2002). Importantly, a plethora of studies show that they are able to correctly identify a wide range of emotions in musical excerpts (Allen, Hill, & Heaton, 2009b; L. Gebauer, Skewes, Westphael, Heaton, & Vuust, 2014; Quintin, Bhatara, Poissant, Fombonne, & Levitin, 2011) and show intact physiological responses to music (Allen, Davis, & Hill, 2013). This suggest that musical stimuli would be perfectly suited for studying implicit processing of affective cues in ASD.

Music is an incredibly versatile form of communication and is that has long been an integral part of society. Studies found that emotion in music can be recognised very fast, even under one second (Daltrozzo & Schön, 2009). Specific acoustic features of music such as pitch, tempo and intensity are connected with affective connotations, which communicate discrete emotions in musical stimuli (Ilie & Thompson, 2006). Models of music processing suggest that every musical feature is capable of expressing an emotion; even short sequences of tones or chords can differ in affective reactions they evoke, which in turn activate associated meaningful concepts (Koelsch & Siebel, 2005; Sollberge, Rebe, & Eckstein, 2003).

Musical chords consist of two or more tones sounding simultaneously. The regularity of frequency ratios with which the simultaneously presented tones resonate is referred to as harmonic roughness (Plomp & Levelt, 1965). Simultaneous tone combinations can be categorised as either consonant, producing pleasant, 'stable' sound sensation and perception of tonal fusion, or dissonant, often described as unpleasant, harsh, grating sound. Research studies report sensitivity to consonance and dissonance both in infants (Schellenberg & Trehub, 1994; Trainor, Tsang, & Cheung, 2002; Virtala, Huotilainen, Partanen, Fellman, & Tervaniemi, 2013; Zentner & Kagan, 1996) and adults (Koelsch, Gunter, Friederici, & Schröger, 2000; Minati et al., 2009; Peretz & Zatorre, 2005). This opens a possibility that the ability to perceive consonance and dissonance may be innate. Moreover, functional imagining revealed that consonant/dissonant stimuli elicit activity changes in limbic and paralimbic brain structures involved in emotional processing (Blood, Zatorre, Bermudez, & Evans, 1999; Koelsch, 2006), further supporting the notion that harmonic roughness contains information capable of signalling affective categories, such as pleasantness and unpleasantness.

While individual musical chords do not resemble music as such, they represent fundamental constituents of music. Previous studies showed that consonant and dissonant chords have the capacity to activate affect automatically in typical individuals and in turn influence processing of subsequently presented words (Goerlich et al., 2012; Sollberge et al., 2003; Steinbeis & Koelsch, 2008, 2011). This effect was demonstrated through the use of affective priming paradigm, where played musical chords were used as prime stimuli, which were followed by the affectively charged words to be speedily categorised on the basis of their valence.

With the means of such affective priming paradigm, the current study used consonant and dissonant chords to explore automatic affective responses in ASD individuals as compared to typically-developed control group. It was hypothesised that in line with previous findings, typically-developed participants will evaluate emotional words, whose valence is congruent with that of the affect expressed by preceding chord, faster than emotional words that are incongruous with the affect of the preceding chord. If disruption in automatic emotional processing is somehow constrained to social contexts, similar priming effect should be observed in the ASD group. However, if more widespread abnormalities in automatic processing of emotions exist in ASD, no priming effect should be observed in this group.

Methods

Participants

A total of 62 undergraduate students took part in Experiment 13. Twenty-six ASD individuals were recruited through Disability Services at Hull University. It was established that none of the participants suffered from sensitivity to sounds. After applying exclusion criteria four ASD participants were excluded from the analysis (see below). The final ASD sample consisted of seven women and fifteen men, with a mean age of 19.77 (*SD* = 1.11), a mean total IQ score of 115.20 (*SD* = 9.43) and a mean ADOS score of 9.45 (*SD* = 2.58).

The control group consisted of 36 participants, matched for age, sex and intellectual abilities. After applying exclusion criteria (see below), the data of 31 participants were included in the analysis (seventeen women, fourteen men), with a mean age of 19.35 (SD = 1.66) and a mean total IQ score of 114.02 (*SD* = 6.45). The ASD and TD groups did not differ significantly in terms of age ($t(51) = 1.03$, $p = .310$), gender ratio ($X_2(1, N = 53) = 2.75$, $p = .097$) nor IQ ($t(51) = .545$, p = .588). The AQ scores were significantly higher in the ASD group than in the TD group ($t(51) = 9.53$, $p < .001$). Participants' characteristics are presented in Table 11.

Table 11 Participants' characteristics.

	AGE	SEX	IQ-total	AQ	ADOS
ASD GROUP (n = 22)	19.77 (1.11)	7 women 15 men	115.20 (9.43)	33.82 (7.04)	9.45 (2.58)
TD GROUP (n = 31)	19.35 (1.66)	17 women 14 men	114.02 (6.45)	16.45 (6.16)	-

Stimuli

The primes consisted of sixteen chords of piano timbre, of which eight were consonant and therefore, pleasant sounding and eight were dissonant, and therefore, unpleasant sounding. The chords were created using methods presented in Steinbeis and Koelsch (2011) and were recorded and modified with Logic Pro 8 software (sampling rate = 44.1 kHz; 16-bit resolution). The target stimuli consisted of positive and negative words selected on the basis of their valence, arousal and frequency ((Bradley et al., 1999). The valence, arousal and frequency of the words were matched between the two conditions (consonant and dissonant chords; Jellema et al., 2011). There were 32 positive and 32 negative words. In one version of the experiments, half of the words were preceded by a congruent prime and the other half by the incongruent prime. In the second version of the experiment, the words were swapped, in such a way that half of the words previously preceded by a congruent prime were now preceded by an incongruent prime and vice versa. Half of the participants completed the first version of the experiment and the other half completed the second version of the experiment.

Procedure

Each trial began with the presentation of a fixation cross at the centre of the computer screen approximately 60cm in front of them. The primes were played for 225ms through headphones and were immediately followed by the target words appearing on the computer screen, which remained there until a response was made, but for no longer than 3000ms (see Figure 48). The targets could affectively match the prime: positive prime/positive target, negative prime/negative target (congruent trials) or affectively mismatch: positive prime/negative target, negative prime/positive target (incongruent trials). Participants were instructed to respond as fast as possible by evaluating the target words as either positive or negative (using two keys on the keyboard labelled with ‘positive’ and ‘negative’).

Post-study session: After the main study task, participants completed a short session, in which they were played five chords selected randomly from the prime stimuli and had to verbally indicate whether the chord was pleasant or unpleasant sounding. The purpose of the session was to ensure that participants were capable of differentiating between affective value contained in the chords.

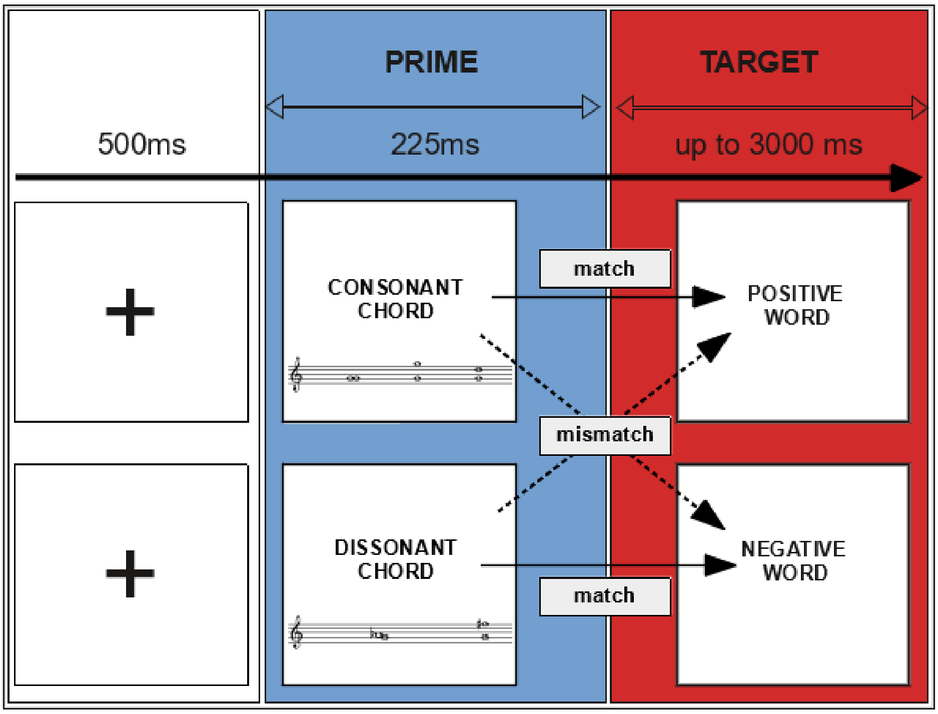


Figure 48 Illustration of stimulus presentation in Experiment 13.

Results

Data Reduction

The dependent variable in the current study was the reaction time (RT) to the target words. A +/- 2.5 SD rule was applied to the mean RT per participant, with trials outside of this range considered outliers and were removed from the analysis (ASD, 4%; TD, 5%). The data of any participants with an error rate of more than 30% were also excluded (ASD, n=3; TD, n=3). Participants, who failed to correctly categorise at least 60% of the chords in the post-study session were not included in the analysis (ASD, n=1; TD, n=2). [6]

[6] On average, typically developed participants correctly categorised 83% of chords in the post-study session, whereas ASD participants correctly categorised 90% of chords.

Data Analysis

The data were analysed using a mixed 2x2x2 ANOVA Chord Prime (Consonant and Dissonant) and Target Word (Positive and Negative) as within-subject factors and Group as a between-subject factor (TD and ASD). The results are presented in Figure 49.

There was a main effect of Chord Prime, with consonant primes facilitating the faster response times (M= 606.29, SD = 85.02) than dissonant primes (M= 615.64, SD = 95.49, $F_{1,51} = 4.79$, $p = .033$, $\eta p^2 = .086$). The main effect of Target Word was also significant, with negative words evaluated faster overall (M = 579.81, SD = 98.42) than positive words (M= 624.12, SD = 150.98, $F_{1,51} = 13.50$, $p = .001$, $\eta p2 = .201$). Importantly, this was qualified by a significant interaction between Chord Prime and Target Word ($F_{1,51} = 12.11$, $p = .001$, $\eta p^2 = .192$), suggesting that priming has occurred.

Further, a significant 3-way interaction between Chord Prime, Target Word and Group was found ($F_{1,52} = 5.77$, $p = .020$, $\eta p2 = .102$). Therefore, the two groups were analysed separately using 2x2 ANOVAs.

TD group: The main effect of Chord Prime was not significant ($F_{1,30} = 1.60$, $p = .216$, $\eta p2 = .051$). However, there was a significant main effect of Target Word, with negative words evaluated faster than positive words ($F_{1,30} = 10.68$, $p = .003$, $\eta p2 = .263$). Further to this, a significant interaction between the two factors was found ($F_{1,30} = 10.54$, $p = .003$, $\eta p2 = .258$). Follow-up t-test revealed that the typically-developed group evaluated positive words faster when they were preceded by consonant chords (*M*=557.07; *SD*=67.66), than when they were preceded by dissonant chords (*M*=595.74, *SD*=76.90, $t(30) = 6.37$, $p < .001$, $d = 1.14$). The opposite trend was observed for negative words, which were evaluated faster when preceded by a dissonant chords (*M*=539.85, *SD*=61.50), than when they were preceded by an consonant chords (*M*=568.86; *SD*=72.62; $t(30) = 4.56$, $p <.001$, $d = 0.82$).

ASD group: The main effect of Chord Prime was not significant ($F_{1,21} = 2.58$, $p = .123$, $\eta p2 = .110$). However, there was a significant main effect of Target Word ($F_{1,21} = 4.68$, $p = .042$, $\eta p2 = .182$). Importantly, the priming effects were absent in

ASD individuals, as demonstrated by the non-significant interaction between Chord Prime and Target Word ($F_{1,21}$ = .275, p = .605, ηp2 = .013).

The main effect of the group was significant, with ASD individuals being much slower at evaluating the target words (M= 656.56, SD = 87.76) in comparison to typically-developed group (M= 565.38, SD = 87.76; $F_{1,51}$ = 13.89, p <.001, ηp^2 = .214). All remaining interactions were all non-significant (p's > .296).

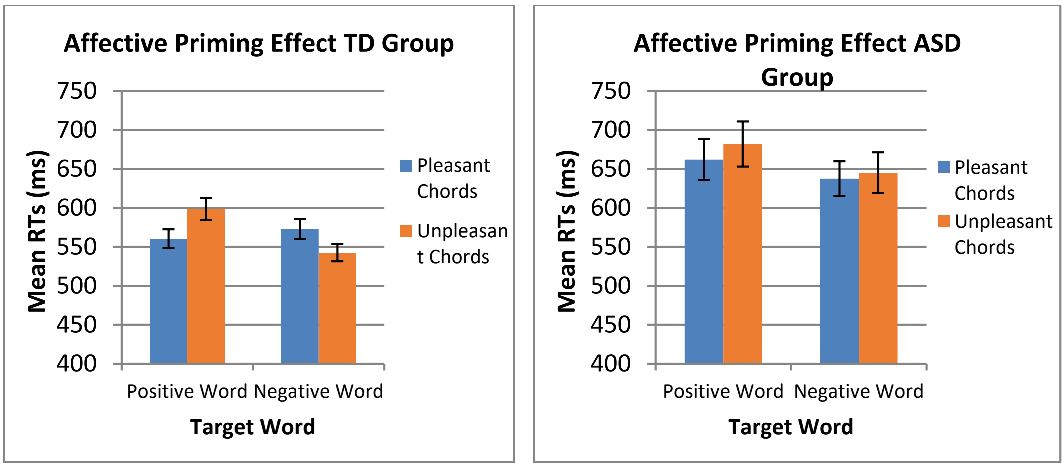


Figure 49 The mean RTs for each Prime/Target combinations in TD Group (left panel) and ASD group (right panel). Error bars represent SE.

Analysis of Errors

Examination of the errors made in evaluating the word valences showed that most errors were made in response to the positive words preceded dissonant chords (on average 2.6% of trials). There were no significant differences in the accuracy between the TD (8.5% of errors) and ASD group (6.3% of errors; t(50) = 1.00, p = .322, d = 0.28). However, a paired samples t-tests revealed that TD individuals made more errors on incongruent trials than congruent trials (t(29) = 2.82, p = .008, d = 0.68), while this was not the case in ASD group. The mean error rates for both groups are presented in Figure 50.

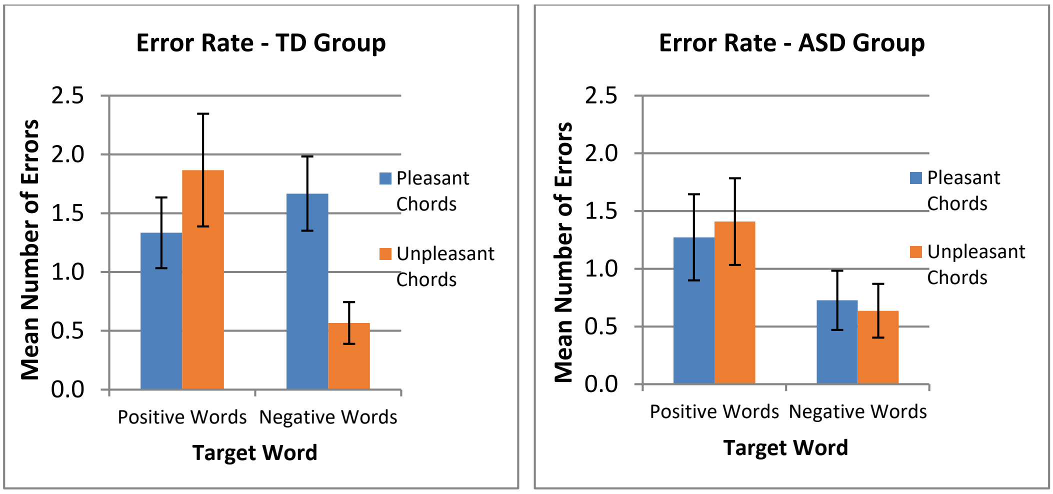


Figure 50 The average number of errors for each Prime/Target combinations in TD Group (left panel) and ASD group (right panel).

Discussion

The current study investigated automatic responses to affective value in consonant and dissonant chords in ASD individuals as compared to matched control subjects to determine whether individuals with ASD were capable to automatically affected by the emotional significance of presented chords. Results revealed evidence of affective priming in typically-developed individuals, corroborating previous findings, while this effect was absent in of priming in individuals with ASD. Importantly, both groups were capable to successfully categorise musical chords on the basis of their affective value in the post-study session when explicitly asked to do so. This suggests that both groups were equally perceptive to the emotional cues contained in the chords used in this experiment, eliminating the possibility that lack of priming in individuals with ASD was the result of diminished ability to recognise pleasant and unpleasant musical chords.

These findings provide initial evidence for a more widespread abnormalities in automatic processing of emotions in ASD, which are not necessarily constrained to social information. It seems that individuals with ASD were not influenced by the affective value of the consonant and dissonant chords, and thus, were able to categorise subsequent emotional words without the interference of the prime stimuli. This opens a possibility that implicit emotional processing may be impaired in ASD, with the majority of atypicalities observed in the social domain because of the fact that social information is often inherently emotionally-charged.

Alternatively, it could be argued that cross-modal version of the affective priming paradigm used in this study, required coordination between visual and auditory domains, which may have negatively impacted the performance of the ASD group. Numerous fMRI studies provided evidence that individuals with ASD demonstrate dysfunctional integration within the circuitry involved in cognitive, perceptual and motor abilities, referred to as the underconnectivity theory (Just, Cherkassky, Keller, Kana, & Minshew, 2006; Just, Cherkassky, Keller, & Minshew, 2004; Kana, Keller, Cherkassky, Minshew, & Just, 2006; Minshew & Williams, 2007). This theory suggests that individuals with ASD lack general connectivity throughout the entire brain compared to typically developing peers. Therefore, the current task, which required coordinating auditory and visual information might have been problematic for ASD individuals.

At the same time, Just et al. (2004) argued that diminished interaction between different brain areas in ASD may be compensated for by enhanced development and strengthening of the independent and free-standing brain structures. Therefore, perception and learning that occurs within one modality (e.g. audition) might actually be better in individuals with ASD compared to individuals with TD. This prediction is consistent with studies reporting that individuals with ASD are less susceptible to the McGurk illusion, in which the perception of a speech sound is influenced by the simultaneous presentation of incongruent visual speech articulation, which has been observed despite typical auditory accuracy, suggesting preserved auditory perception in ASD (E. G. Smith & Bennetto, 2007; Taylor, Isaac, & Milne, 2010). This suggests deficits in audio-visual integration in individuals with ASD.

To eliminate the possibility of underconnectivity between the brain regions being responsible for lack of priming effect in ASD group, in Experiment 14, the affective priming paradigm was modified to occur within one modality.

7.4 Experiment 14

The aim of Experiment 14 was to establish whether the differences in priming with consonant and dissonant chords between TD and ASD individuals obtained in the previous study could be attributed to the cross-modal nature of the paradigm. To this end, target words were no longer presented visually but through the auditory means to match the modality of the musical chords.

If ASD individuals indeed struggled with the integration of visual and auditory information as predicted by underconnectivity theory, but their automatic processing of affective value from musical features is intact, typical priming effect should be observed with the new, modified paradigm. However, if individuals with ASD are still not influenced by the affective value of the consonant and dissonant chords, this would suggest that automatic processing of emotional values is compromised in ASD.

Methods

Participants

A total of fifty-six undergraduate students took part in Experiment 14. Eighteen ASD individuals were recruited through Disability Services at Hull University. After applying exclusion criteria (see below) one participant was excluded from the analysis. The final ASD sample consisted of four women and thirteen men, with a mean age of 19.76 (SD = 1.15), a mean total IQ score of 113.62 (SD = 9.78) and a mean ADOS score of 9.65 (SD = 2.15).

The control group consisted of twenty-eight participants, matched for age, sex and intellectual abilities. After applying exclusion criteria (see below), the data of twenty-four participants were included in the analysis (seventeen women, fourteen men), with a mean age of 20.58 (SD = 4.14) and a mean total IQ score of 113.21 (SD = 6.33).

The ASD and TD groups did not differ significantly in terms of age (t(39) = .792, p = .433), gender ratio (X_2(1, N =41) = 2.13, p = .144) nor IQ (t(39) = .173, p

= .864). The AQ scores were significantly higher in the ASD group than in the TD group ($t(39) = 9.14$, $p < .001$). Participants' characteristics are presented in Table 12.

Table 12 Participants' characteristics.

	AGE	SEX	IQ-total	AQ	ADOS
ASD GROUP (n = 17)	19.76 (1.15)	4 women 13 men	113.62 (9.78)	34.18 (7.83)	9.65 (2.15)
TD GROUP (n = 24)	20.58 (4.14)	11 women 13 men	113.21 (6.33)	16.50 (4.53)	-

Stimuli and procedure

The stimuli and procedure were the same as in Experiment 13, with one exception. The target words were now presented as auditory stimuli. The recorded words were obtained from a freely available online dictionary. As previously, the valence, arousal and frequency of the words were matched between the two conditions (consonant and dissonant chords; Jellema et al., 2011).

Results

Data Reduction

The dependent variable in the current study was the reaction time (RT) to the target words. A +/- 2.5 SD rule was applied to the mean RT per participant, with trials outside of this range considered outliers and were removed from the analysis (ASD, 5%; TD, 6%). The data of any participants with an error rate of more than 30% were also excluded (ASD, n=0; TD, n=2). Participants, who failed to correctly categorise at least 60% of the chords in the post study session were not included in the analysis (ASD, n=1; TD, n=2).[7]

[7] On average, typically developed participants correctly categorised 86% of chords in the post-study session, whereas ASD participants correctly categorised 92% of chords.

Data Analysis

The data were analysed using a mixed 2x2x2 ANOVA Chord Prime (Consonant and Dissonant) and Target Word (Positive and Negative) as within-subject factors and Group as a between-subject factor (TD and ASD). The results are presented in Figure 51.

The main effect of Chord Prime was not significant ($F_{1,39}$ = .015, p =.903, ηp^2 = .000) and neither was the main effect of Target Word ($F_{1,39}$ = .516, p = .477, ηp2 = .013). However, there was a significant interaction between Chord Prime and Target Word ($F_{1,39}$ = 8.72, p =.005, ηp^2 = .183), suggesting that priming has occurred.

Further, a significant 3-way interaction between Chord Prime, Target Word and Group was found ($F_{1,39}$= 5.45, p =.025, ηp2 = .123). Therefore, the two groups were analysed separately using 2x2 ANOVAs.

TD group: The main effect of Chord Prime was not significant ($F_{1,23}$ = .43, p = .518, ηp2 = .018). Similarly, the main effect of Target Word was also not significant ($F_{1,23}$ = .03, p = .862, ηp2 = .001). However, the results revealed a significant interaction between the two factors ($F_{1,23}$ = 20.57, p < .001, ηp2 = .472). Follow-up t-test revealed that the typically-developed group evaluated positive words faster when they were preceded by consonant chords (*M*=1076.70; *SD*=145.66), than when they were preceded by dissonant chords (*M*=1108.98, *SD*=168.20, t(23) = 3.20, p = .004, d = 0.65). The opposite result was observed for negative words, which were evaluated faster when preceded by a dissonant chords (*M*=1075.04, *SD*=178.26), than when they were preceded by an consonant chords (*M*=1117.43; *SD*=209.80; t(23) = 3.44, p =.002, d = 0.71).

ASD group: The main effect of Chord Prime was not significant ($F_{1,16}$ = .62, p = .444, ηp2 = .037), nor was the main effect of Target Word ($F_{1,16}$ = 1.80, p = .198, ηp2 = .101). Importantly, the priming effects were absent in ASD individuals, as demonstrated by the non-significant interaction between Chord Prime and Target Word ($F_{1,16}$ = .13, p = .723, ηp2 = .008).

In contrast to the findings from previous experiment, the main effect of the group was not significant ($F_{1,22}$ = 1.54, p = .221, ηp2 = .038) nor were the remaining interactions (p’s > .322).

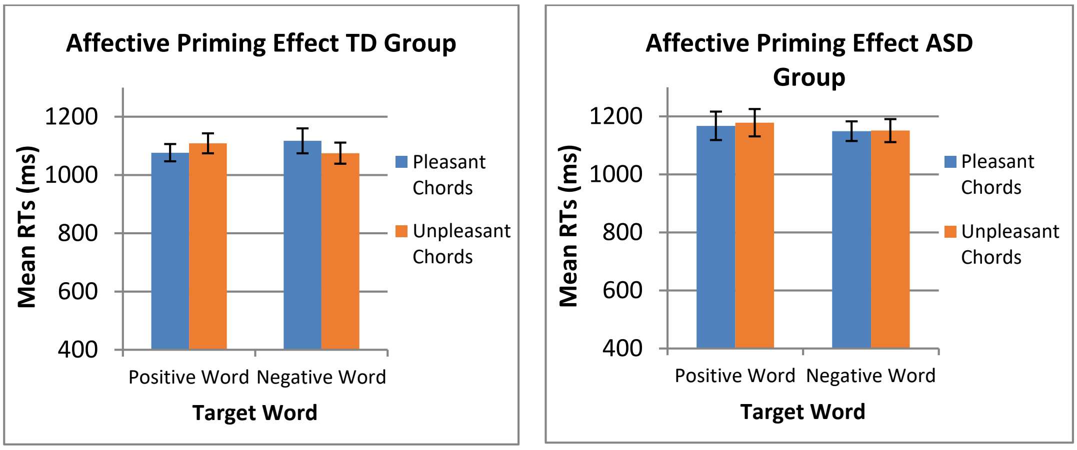


Figure 51 The mean RTs for each Prime/Target combinations in TD Group (left panel) and ASD group (right panel). Error bars represent SE.

Analysis of Errors

Examination of the errors made in evaluating the word valences showed that overall the most errors were made in response to the positive words preceded dissonant chords (on average 1.6% of trials). There was a trend for a lower accuracy amongst TD group (4.7% of errors) as compared to ASD group (2.3% of errors; $t(39) = 1.94$, $p = .060$, $d = 0.61$). However, it should be noted that the error rate in this study was relatively low. While the TD group produced slightly more errors in response to incongruent than congruent trials, this difference was not significant ($t(23) = 1.00$, $p = .328$, $d = 0.20$). Similarly, there was no significant difference between number of errors in congruent and incongruent trials in ASD group ($t(16) = .25$, $p = .801$, $d = 0.05$; see Figure 52).

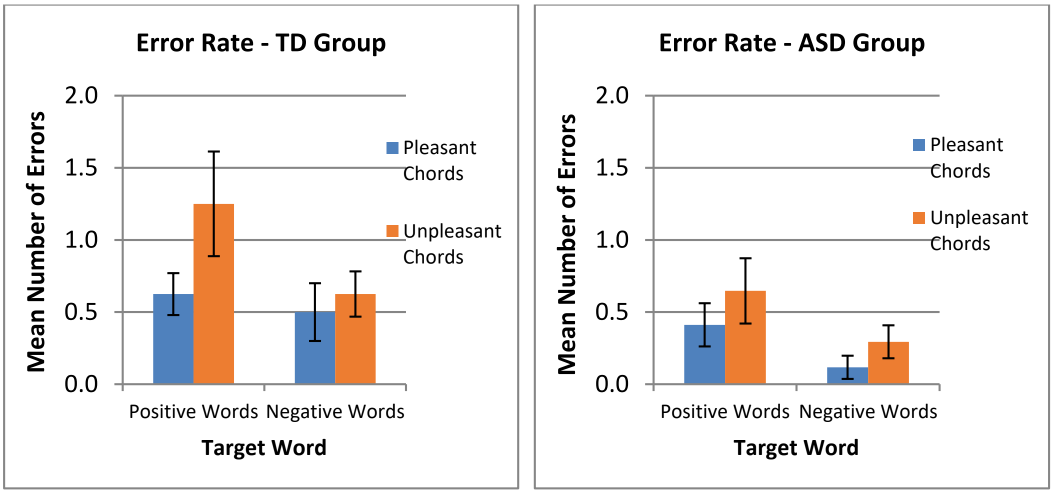


Figure 52 The mean number of errors for each Prime/Target combinations in TD Group (left panel) and ASD group (right panel).

Discussion

This experiment was motivated by the notion that the deficits in audio-visual integration in ASD could have disrupted typically observed influence of emotional prime stimuli on subsequent cognitive processing, resulting in lack of affective priming effect in this group in Experiment 13. To this end, a modified affective priming paradigm was introduced, in which prime stimuli and target words were presented within one modality. Despite these changes, the results largely followed those obtained in Experiment 13, with typically-developed individuals demonstrating faster responding on congruent than incongruent trials and ASD individuals still not being primed by the affective chords. As previously established, the lack of affective priming in ASD cannot be ascribed to the deficit in affect recognition, as all participants were capable to categorise a sample of consonant and dissonant chords used in this study as pleasant and unpleasant.

Previous studies showed that consonant and dissonant chords have the capacity to activate affect automatically (Goerlich et al., 2012; Sollberge et al., 2003; Steinbeis & Koelsch, 2008, 2011). The findings from the current study add further evidence for this phenomenon; typically-developed individuals seem to have perceived affective value of the chords, which then facilitated or interfered with the subsequent processing of emotional words depending on whether or not they matched the emotional connotation of the words. The affective valence of the prime seemed to be processed automatically, even though the prime is task-irrelevant and presented for a very brief period of time. The automatic character of this effect is supported by several lines of research, of which subliminal presentation studies (Draine & Greenwald, 1998), in which participants are not aware of the presented primes yet their responses are still influenced by them, most clearly demonstrate this point.

Comparisons of the reaction times obtained in the current study with Experiment 13 reveal that the comprehension and categorisation of spoken words were slower than written words. This is to be expected, as reading can be quicker than speaking or listening, as written text can be rapidly scanned in ways not possible when listening to serially presented spoken words.

The main finding from the current study is lack of priming effect in the ASD group, even though prime and target stimuli were contained within single, auditory modality. While the similar results from the previous experiment could have been attributed to deficits in audio-visual integration, the use of single modality in this study eliminates such possibility.

There seems to be a clear dissociation between explicit understanding of affective cues and implicit influence of such cues on cognitive processes. ASD participants in this study recognised the emotional value of chord stimuli when explicitly asked to evaluate them. Yet, the affective value of the chords failed to automatically influence their cognitive processing of positive and negative words, as it was the case in TD group. Emotional aspects of the environment automatically capture one's attention and influence learning about their hedonic significance, which may lead to the development of approach/avoidance tendencies. ASD individuals do seem to not direct their attention automatically to the emotional cues in their environment, but instead, perceive emotions more analytically.

Using functional magnetic resonance imaging, a recent study investigated neural correlates of emotion recognition in music in adults with ASD and typically matched control group. The result revealed that ASD individuals show mostly intact neural processing of emotional music, with activation in limbic and paralimbic areas such as parahippocampal gyrus extending into amygdala and midbrain structures, including brain's dopaminergic reward system, such as medial orbitofrontal cortex and ventral stratium, the core regions previously identified for emotional processing in music (Koelsch, 2011). However, in contrast to typically-developed participants, individuals with ASD showed additional activation in left dorsolatelar prefrontal regions, reflecting increased reliance on cognitive processes for emotion recognition than TD group (L. Gebauer et al., 2014).

A recent study found aberrant fear conditioning in ASD, with greater explicit awareness of the contingencies resulting in conditioned responses more similar to participants with typical development (Powell, Travers, Klinger, & Klinger, 2016). Interestingly, these results were observed, despite no differences in the startle response toward the loud aversive sound in comparison to the control group, as measured by galvanic skin response (GSR). This is in line with other studies that demonstrated equivalent GSR in typically-developed individuals and those with ASD to more positive or rewarding stimuli (Neuhaus, Bernier, & Beauchaine, 2015).

The evidence from the studies presented above suggests that the mechanisms underlying the response to emotional stimuli are preserved in ASD, indicating that brain regions associated with emotional response, such as the amygdala function well (L. Gebauer et al., 2014; Powell et al., 2016). However, the emotion fails to influence cognitive processes such as learning in the same manner as it does in typical development. Without such affective guidance, cognitive processes may operate at suboptimal level in ASD.

There is some evidence to suggest that atypical implicit emotion processing in ASD may arise from reduced connectivity between the amygdala and associated cortical brain regions (Kana et al., 2016). Further to this, the failure of emotional cues to modulate individuals responses have been proposed to be the cause of abnormal activity in MNS observed in ASD during emotional tasks (Cook & Bird, 2012; Hamilton, 2013; Y. Wang & Hamilton, 2012). Impairment in implicit affective tagging mechanisms in ASD could explain lack of priming observed in this group in response to emotional cues, as well as difficulties in implicit social learning found in experiments in Chapter 4.

In summary, the findings from the current study suggest that social-emotional characteristics of ASD could be more fruitfully conceptualized in terms of domain-general atypicalities in how emotion influences cognition processes, organises what one learns about salient events in a complex and dynamically changing environment, rather than impairments in social functioning per se.

7.5 General Discussion

The studies in this chapter compared the automatic emotional processing between ASD and matched control participants, when they evaluated the valence of emotionally charged words, following the presentation of sequences of dynamically changing facial expressions and musical chords. The most important findings are the following. Experiment 11 showed that sequences of facial expressions starting with a neutral facial expression morphing into either intense expression of joy or anger implicitly influenced subsequent cognitive information processing in both groups. The presentation of the reverse sequences in Experiment 12 revealed that typically developed participants continued to show priming effect in line with the distortion of the neutral faces induced by the immediate perceptual history. In contrast, the ASD group was no longer affected by the emotional content of the face sequences. This suggests that the affective priming effect in ASD group observed in Experiment 11 was not necessarily due to the ASD individuals automatically incorporating emotional valence of the faces into their cognitive processing, but rather it could have been caused by an alternative mechanism. Experiments 13 and 14 demonstrated that the failure to automatically incorporate emotional value to subsequent cognitive processing in ASD is not exclusive to social domain. Musical chords, which were seamlessly identified by ASD individuals as having positive or negative affect failed to influence their ability to categorise affective words, as it was observed in typically-developed control group.

The results from the studies in this chapter show that automatic processing of even simple emotions in faces in ASD individuals is atypical, even though they show no difficulty in categorising them. Emotional valence is linked to the approach-avoidance dimension of behaviour. Once the affective significance of the face is automatically processed, an individual can employ either approach or avoid strategy, based on its valence. The extent to which the affective stimulus is automatically processed determines the strength that it exerts on one's information processing, judgements and behaviour (for reviews see Fazio, 1995, 2001). A failure in evaluating emotional significance of facial expressions may underlie impairments in higher social cognition, such as failure to understand others emotions and intentions.

Impaired evaluation of the emotional significance of the prime

The emotional expressions embodied into the dynamic sequence may lead to automatic anticipation of the most likely emotional state of others (Jellema et al., 2011; Palumbo et al., 2015, 2018; Palumbo & Jellema, 2013). To compensate for failure in automatic emotional processing, individuals with ASD may adopt systemising mechanisms, based on statistical regularities or input operation-output-relations, which typically govern the motions of non-agentive objects to understand and anticipate others' behaviour (Baron-Cohen, 2002; Jellema & Perret, 2002; Jellema & Perrett, 2012; Ristic et al., 2005). One such strategy may be reliance on low-level visual characteristics provided by facial expressions with different emotional content. Face perception is typically considered to be a bottom-up process. That is, a perceptual categorisation of facial expressions may be achieved on the basis of physical features, which subsequently in combination with contextual information is used to infer emotional states of others' (Blakemore & Decety, 2001). This explanation seems supported by the conflicting result between the two studies reported in this chapter. A typical priming effect has been found in Experiment 11, where the prime stimuli sequences could be easily understood based on their literal value (Neutral-to-Joy = Joy and Neutral-to-Anger = Anger). On the contrary, the reverse sequences of facial expressions used in Experiment 12 did not contain the features that would allow ASD individuals to perceive to distortion of neutral faces observed in typically-developed participants. For example, perceptual description of anger was nowhere to be found in Joy-to-Neutral video sequences. Therefore, no priming has been observed in the ASD group.

Although it is possible for some ASD individuals to show a typical capacity for processing social information in experimental settings where there were explicit instructions to attend to the social stimuli, they often failed to do so in the absence of explicit instructions or task demands (Senju, 2013). Kamio et al. (2006) found that while individuals with ASD were able to identify facial expressions at the conscious level, automatic preferential responses to emotional faces were not observed with subliminal presentation suggesting a disruption in the preconscious evaluation of facial expressions. Ability to instantaneously predict emotional states important crucial for social interaction. Preconscious emotional responses may occur to social stimuli in everyday life situation and prime conscious evaluations of various environmental stimuli. Several studies on individuals with ASD reported abnormal neural activity in response to face stimuli in social brain areas that involve fusiform gyrus (Critchley et al., 2000; Pierce, 2001; Schultz et al., 2000; A. T. Wang, Dapretto, Hariri, Sigman, & Bookheimer, 2004), the amygdala (Ashwin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, 2007; Bookheimer, Wang, Scott, Sigman, & Dapretto, 2008; Critchley et al., 2000; Kleinhans et al., 2011; Pierce, 2001) and the posterior STS (Castelli, Frith, Happé, & Frith, 2002; Pelphrey, Morris, McCarthy, & Labar, 2007). This network has been argued to be crucial in evaluating the emotional significance of incoming social stimuli. The finding that ASD individuals do not seem to recruit fusiform gyrus, the region activated in normal individuals for face processing but instead the area typically activated in object processing (Schultz et al., 2000), suggests that faces in ASD may be processed in a similar manner as other non-social objects (Baron-Cohen, 2002; Jellema & Perret, 2002; Jellema & Perrett, 2007), which could explain their difficulties with social functioning.

Dysfunction of the MNN also been related to social impairment in ASD, resulting in a failure of a basic simulation system in the MNN in ASD may cause a widespread difficulty in ToM and empathy (Dapretto et al., 2006; Minio-Paluello, Baron-Cohen, Avenanti, Walsh, & Aglioti, 2009; Oberman, Ramachandran, & Pineda, 2008; Rizzolatti et al., 2009; J. H. G. Williams, Whiten, & Singh, 2004). Recent theories of an embodiment of other's facial expressions have suggested that processes involved in emotion perception can be modulated by an involuntary experiential appreciation of other's emotional/mental state (Gallese, 2007; Niedenthal et al., 2010; Palumbo & Jellema, 2013). That is, the emotional state of another person is directly simulated in an automatic manner as if actually experienced by the observer. There is evidence that the MNN in the premotor cortex becomes activated not only when observing others action but also emotional facial expressions (Bastiaansen, Thioux, & Keysers, 2009; Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Moore, Gorodnitsky, & Pineda, 2012). Therefore, the motor simulation may underlie the intuitive understanding of other's facial expressions (Rizzolatti & Craighero, 2004), which in turn may shape the perception of those expressions. The involuntary simulation does not involve any cognitive processes or deliberate reasoning, rather, MNN activity is a part of the low-level reading mechanism (Goldman, 2006, 2009), which enable emotional anticipation. However, the evidence that the MNN is actually abnormal in individuals with ASD is still debated (Hamilton, 2013).

<u>The diminished strength of affective valence on cognitive processing</u>

Another explanation for the lack of priming in ASD individuals could be that the affective valence of the facial/musical stimuli was perceived, but the strength it exerted on ASD individuals was not sufficient to influence the cognitive processing of the target words. In other words, the evaluation of the target emotionally-charged words and the perception of facial sequences/musical chords were somehow treated as unrelated events. In could be that ASD individuals were capable to focus on the task at hand to such extent that they were able to suppress the influence of the prime stimuli. However, the priming effect is thought to be automatic and occur outside of conscious awareness, therefore, it would be extremely difficult, if not impossible to exercise any form of control over it. In addition, studies have shown an increased distractor processing in ASD, as compared to matched control participants, even under high perceptual load (Remington, Swettenham, Campbell, & Coleman, 2009; Remington, Swettenham, & Lavie, 2012). Further to this, the typical priming effects were observed in the ASD group in Experiment 11. There is no apparent reason why the interference of task-irrelevant distractors would be present in one study but not another, other than that they have not been processed in the same manner.

7.6 Conclusion

The automatic perception of affective value allows one to implicitly anticipate how the emotional state might change on, based on the immediate perceptual history and those implicit evaluations have been found shape the perception of subsequent stimuli present in the environment. The studies in Chapter 7 suggest that individuals with ASD may not rely on such an anticipatory mechanism to understand others' emotional states but use more analytical and cognitive approach. The results indicate that one reason for why automatic social perception is impaired in ASD is a failure in implicitly attributing emotional value to the representation of stimuli, i.e. a dysfunction of the implicit affective tagging mechanism. Consequently, the affective states fail to assist in guiding the response or attitude formation towards the incoming stimuli. This effect is observed in studies examining implicit cognition even when only basic emotional expressions are employed or when emotional valence information is transmitted through non-social means, such as musical chords, extending beyond the realm of the social world. This indicates a more general impairment in how emotion influence cognition in ASD, rather than one confined to the social domain. A compromised implicit evaluation of the significance of incoming stimuli is likely underpinned by the deficit in emotion-related associative learning, negatively affecting one's ability to understand predictive value of emotional cues, which would undoubtedly contribute to problems in navigating the social world.

Chapter 8 General discussion and conclusions.

8.1 Summary and findings of the current project

The collection of studies presented in this thesis initially aimed to contribute to the discussion about the role of implicit learning processes in the understanding of others' mental/emotional states and development of social intuition in typical and ASD individuals. Although numerous studies have investigated domain-general implicit learning abilities in these populations, little is known about the extent to which the distinction between the social and non-social domain is important for implicit learning processes, in particular in relation to ASD (i.e. to what extent it underpins the impaired social intuition in ASD).

With this question in mind, a novel implicit learning paradigm was developed to allow for direct comparison of social and non-social implicit learning abilities in typical and ASD-individuals. A further advantage of the new paradigm, over the traditional probabilistic tasks investigating implicit learning, lies in the use of contingency, rather than probability, to examine the implicit learning abilities. In our paradigm, a specific contingency between coordinated changes in three different social cues has to be learned. Therefore, the task does not require the use of hundreds of trials in order for learning to take place as it is typically the case with probabilistic tasks, such as SRTT.

Once the differences in implicit learning processes between typical and ASD individuals have been found specifically in the social domain, the aim of the thesis shifted towards an attempt to understand and explain the observed behavioural effect. The focus was on the potential contribution of other cognitive processes to the ability to learn implicitly, especially in the context of social information has been examined and the role of affective valences, inherent in the nature of social stimuli.

Chapter summaries

Studies in Chapter 3 provided evidence that typically developed individuals are capable of implicitly learning contingencies within their environment. Experiments 1 and 2 demonstrated that social learning of others' mental/emotional states can occur implicitly on the basis of social cue contingencies. People seem to implicitly learn associations between social cues and use this knowledge to guide their behaviour, even in the absence of explicit knowledge. Implicit learning is argued to be a building block for the development of social intuition and contributes to normal social functioning (Lieberman, 2000). Similar learning effects were observed in Experiment 3, where a matched task involving non-social objects was used, suggesting the implication of general learning processes in social cognition.

The main finding of Chapter 3, however, was a striking dissociation between social and non-social implicit learning found in individuals scoring high on the AQ (Autism Quotient), with failure to acquire implicit knowledge evident only in the social domain. No such dissociation was found in TD individuals scoring low on the AQ. However, conflicting findings from direct (likability questionnaires) and indirect (perceptual bias task) implicit learning measures employed in the social learning tasks left the results open to different interpretations.

It was argued that implicit learning in the high AQ group could have occurred to some extent; however, the implicit associations between social cues and character might not have been strong enough to emerge when probed indirectly. The dissociation between results obtained through direct versus indirect assessments is in line with previous studies that found impaired social implicit learning in TD individuals with high AQ scores when the implicit learning effect is assessed with indirect measures (Bayliss & Tipper, 2006; Hudson, Nijboer, et al., 2012).

An impaired ability to form implicit memories on the basis of social signals may lead to difficulties in social communication and interaction, which is one of the major symptoms reported in ASD. A set of studies in Chapter 4 were the first to provide evidence for dissociated implicit learning in the social and non-social domain in ASD. The capacity for implicit learning in the non-social domain was found intact in ASD individuals and comparable to the typically developed control group, corroborating previous research (Foti et al., 2014). However, there was no evidence of implicit social learning in the ASD group on the basis of the dispositions displayed by the study characters. Importantly, this impairment could not be accounted for by (i) a failure to recognise emotional expressions and gaze direction (as confirmed by the debriefing session), (ii) a failure to recognise the two identities used in the learning task (as confirmed by the catch trials), nor (iii) a failure to integrate multiple cues (as the non-social task was comparable in terms of difficulty and number of cues to the social task). An impaired ability to acquire implicit associations between social signals may lead to underdevelopment of social intuition, and thus may have far-reaching consequences for social functioning. Overreliance on explicit aspects of the environment could be a direct consequence of (i.e. compensation for) a dysfunctional ability to learn implicitly in some circumstances. Indeed, it has been argued those on the autism spectrum are prone to adopt explicit learning strategies and rely more on explicitly acquired knowledge. While this approach could be very useful for understanding the physical world, the interpretation of social cues using effortful cognitive processes would negatively impact on the ability to adjust one's behaviour to a given social context, within the narrow time window available.

Once the difficulties in the ability to implicitly learn social information emerged in high AQ and ASD groups (Chapters 3 & 4), the next step was to examine the potential contribution of other cognitive processes to the ability to learn implicitly, especially in the context of social information. Atypical cognitive processes such as a specific deficit in social memory and/or aberrant social attention often observed in ASD could affect one's ability to learn implicitly. Therefore, these processes were explored in Chapters 5 and 6.

Studies in Chapter 5 examined whether certain combinations of social cues are more memorable than others and whether any potential differences in memory for social information influence implicit learning processes in typical development and ASD. The result revealed that emotional displays accompanied by direct gaze enhance their memorability. However, we failed to find a specific emotion-gaze combination that would impact on one's ability to remember that expression, rather expressions of joy and anger both seem to have a capacity to enhance memory when directed at the observer. These findings have a direct consequence for interpreting the results from the implicit learning chapters. They suggest that social implicit learning was not primarily driven by enhanced memorability of expressions of anger accompanied by direct gaze since both expressions exert a similar influence on memory when directed at the observer. Most importantly, the pattern of social memory in the current study was similar across both the typically-developed and ASD group, providing evidence against the direct gaze avoidance hypothesis of autism (Dalton et al., 2005; Kylliäinen et al., 2012; Senju & Johnson, 2009), and thus against atypical social memory for facial expressions as an explanation for impaired implicit social learning. Further, if the processing of faces with averted gaze was somewhat enhanced in high AQ and ASD groups, then their memory for facial expressions accompanied by averted gaze should, in theory, be better for this type of stimuli but this was not was found. Moreover, a similar ability in remembering characters facial expressions in the TD and ASD groups further indicates that ASD individuals were, in fact, able to recognise the emotional expressions used in the study, differentiate between characters' identities and integrate these two cues to successfully complete the task.

Although the role of attention in implicit learning processes is currently debated and it is not clear to what extent attention is required for implicit learning process to occur, we also wanted to explore whether the aberrant social attention sometimes reported in ASD may have negative implications for implicit learning processes. As such, the studies in Chapter 6 investigated visual fixation patterns of emotional faces in TD individuals with a varying number of autistic traits and in ASD individuals. For instance, if individuals with ASD would completely ignore the eye region then that would make it very hard for them to learn any associations with eye gaze and hence they would not be able to implicitly learn the agents' dispositions toward them. The results revealed that individuals with more autistic traits focused on critical areas of the face (eyes/mouth) as much as individuals with fewer AQ traits. This pattern was somewhat different for the ASD group, where atypical social attention toward the emotional faces was found. However, as no apparent difference was found between visual exploration of the eyes of faces with a direct versus averted gaze, the current results do not support the hyperarousal hypothesis of ASD. Most importantly, however, the difference in visual fixation patterns in the ASD group did not seem to explain the deficits in social implicit learning observed in Chapter 4, as still more than 50% of the viewing time in the ASD group was devoted to the eye region and there were no associations found between the time fixated on the eyes and amount of implicit learning observed in that chapter. Aberrant attention alone cannot explain differences in implicit social learning, especially given the fact that the viewing behaviour between the low and high AQ groups was comparable, yet the implicit social learning was considerably impaired in high AQ group.

An essential difference between the social and non-social version of the implicit learning paradigm is that in the social learning task the cue combinations convey the individual's affective disposition toward the observer, whereas no such affective meaning is associated with the non-social stimuli. We claimed that one reason why social implicit learning may be particularly problematic in individuals with ASD may be because a defective affective tagging mechanism that allows for implicit linking of emotional valence to social information, i.e. the implicit affective tagging hypothesis. It is not sufficient to store a set of implicitly learnt patterns, without the information about their emotional or affective significance it may not have much relevance for the owner. For example, in case of social intuition, associations between the specific sequence of social cues and their outcomes will not be meaningful for the observer without information about the emotional salience they carry in relation to the observer, such as danger or satisfaction from previous episodes. Impairment in implicit processing of affective valences can reduce the usefulness of implicitly acquired information and as a result, may lead to overreliance on explicit strategies to understand one's environment.

One possibility as to why the individuals with ASD did not implicitly learn the social dispositions of the characters is that the affective valence related to the prosocial or antisocial disposition of the agent toward the observer did not implicitly get attached to the identity of the particular agent displaying that disposition. If the affective valence failed to get linked to the character's identity, the participants would not show a response bias in the test phase, which then would lead to the conclusion that the participants had not implicitly learned the agent's disposition. Thus, it is possible that the ASD group had implicitly learned the contingency between the three social cues, but either no affective valences were evoked in them, or affective valences were evoked but they did not implicitly get attached to the respective identities. To look further into any possible differences that may exist between TD and ASD individuals with respect to their ability to be implicitly influenced by affective valences evoked by emotional stimuli, the experiments in Chapter 7 employed an affective priming paradigm.

Studies in Chapter 7showed that sequences of facial expressions starting with a neutral facial expression morphing into either an intense expression of joy or anger implicitly influenced subsequent cognitive information processing in both groups. However, the presentation of the reverse sequences revealed that TD participants continued to show priming effects in line with the visual distortion (i.e. extrapolation) of the neutral faces induced by the immediate perceptual history. In contrast, the ASD group was no longer affected by the emotional content of the face sequences. This suggests that the affective priming effect in observed the ASD group was not necessarily due to the ASD individuals automatically incorporating emotional valence of the faces into their cognitive processing, but rather it could have been caused by an alternative mechanism. In other words, the affective priming in ASD occurred when the value of the face was obvious and could be read from the social cues contained within the face (Experiment 11). That is, an intense smile is a synonym for 'positive', an intense frown is a synonym for 'negative', which does not necessarily require the processing of affective valence. These prime stimuli convey the abstract concepts of positivity and negativity (in addition to any real affect they induce), which could be enough to produce the affective priming effects in the ASD group in this condition. However, the effect was no longer present when the affective value had to be inferred through the implicit reading of the affective meaning of the changes in the emotional state of mind of the agent, conveyed in the immediate perceptual history (Experiment 12). Further experiments in this chapter demonstrated that the failure to automatically incorporate emotional value to subsequent cognitive processing in ASD is not exclusive to the social domain, therefore, it cannot be explained by aberrant attention or insufficient motivation towards social stimuli. Musical chords, which were correctly identified by ASD individuals in the debrief session as having positive or negative affect, failed to influence their ability to categorise subsequently presented affective words in the way it was observed in the TD control group. Yet again, the emotional value failed to get incorporated into cognitive processing, further supporting the affective tagging hypothesis. The findings from the studies in Chapter 7 suggest that the affective valences seem to play a crucial role in bringing about learning differences between the TD and ASD groups.

8.2 Dysfunctional implicit affective tagging

People routinely make quick intuitive assumptions about the dispositions, thoughts and intentions of others, and about which course of action to select, without using any deliberate and effortful reasoning. The appropriate response reveals itself as an immediate apprehension, insight or decision. This ability sometimes referred to as social intuition, is crucial to successfully navigate a rapidly changing social world (Lieberman, 2000). Social intuition has been claimed to be supported by a toolbox of social learning heuristics (Hertwig et al., 2013), many of which are implicit in nature. The implicit nature implies that one is not aware of the learning process, even though its effects can be observed in one's behaviour and decision making. Implicit learning is thought to be fairly automatic and involuntary (Shanks et al., 2005) and is thus pre-eminently suited to influence and guide our social decision-making processes in the quick manner required to operate successfully (Lieberman, 2000; Bechara et al., 1997).

Social impairments in ASD are thought to be linked to an impaired ToM; the ability to understand others as agents capable of having mental states and intentions, that is, to interpret their minds in terms of mental intentional states such as desires and beliefs (Baron-Cohen et al., 1985). This impairment is typically described in terms of cognitive knowledge about emotional states, assuming deficits in understanding cognitive or belief-based emotions, such as surprise, with an understanding of basic emotional expressions intact. However, this project provided further evidence to support the initial suggestions that social deficits seen in individuals with ASD are especially related to a failure in *automation* of social cue processing rather than in the ability to understand intentions per se (Hudson, Liu, et al., 2009; Hudson, Nijboer, et al., 2012; Jellema et al., 2009; Schneider et al., 2013; Senju et al., 2009).

Explicit social cognition seems to be preserved in ASD individuals, who often consciously engage in reasoning about others' minds to compensate for the difficulties experienced during social exchanges (Schilbach et al., 2013). What seems to be impaired is the ability to intuitively extract socially relevant information from their environment to successfully navigate the social world and dynamically adjust their behaviour in response to others. Aberrant functioning of social intuition cannot be explained by the dysfunction of implicit learning processes. The studies presented in the current thesis together with previous research indicate that implicit learning mechanism is intact in ASD (Foti et al., 2014). If the cognitive processes itself is intact, if the implicit learning mechanism is preserved in ASD, this implicates deficits in affective components that gave rise to intuition. These would be particularly important for the formation of intuitive thoughts within the social domain, where affective valences are imprinted in the nature of the stimuli.

This thesis argues that one reason for why automatic social perception is impaired in ASD may be a failure in implicitly attributing emotional value to the representation of social stimuli, i.e. a dysfunction of the implicit affective tagging mechanism. As a result, affective states fail to assist in guiding the response or attitude towards the stimuli. This effect seems to be observed in studies examining implicit cognition even when basic emotional expressions are employed or when emotional valence information is transmitted through non-social means, such as musical chords. "*For cognition to be fully effective, it is not enough that the agent is able* *to understand and predict developments in the environment, it must also care about them, it must desire certain types of outcomes and shun others*" (Cleeremans, 2011, p.9). This suggests that emotions are basically computational tags that subserve and facilitate cognitive processes. There is ample evidence that an affective value can get attached to a stimulus, even when the stimulus itself is not consciously recognised (e.g. Kunst-Wilson & Zajonc, 1980). Therefore, emotions are thought to play a pivotal role in implicit learning processes, as they can drive and guide behaviour effectively, and help the individual make quick intuitive decisions that are beneficial and that ultimately support its survival (Cleeremans, 2011).

The automatic perception of affective value allows one to implicitly anticipate how the emotional state might change, based on the immediate perceptual history and those implicit evaluations have been found to shape the perception of subsequent stimuli present in the environment. The current findings suggest that individuals with ASD may not rely on such an anticipatory mechanism to understand others' emotional states, but use an alternative mechanism. Such compensatory activities do not seem sufficient to affect the subsequent cognitive information in ASD individuals in the same manner as in typical development. A compromised implicit evaluation of the emotional valence of incoming stimuli and failure to understand its predictive value would undoubtedly contribute to problems in navigating the social world.

Neuroimaging studies report reduced levels of brain activation in individuals with ASD during implicit emotion processing in the medial prefrontal cortex and superior temporal gyrus, with typical activations during explicit emotion processing (Kana et al., 2016). This suggests, that in typically-developed subjects, the emotional value of the stimuli is processed, even when it is not explicitly required; in contrast individuals with ASD may not automatically engage structures playing role in detecting emotional information perceived incidentally. Further to this, the same study found reduced functional connectivity between the medial prefrontal cortex and the amygdala in ASD only for emotional processing that is automatic or implicit. Interestingly, brain regions such as the amygdala, orbitofrontal cortex, and anterior cingulate gyrus have been implicated in the perception of consonance and dissonance in music (Dellacherie et al., 2009). Research suggests that it is a pre-attentive, sensory-level processing in humans that may account for the perceived consonance of musical pitch relationships (Bidelman & Krishnan, 2009). It would be interesting to investigate the brain activity during the perception of consonance and dissonance in ASD.

The findings from the above studies suggest that neural mechanisms underlying implicit, but not explicit, emotion processing may be altered at multiple levels in individuals with ASD. This is further supported by studies exploring automatic mimicry of facial expressions, which found deficits in involuntary imitation of emotional expressions in ASD. If the role of the mirror mechanism is to provide direct experiences of others' mental states to aid learning from observation, then lack of modulation by affective value of the stimuli may have far-reaching consequences for individuals with ASD. While explicit instruction can help people with ASD navigate the social and emotional world more effectively over time, a failure to use implicit emotions could significantly affect the quality of social interaction in individuals with ASD.

8.3 Limitations

Social cue perception tasks contributed to the body of knowledge about how individuals understand the mental states of others. However, they tend to be limited in their ecological validity due to their offline designs. Tasks employed in this project were simple computer tasks, with participants presented with decontextualized images of faces, which were only a human-artefact representation of social interactions. Even though the majority of studies presented in this thesis used dynamic stimuli, which have been found to have a higher ecological validity and evoke stronger emotional responses than still images, participants were often given time to observe the stimulus and consider its properties before making any judgments. Emotional facial expressions are rarely presented in isolation. Such displays of others may underestimate actual abilities due to decontextualized cues and at the same time overestimate them due to prolonged observation and thinking time, only partially reflecting the perception of social cues in everyday interaction.

For instance, previous research showed that when social information is presented in competition with non-social stimuli, ASD individuals tend to direct their attention more to non-social aspects of the environment (Chita-Tegmark, 2016). Furthermore, participants were typically instructed to pay attention to the displayed stimuli, which may have altered their natural behaviour, especially in the case of ASD-participants. While the undercomplexity of the current designs allowed for more control over the experimental procedures, the observed results need to be approached with caution when generalising them to naturalistic settings.

Some of the studies presented in this thesis could benefit from the use of within-subject design, rather than the between-subject alternative. While some participants completed all of the experiments in this project, within-subject comparisons were not always possible, as the participant numbers varied from study to study due to participant availability, exclusion criteria and participants' performance (e.g. too many missing trials).

Finally, the ASD sample in the current project consisted only of high-functioning, university students, mostly with higher than average cognitive functioning, which limits generalisability of the findings to this particular subset of the ASD population. However, evidence of impaired implicit social learning in this higher IQ adult sample (a group usually thought of as having substantially better learning abilities than others with the ASD) makes it reasonable to speculate that the same type of impairment may be present in lower-functioning or younger samples with ASD.

8.4 Future directions

Some of the limitations presented above could be overcome with the use of new interactive paradigms developed to study social interaction in the real-time. "Second person" approach to social interaction has recently gained popularity, based on the observation that social cognition is fundamentally different during social interaction than during the mere observation of others (Schilbach et al., 2013). In contrast with "offline" social interaction, this approach offers a more promising framework based on two-person experimental setups, where real-time interactions between individuals can be investigated (Auvray & Rohde, 2012; Zapata-Fonseca, Froese, Schilbach, Vogeley, & Timmermans, 2018). Virtual reality technologies (VR) are also currently being incorporated into the study of social interactions. With the use of VR, social interaction can be realistically simulated. For example, an interaction partner can be represented by a virtual human, which is a computer-generated three-dimensional digital representation that looks and acts like a real human and can be controlled either by human or pre-programmed by a computer (Blascovich et al., 2002). Virtual simulations achieved through such technologies provide high ecological validity and they can often be combined with eye/head tracking, motion detection and EEG measures to achieve more realistic experiences. Growing evidence shows that indeed studies conducted with such technologies can replicate some well-known findings of social psychology (for a review see: Bombari et al., 2015). Moreover, VR applications allow for full control over the characteristics of the environment (e.g. visual cues) or of the social partner (e.g. physical appearance) to investigate their influences on participants' behaviour and cognition, providing at the same time a realistic social experience.

In addition to exploring possible methodological approaches, future investigations could elaborate on the studies presented in this thesis in the following ways:

(i) Increased cognitive load has been shown to disrupt automatic ToM processing in TD individuals (Schneider et al., 2012). It could be that individuals with ASD experience the social condition (but not the non-social condition) as more cognitively demanding, which then in itself could prevent implicit learning from occurring. Future studies could firstly investigate whether the higher cognitive load is indeed experienced by ASD individuals when confronted with social information and secondly, manipulate the cognitive load to see if that would affect implicit non-social learning. This could be achieved with the use of tasks that have to be carried out concurrently, such as the n-back task (Kane et al., 2007) during the learning phase. If implicit learning abilities in the non-social domain are disrupted under the high cognitive load and both TD and ASD groups would no longer show evidence of implicit learning, then this would implicate the importance of cognitive resources in implicit learning processes and provide an initial explanation as to why implicit social learning may be more difficult for ASD individuals.

(ii) Experiment 12, in which a priming effect in line with the distortion of the neutral faces was induced by the immediate perceptual history, could be complemented with the use of EMG to evaluate the contribution of embodied simulation (Gallese, 2007; Niedenthal et al., 2010) as the underlying mechanism of the overshoot bias. Such a study could assess whether the observation of the Joy-to-Neutral videos would induce an initial activity in the EMG of the observer's 'smiling' muscles (Zygomaticus Major), followed by activity in the 'frowning' muscles (Corrugator Supercilii) at the end of the video during the presentation of the neutral expression. While this would be surprising as there is no angry facial expression displayed in these videos, it would suggest the influence of embodied simulation in the perception of dynamic facial expressions. If found, an opposite activity of facial muscles would be expected in response to the Anger-to-Neutral videos.

(iii) The implicit affective tagging hypothesis could be further tested in a number of ways. An essential difference between the social and non-social conditions is that in the social condition the cue contingency conveys the actor's affective (positive or negative) disposition toward the observer, whereas no such affective meaning is associated with the non-social stimuli. Firstly, an additional non-social condition can be designed in which the implicit learning crucially depends on its association with a positive or negative affective valence, for example, gaining or losing a monetary reward. If the ASD group fails to show evidence of implicit learning in this condition, then that would support the 'implicit affective tagging hypothesis'. Alternatively, physiological measures, such as galvanic skin conductance, could be used to determine affective responses toward the stimuli. The skin conductance response (Lykken & Venables, 1971) reflects that the skin momentarily becomes a better conductor of electricity when either external or internal stimuli occur that are physiologically arousing. If the TD group showed an increased response towards positive/negative characters following implicit social learning but the ASD group would not (Mathersul et al., 2013), then that would also support the affective tagging hypothesis.

(iv) It is not clear to what extent the deficits in implicit ToM abilities can be modified by experience. The lack of guidance from affective aspects of the environment in implicit learning processes can potentially diminish the value of implicitly acquired knowledge and result in inflexible learning, which cannot be effectively applied across contexts. Future studies could investigate whether interventions consisting of controlled social experiences could positively influence implicit ToM abilities in ASD. For example, one study could employ an experimental design in which false and true belief– based actions and their outcomes are showed on multiple trials. This would make it possible to test if and when experience with this type of implicit ToM task is sufficient to elicit beliefs congruent with anticipatory looking (implicit measure). Such findings would be crucial to better understand if and how individuals with ASD can make use of experience to compensate for deficits in implicit ToM reasoning.

8.5 Conclusions

To the best of our knowledge, the current project is the first to directly compare implicit learning abilities in the social and non-social domain in typical and ASD individuals. It thereby uniquely contributed to the discussion about the role of implicit learning processes in the understanding of others' mental states and the development of social intuition.

Nearly all studies to date on implicit learning were limited to the non-social domain, which led to our proposition that individuals with ASD may show domain-specific implicit learning deficits, in particular when social learning is involved. Human behaviour is dynamic, variable and complex and therefore detecting regularities in social interactions may be more difficult than detecting regularities in the physical environment. Implicit learning in the social domain relies inherently on associated emotions and affective valences, with abstract concepts such as disposition, attitude and intention being an intrinsic part of what is learned.

Indeed, it was determined that impairments in implicit learning in individuals with ASD emerge with respect to implicit social learning, with intact implicit learning abilities in the non-social domain. Deficits in implicit social learning were observed despite the participants' intact ability to recognise the facial expression, gaze direction and identity of the characters used in the studies.

The relative contributions of three potential mechanisms underpinning implicit social learning were then examined: (i) contingency learning *per se,* (ii) contribution of other cognitive processes such as memory for facial expressions and social attention, (iii) implicit affective tagging. The evidence gathered so far points toward the final explanation, suggesting that ASD individuals may be impaired in their ability to implicitly incorporate affective values into cognitive processing.

Taken together the studies presented in this thesis suggest that individuals with ASD use alternative strategies to comprehend others' minds, which may rely more on physical characteristic rather than social meaning. Intuitive judgements are thought to be comprised of both cognitive and affective components, with emotions acting as computational tags that subserve and facilitate cognitive processes. Impaired ability to acquire implicit associations on the basis of the emotional value of social signals may lead to underdevelopment of social intuition and thus have far-reaching consequences for social functioning. Research shows that those on the autism spectrum are prone to adopt explicit learning strategies and rely more on explicitly acquired knowledge, which may as well be an adaptive strategy to compensate for deficits in affect-related implicit learning. While this approach could be to some extent useful for understanding the physical world, the interpretation of social cues using effortful cognitive processes would negatively impact the ability to adjust one's behaviour to a given social context, within the narrow time window available.

Bibliography

Adams, R. B., & Kleck, R. E. (2003). Perceived Gaze direction and the processing of facial displays of emotion. *Psychological Science*, *14*(6), 644–647. https://doi.org/10.1046/j.0956-7976.2003.psci_1479.x

Adams, R. B., & Kleck, R. E. (2005). Effects of Direct and Averted Gaze on the Perception of Facially Communicated Emotion. *Emotion*, *5*(1), 3–11. https://doi.org/10.1037/1528-3542.5.1.3

Adolphs, R. (1999). Social cognition and the human brain. *Trends in Cognitive Sciences*, *3*(12), 469–479.

Adolphs, R., Sears, L., & Piven, J. (2001). Abnormal processing of social information from faces in autism. *Journal of Cognitive Neuroscience*. US: MIT Press. https://doi.org/10.1162/089892901564289

Aizenstein, H. J., Stenger, V. A., Cochran, J., Clark, K., Johnson, M., Nebes, R. D., & Carter, C. S. (2004). Regional Brain Activation during Concurrent Implicit and Explicit Sequence Learning. *Cerebral Cortex*, *14*(2), 199–208. https://doi.org/10.1093/cercor/bhg119

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211. https://doi.org/https://doi.org/10.1016/0749-5978(91)90020-T

Aldridge, M. A., Stone, K. R., Sweeney, M. H., & Bower, T. G. R. (2000). Preverbal children with autism understand the intentions of others. *Developmental Science*, *3*(3), 294–301.

Allen, R., Davis, R., & Hill, E. (2013). The effects of autism and alexithymia on physiological and verbal responsiveness to music. *Journal of Autism and Developmental Disorders*, *43*(2), 432–444. https://doi.org/10.1007/s10803-012-1587-8

Allen, R., Hill, E., & Heaton, P. (2009a). Hath charms to soothe...’ An exploratory study of how high-functioning adults with ASD experience music. *Autism*, *13*(1), 21–41.

Allen, R., Hill, E., & Heaton, P. (2009b). The subjective experience of music in autism spectrum disorder. *Annals of the New York Academy of Sciences*, *1169*(1), 326–331.

Amodio, D. M., & Frith, C. D. (2006). Meeting of minds: the medial frontal cortex and social cognition. *Nature Reviews Neuroscience*, *7*(4), 268.

Amso, D., & Davidow, J. (2012). The development of implicit learning from infancy to adulthood: Item frequencies, relations, and cognitive flexibility. *Developmental Psychobiology*, *54*(6), 664–673. https://doi.org/10.1002/dev.20587

Apperly, I. A. (2008). Beyond Simulation–Theory and Theory–Theory: Why social cognitive neuroscience should use its own concepts to study "theory of mind." *Cognition*, *107*(1), 266–283.

Apperly, I. A. (2012). What is "theory of mind"? Concepts, cognitive processes and individual differences. *The Quarterly Journal of Experimental Psychology*, *65*(5), 825–839.

Apperly, I. A., & Butterfill, S. A. (2009). Do humans have two systems to track beliefs and belief-like states? *Psychological Review*. Apperly, Ian A.: School of Psychology, University of Birmingham, Edgbaston, Birmingham, United Kingdom, B15 2TT, i.a.apperly@bham.ac.uk: American Psychological Association. https://doi.org/10.1037/a0016923

Armstrong, K., & Iarocci, G. (2013). Brief report: The autism spectrum quotient has convergent validity with the social responsiveness scale in a high-functioning sample. *Journal of Autism and Developmental Disorders*, *43*(9), 2228–2232.

Artuso, C., & Palladino, P. (2015). Social updating : The role of gaze direction in updating and memorizing emotional faces. *Social Cognition*, *33*(6), 543–561. https://doi.org/10.1521/soco.2015.33.6.543

Åsberg Johnels, J., Hovey, D., Zürcher, N. R., Hippolyte, L., Lemonnier, E., Gillberg, C., & Hadjikhani, N. (2017). Autism and emotional face-viewing. *Autism Research*, *10*(5), 901–910. https://doi.org/10.1002/aur.1730

Ashby, F. G., & Maddox, W. T. (2005). Human category learning. *Annu. Rev. Psychol.*, *56*, 149–178.

Ashwin, C., Baron-Cohen, S., Wheelwright, S., O'Riordan, M., & Bullmore, E. T.

(2007). Differential activation of the amygdala and the ‘social brain’ during fearful face-processing in Asperger Syndrome. *Neuropsychologia*, *45*(1), 2–14. https://doi.org/https://doi.org/10.1016/j.neuropsychologia.2006.04.014

Ashwin, C., Hietanen, J. K., & Baron-Cohen, S. (2015). Atypical integration of social cues for orienting to gaze direction in adults with autism. *Molecular Autism*, *6*(1), 5. https://doi.org/10.1186/2040-2392-6-5

Association, A. P. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.

Austin, E. J. (2005). Personality correlates of the broader autism phenotype as assessed by the Autism Spectrum Quotient (AQ). *Personality and Individual Differences*, *38*(2), 451–460.

Auvray, M., & Rohde, M. (2012). Perceptual crossing: the simplest online paradigm. *Frontiers in Human Neuroscience*, *6*, 181.

Baillargeon, R., Scott, R. M., & He, Z. (2010). False-belief understanding in infants. *Trends in Cognitive Sciences*, *14*(3), 110–118. https://doi.org/10.1016/j.tics.2009.12.006

Bal, E., Harden, E., Lamb, D., Van Hecke, A. V., Denver, J. W., & Porges, S. W. (2010). Emotion recognition in children with autism spectrum disorders: Relations to eye gaze and autonomic state. *Journal of Autism and Developmental Disorders*, *40*(3), 358–370. https://doi.org/10.1007/s10803-009-0884-3

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review*, *84*(2), 191.

Bar-Haim, Y., Shulman, C., Lamy, D., & Reuveni, A. (2006). Attention to eyes and mouth in high-functioning children with autism. *Journal of Autism and Developmental Disorders*, *36*(1), 131–137.

Bargh, J. a., Chaiken, S., Govender, R., & Pratto, F. (1992). The generality of the automatic attitude activation effect. *Journal of Personality and Social Psychology*, *62*(6), 893–912. https://doi.org/10.1037/0022-3514.62.6.893

Bargh, J. a., & Williams, E. (2006). The Automaticity of Social Life: At USF Libraries. *Current Directions in Psychological Science*, *2*(1), 1–4. https://doi.org/10.1038/nature13314.A

Barnes, K. A., Howard, J. H., Howard, D. V, Gilotty, L., Kenworthy, L., Gaillard, W. D., & Vaidya, C. J. (2008). Intact Implicit Learning of Spatial Context and Temporal Sequences in Childhood Autism Spectrum Disorder. *Neuropsychology*, *22*(5), 563–570. https://doi.org/10.1037/0894-4105.22.5.563

Baron-Cohen, S. (2002). The extreme male brain theory of autism. *Trends in Cognitive Sciences*, *6*(6), 248–254. https://doi.org/10.1016/S1364-6613(02)01904-6

Baron-Cohen, S., Campbell, R., Karmiloff-Smith, A., Grant, J., & Walker, J. (1995). Are children with autism blind to the mentalistic significance of the eyes? *British Journal of Developmental Psychology*, *13*(4), 379–398. https://doi.org/10.1111/j.2044-835X.1995.tb00687.x

Baron-Cohen, S., Jolliffe, T., Mortimore, C., & Robertson, M. (1997). Another Advanced Test of Theory of Mind: Evidence from Very High Functioning Adults with Autism or Asperger Syndrome. *Journal of Child Psychology and Psychiatry*, *38*(7), 813–822. https://doi.org/10.1111/j.1469-7610.1997.tb01599.x

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a "thoery of mind"? *Cognition*, *21*, 37–46.

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1986). Mechanical, behavioural and intentional understanding of picture stories in autistic children. *British Journal of Developmental Psychology*, *4*(2), 113–125.

Baron-Cohen, S., Ring, H., Wheelwright, S., Bullmore, E. T., Brammer, M. J., Simmons, A., & Williams, S. C. R. (1999). Social intelligence in the normal and autistic brain: an fMRI study. *European Journal of Neuroscience*, *11*(6), 1891–1898.

Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The "Reading the Mind in the Eyes" Test revised version: a study with normal adults, and adults with Asperger syndrome or high-functioning autism. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *42*(2), 241–251. https://doi.org/10.1111/1469-7610.00715

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders*, *31*(1), 5–17. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11439754

Barr, R., & Hayne, H. (1999). Developmental changes in imitation from television during infancy. *Child Development*, *70*(5), 1067–1081.

Barrera, M. E., & Maurer, D. (1981). The Perception of Facial Expressions by the Three-Month-Old. *Child Development*, *52*(1), 203–206. https://doi.org/10.2307/1129231

Bastiaansen, J. A. C. J., Thioux, M., & Keysers, C. (2009). Evidence for mirror systems in emotions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1528), 2391–2404. https://doi.org/10.1098/rstb.2009.0058

Bayliss, A. P., Griffiths, D., & Tipper, S. P. (2009). Predictive gaze cues affect face evaluations: The effect of facial emotion. *The European Journal of Cognitive Psychology*, *21*(7), 1072–1084. https://doi.org/10.1080/09541440802553490

Bayliss, A. P., & Tipper, S. P. (2005). Gaze and arrow cueing of attention reveals individual differences along the autism spectrum as a function of target context. *British Journal of Psychology*, *96*(1), 95–114.

Bayliss, A. P., & Tipper, S. P. (2006). Predictive gaze cues and personality judgments: Should eye trust you? *Psychological Science*, *17*(6), 514–520. https://doi.org/10.1111/j.1467-9280.2006.01737.x

Beall, P. M., Moody, E. J., McIntosh, D. N., Hepburn, S. L., & Reed, C. L. (2008). Rapid facial reactions to emotional facial expressions in typically developing children and children with autism spectrum disorder. *Journal of Experimental Child Psychology*, *101*(3), 206–223.

Beaudry, O., Roy-Charland, A., Perron, M., Cormier, I., & Tapp, R. (2014). Featural processing in recognition of emotional facial expressions. *Cognition & Emotion*, *28*(3), 416–432.

Becchio, C., Pierno, A., Mari, M., Lusher, D., & Castiello, U. (2007). Motor contagion from gaze: The case of autism. *Brain*, *130*(9), 2401–2411.

Behrmann, M., Thomas, C., & Humphreys, K. (2006). Seeing it differently: visual processing in autism. *Trends in Cognitive Sciences*, *10*(6), 258–264. https://doi.org/10.1016/j.tics.2006.05.001

Belardinelli, C., Raza, M., & Taneli, T. (2016). Comorbid behavioral problems and psychiatric disorders in Autism Spectrum Disorders. *Journal of Childhood & Developmental Disorders*, *2*(11), 1786–2472.

Berridge, K. C., & Kringelbach, M. L. (2013). Neuroscience of affect: brain mechanisms of pleasure and displeasure. *Current Opinion in Neurobiology*, *23*(3), 294–303.

Bindemann, M., Scheepers, C., & Burton, A. M. (2009). Viewpoint and center of gravity affect eye movements to human faces. *Journal of Vision*, *9*(2), 7. Retrieved from http://dx.doi.org/10.1167/9.2.7

Bird, G., Leighton, J., Press, C., & Heyes, C. M. (2007). Intact automatic imitation of human and robot actions in autism spectrum disorders. *Proceedings of the Royal Society of London B: Biological Sciences*, *274*(1628), 3027–3031.

Bird, G., Press, C., & Richardson, D. C. (2011). The role of alexithymia in reduced eye-fixation in autism spectrum conditions. *Journal of Autism and Developmental Disorders*, *41*(11), 1556–1564.

Birmingham, E., Bischof, W. F., & Kingstone, A. (2008). Social Attention and Real-World Scenes: The Roles of Action, Competition and Social Content. *Quarterly Journal of Experimental Psychology*, *61*(7), 986–998. https://doi.org/10.1080/17470210701410375

Blakemore, S., & Decety, J. (2001). From the perception of action to the understanding of intention. *Nature Reviews Neuroscience*, *2*(28), 561–567. https://doi.org/10.1038/35086023

Blood, A. J., Zatorre, R. J., Bermudez, P., & Evans, A. C. (1999). Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nature Neuroscience*, *2*(4), 382.

Bonnel, A., Mottron, L., Peretz, I., Trudel, M., Gallun, E., & Bonnel, A.-M. (2003). Enhanced pitch sensitivity in individuals with autism: a signal detection analysis. *Journal of Cognitive Neuroscience*, *15*(2), 226–235.

Bookheimer, S. Y., Wang, A. T., Scott, A. A., Sigman, M., & Dapretto, M. (2008). Frontal contributions to face processing differences in autism: evidence from fMRI of inverted face processing. *Journal of the International Neuropsychological Society : JINS*, *14*(6), 922–932. https://doi.org/10.1017/S135561770808140X

Boshuizen, H. P. A., & Schmidt, H. G. (1992). On the role of biomedical knowledge in clinical reasoning by experts, intermediates and novices. *Cognitive Science*, *16*(2), 153–184.

Boucher, J., & Lewis, V. (1992). Unfamiliar Face Recognition in Relatively Able Autistic Children. *Journal of Child Psychology and Psychiatry*, *33*(5), 843–859. https://doi.org/10.1111/j.1469-7610.1992.tb01960.x

Bowers, K. S., Regehr, G., Balthazard, C., & Parker, K. (1990). Intuition in the context of discovery. *Cognitive Psychology*, *22*(1), 72–110.

Bowler, D. M. (1992). "Theory of Mind" in Asperger's Syndrome. *Journal of Child Psychology and Psychiatry*, *33*(5), 877–893. https://doi.org/10.1111/j.1469-7610.1992.tb01962.x

Bradley, M. M., Lang, P. J., Bradley, M. M., & Lang, P. J. (1999). M2_19.pdf. https://doi.org/10.1109/MIC.2008.114

Breslau, J., Miller, E., Breslau, N., Bohnert, K., Lucia, V., & Schweitzer, J. (2009). The impact of early behavior disturbances on academic achievement in high school. *Pediatrics*, *123*(6), 1472–1476.

Brezis, R. S., Galili, T., Wong, T., & Piggot, J. I. (2014). Impaired social processing in autism and its reflections in memory: A deeper view of encoding and retrieval processes. *Journal of Autism and Developmental Disorders*, *44*(5), 1183–1192. https://doi.org/10.1007/s10803-013-1980-y

Brown, J., Aczel, B., Jiménez, L., Kaufman, S. B., & Grant, K. P. (2010). Intact implicit learning in autism spectrum conditions. *Quarterly Journal of Experimental Psychology (2006)*, *63*(October 2014), 1789–1812. https://doi.org/10.1080/17470210903536910

Buccino, G., Binkofski, F., Fink, G. R., Fadiga, L., Fogassi, L., Gallese, V., … Freund, H. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study. *European Journal of Neuroscience*, *13*(2), 400–404.

Burrows, A. M. (2008). The facial expression musculature in primates and its evolutionary significance. *BioEssays*, *30*(3), 212–225. https://doi.org/10.1002/bies.20719

Byom, L. J., & Mutlu, B. (2013). Theory of mind: mechanisms, methods, and new directions. *Frontiers in Human Neuroscience*, *7*, 413. https://doi.org/10.3389/fnhum.2013.00413

Callenmark, B., Kjellin, L., Rönnqvist, L., & Bölte, S. (2014). Explicit versus implicit social cognition testing in autism spectrum disorder. *Autism*, *18*(6), 684–693. https://doi.org/10.1177/1362361313492393

Calvo, M. G., & Lundqvist, D. (2008). Facial expressions of emotion (KDEF): Identification under different display-duration conditions. *Behavior Research Methods*, *40*(1), 109–115. https://doi.org/10.3758/BRM.40.1.109

Canli, T., Sivers, H., Whitfield, S. L., Gotlib, I. H., & Gabrieli, J. D. E. (2002). Amygdala response to happy faces as a function of extraversion. *Science*, *296*(5576), 2191. https://doi.org/10.1126/science.1068749

Caria, A., Venuti, P., & De Falco, S. (2011). Functional and dysfunctional brain circuits underlying emotional processing of music in autism spectrum disorders. *Cerebral Cortex*, *21*(12), 2838–2849.

Carlson, S. M., Mandell, D. J., & Williams, L. (2004). Executive Function and Theory of Mind: Stability and Prediction From Ages 2 to 3. *Developmental Psychology*. Carlson, Stephanie M.: Department of Psychology, University of Washington, Seattle, WA, US, 98195-1525, carlsons@u.washington.edu: American Psychological Association. https://doi.org/10.1037/0012-1649.40.6.1105

Carney, D. R., Colvin, C. R., & Hall, J. A. (2007). A thin slice perspective on the accuracy of first impressions. *Journal of Research in Personality*, *41*(5), 1054–1072.

Carpenter, M., Pennington, B. F., & Rogers, S. J. (2001). Understanding of others' intentions in children with autism. *Journal of Autism and Developmental Disorders*, *31*(6), 589–599.

Carr, L., Iacoboni, M., Dubeau, M.-C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: a relay from neural systems for imitation to limbic areas. *Proceedings of the National Academy of Sciences*, *100*(9), 5497–5502.

Castelli, F. (2005). Understanding emotions from standardized facial expressions in autism and normal development. *Autism*, *9*(4), 428–449.

https://doi.org/10.1177/1362361305056082

Castelli, F., Frith, C. D., Happé, F., & Frith, U. (2002). Autism, Asperger syndrome and brain mechanisms for the attribution of mental states to animated shapes. *Brain*, *125*(8), 1839–1849. Retrieved from http://dx.doi.org/10.1093/brain/awf189

Cattaneo, L., Fabbri-Destro, M., Boria, S., Pieraccini, C., Monti, A., Cossu, G., & Rizzolatti, G. (2007). Impairment of actions chains in autism and its possible role in intention understanding. *Proceedings of the National Academy of Sciences*, *104*(45), 17825–17830.

Cattaneo, L., & Rizzolatti, G. (2009). The mirror neuron system. *Archives of Neurology*, *66*(5), 557–560.

Celani, G., Battacchi, M. W., & Arcidiacono, L. (1999). The Understanding of the Emotional Meaning of Facial Expressions in People with Autism. *Journal of Autism and Developmental Disorders*, *29*(1), 57–66. https://doi.org/10.1023/A:1025970600181

Chakrabarti, B., Dudbridge, F., Kent, L., Wheelwright, S., Hill-Cawthorne, G., Allison, C., … Baron-Cohen, S. (2009). Genes related to sex steroids, neural growth, and social–emotional behavior are associated with autistic traits, empathy, and Asperger syndrome. *Autism Research*, *2*(3), 157–177.

Charman, T., Swettenham, J., Baron-Cohen, S., Cox, A., Baird, G., & Drew, A. (1997). Infants with autism: An investigation of empathy, pretend play, joint attention, and imitation. *Developmental Psychology*, *33*(5), 781.

Chawarska, K., Macari, S., Powell, K., DiNicola, L., & Shic, F. (2016). Enhanced social attention in female infant siblings at risk for autism. *Journal of the American Academy of Child & Adolescent Psychiatry*, *55*(3), 188–195.

Chawarska, K., Macari, S., & Shic, F. (2013). Decreased spontaneous attention to social scenes in 6-month-old infants later diagnosed with autism spectrum disorders. *Biological Psychiatry*, *74*(3), 195–203. https://doi.org/10.1016/j.biopsych.2012.11.022

Chawarska, K., & Shic, F. (2009). Looking but not seeing: Atypical visual scanning and recognition of faces in 2 and 4-year-old children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *39*(12), 1663.

Chen, F. S., & Yoon, J. M. D. (2011). Brief report: broader autism phenotype predicts spontaneous reciprocity of direct gaze. *Journal of Autism and Developmental Disorders*, *41*(8), 1131–1134.

Chen, M., & Bargh, J. a. (1999). Consequences of automatic evaluation: Immediate behavioral predispositions to approach or avoid the stimulus. *Personality and Social Psychology Bulletin*, *25*(2), 215–224.

Chen, W., Liu, C. H., Li, H., Tong, K., Ren, N., & Fu, X. (2015). Facial expression at retrieval affects recognition of facial identity. *Frontiers in Psychology*, *6*(JUN), 1–9. https://doi.org/10.3389/fpsyg.2015.00780

Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Sciences*, *16*(4), 231–239.

Chita-Tegmark, M. (2016). Social attention in ASD: A review and meta-analysis of eye-tracking studies. *Research in Developmental Disabilities*, *48*, 79–93. https://doi.org/10.1016/j.ridd.2015.10.011

Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology*, *36*(1), 28–71.

Clark, A. (1998). *Being there: Putting brain, body, and world together again*. MIT press.

Clark, T. F., Winkielman, P., & McIntosh, D. N. (2008). Autism and the extraction of emotion from briefly presented facial expressions: Stumbling at the first step of empathy. *Emotion*, *8*(6), 803–809. https://doi.org/10.1037/a0014124

Cleeremans, A. (1997). Principles for implicit learning. *How Implicit Is Implicit Learning?*, 196–234.

Cleeremans, A., & Dienes, Z. (2008). Computational models of implicit learning. *Cambridge Handbook of Computational Psychology*, 396–421.

Cleeremans, A., & Jiménez, L. (1998). Implicit sequence learning: The truth is in the details. *Handbook of Implicit Learning*, 323–364.

Cohen, A., Ivry, R. I., & Keele, S. W. (1990). Attention and structure in sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(1), 17.

Cohen, M., Prather, A., Town, P., & Hynd, G. (1990). Neurodevelopmental differences in emotional prosody in normal children and children with left and right temporal lobe epilepsy. *Brain and Language*, *38*(1), 122–134.

Cohen, N. J., Poldrack, R. A., & Eichenbaum, H. (1997). Memory for items and memory for relations in the procedural/declarative memory framework. *Memory*, *5*(1–2), 131–178.

Constantino, J. N., & Todd, R. D. (2003). Autistic traits in the general population: a twin study. *Archives of General Psychiatry*, *60*(5), 524–530. https://doi.org/10.1001/archpsyc.60.5.524

Conty, L., & Grèzes, J. (2012). Look at me, I'll remember you: The Perception of Self-Relevant Social Cues Enhances Memory and Right Hippocampal Activity. *Human Brain Mapping*, *33*(10), 2428–2440. https://doi.org/10.1002/hbm.21366

Cook, J. L., & Bird, G. (2012). Atypical social modulation of imitation in autism spectrum conditions. *Journal of Autism and Developmental Disorders*, *42*(6), 1045–1051. https://doi.org/10.1007/s10803-011-1341-7

Corden, B., Chilvers, R., & Skuse, D. (2008). Avoidance of emotionally arousing stimuli predicts social-perceptual impairment in Asperger's syndrome. *Neuropsychologia*, *46*(1), 137–147. https://doi.org/10.1016/j.neuropsychologia.2007.08.005

Coricelli, G. (2005). Two-levels of mental states attribution: from automaticity to voluntariness. *Neuropsychologia*, *43*(2), 294–300.

Cox, A., Kohls, G., Naples, A. J., Mukerji, C. E., Coffman, M. C., Rutherford, H. J. V, … McPartland, J. C. (2015). Diminished social reward anticipation in the broad autism phenotype as revealed by event-related brain potentials. *Social Cognitive and Affective Neuroscience*, *10*(10), 1357–1364.

Crane, L., & Goddard, L. (2008). Episodic and semantic autobiographical memory in adults with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *38*(3), 498–506. https://doi.org/10.1007/s10803-007-0420-2

Crawford, H., Moss, J., Oliver, C., Elliott, N., Anderson, G. M., & McCleery, J. P. (2016). Visual preference for social stimuli in individuals with autism or neurodevelopmental disorders: an eye-tracking study. *Molecular Autism*, *7*(1), 24. https://doi.org/10.1186/s13229-016-0084-x

Cristinzio, C., N'Diaye, K., Seeck, M., Vuilleumier, P., & Sander, D. (2010).

Integration of gaze direction and facial expression in patients with unilateral amygdala damage. *Brain*, *133*(1), 248–261. https://doi.org/10.1093/brain/awp255

Critchley, H. D., Daly, E. M., Bullmore, E. T., Williams, S. C. R., Van Amelsvoort, T., Robertson, D. M., … Murphy, D. G. M. (2000). The functional neuroanatomy of social behaviour: Changes in cerebral blood flow when people with autistic disorder process facial expressions. *Brain: A Journal of Neurology*. United Kingdom: Oxford University Press. https://doi.org/10.1093/brain/123.11.2203

Csibra, G. (2008). Action mirroring and action understanding: An alternative account. *Sensorymotor Foundations of Higher Cognition. Attention and Performance XXII*, 435–459.

D’Argembeau, A., Comblain, C., & Van der Linden, M. (2005). Affective valence and the self-reference effect: Influence of retrieval conditions. *British Journal of Psychology*, *96*(4), 457–466.

D’argembeau, A., & Van der Linden, M. (2007). Facial expressions and memory for facial identity. *Emotion*, *7*(3), 507–515. https://doi.org/10.1037/1093-4510.

D’Argembeau, A., Van der Linden, M., Comblain, C., & Etienne, A. M. (2003). The effects of happy and angry expressions on identity and expression memory for unfamiliar faces. *Cognition and Emotion*, *17*(4), 609–622.

D’Argembeau, A., Van der Linden, M., Etienne, A. M., & Comblain, C. (2003). Identity and expression memory for happy and angry faces in social anxiety. *Acta Psychologica*, *114*(1), 1–15. https://doi.org/10.1016/S0001-6918(03)00047-7

Dalton, K. M., Nacewicz, B. M., Alexander, A. L., & Davidson, R. J. (2007). Gaze-fixation, brain activation, and amygdala volume in unaffected siblings of individuals with autism. *Biological Psychiatry*, *61*(4), 512–520.

Dalton, K. M., Nacewicz, B. M., Johnstone, T., Schaefer, H. S., Gernsbacher, M. A., Goldsmith, H. H., … Davidson, R. J. (2005). Gaze fixation and the neural circuitry of face processing in autism, *8*(4), 519–526. https://doi.org/10.1038/nn1421.Gaze

Daltrozzo, J., & Schön, D. (2009). Is conceptual processing in music automatic? An electrophysiological approach. *Brain Research*, *1270*, 88–94.

Dapretto, M., Davies, M. S., Pfeifer, J. H., Scott, A. A., Sigman, M., Bookheimer, S.

Y., & Iacoboni, M. (2005). Understanding emotions in others: mirror neuron dysfunction in children with autism spectrum disorders. *Nature Neuroscience*, *9*, 28. Retrieved from https://doi.org/10.1038/nn1611

Dapretto, M., Davies, M. S., Pfeifer, J. H., Scott, A. A., Sigman, M., Bookheimer, S. Y., & Iacoboni, M. (2006). Understanding emotions in others: mirror neuron dysfunction in children with autism spectrum disorders. *Nature Neuroscience*, *9*(1), 28.

Davis, J. I., Senghas, A., Brandt, F., & Ochsner, K. N. (2010). The effects of BOTOX injections on emotional experience. *Emotion (Washington, D.C.)*, *10*(3), 433–440. https://doi.org/10.1037/a0018690

Dawson, G., Meltzoff, A. N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occuring social stimuli. *Journal of Autism and Developmental Disorders*, *28*(6), 479–485. https://doi.org/10.1023/A:1026043926488

Dawson, G., Webb, S. J., & McPartland, J. C. (2005). Understanding the Nature of Face Processing Impairment in Autism: Insights From Behavioral and Electrophysiological Studies. *Developmental Neuropsychology*, *27*(3), 403–424. https://doi.org/10.1207/s15326942dn2703_6

De Gelder, B., Vroomen, J., Pourtois, G., & Weiskrantz, L. (1999). Non-conscious recognition of affect in the absence of striate cortex. *NeuroReport*, *10*(18). Retrieved from https://journals.lww.com/neuroreport/Fulltext/1999/12160/Non_conscious_recognition_of_affect_in_the_absence.7.aspx

De Gelder, B., Vroomen, J., & Van der Heide, L. (1991). Face recognition and lip-reading in autism. *European Journal of Cognitive Psychology*, *3*(1), 69–86. https://doi.org/10.1080/09541449108406220

de Houwer, J. (2006). What are implicit measures and why are we using them. *The Handbook of Implicit Cognition and Addiction*, 11–28.

de Houwer, J., & Moors, A. (2012). How to define and examine implicit processes. *Implicit and Explicit Processes in the Psychology of Science*, *183*, 198.

De Sonneville, L. M. J., Verschoor, C. A., Njiokiktjien, C., Op het Veld, V., Toorenaar, N., & Vranken, M. (2002). Facial Identity and Facial Emotions: Speed, Accuracy, and Processing Strategies in Children and Adults. *Journal of Clinical and Experimental Neuropsychology*, *24*(2), 200–213. https://doi.org/10.1076/jcen.24.2.200.989

De Wit, T. C. J., Falck-Ytter, T., & von Hofsten, C. (2008). Young children with Autism Spectrum Disorder look differently at positive versus negative emotional faces. *Research in Autism Spectrum Disorders*, *2*(4), 651–659. https://doi.org/10.1016/j.rasd.2008.01.004

DeCoster, J., Iselin, A.-M. R., & Gallucci, M. (2009). A conceptual and empirical examination of justifications for dichotomization. *Psychological Methods*. DeCoster, Jamie: Institute for Social Science Research, University of Alabama, Box 870216, Tuscaloosa, AL, US, 35487, jamie@ua.edu: American Psychological Association. https://doi.org/10.1037/a0016956

Devine, R. T., & Hughes, C. (2014). Relations Between False Belief Understanding and Executive Function in Early Childhood: A Meta-Analysis. *Child Development*, *85*(5), 1777–1794. https://doi.org/10.1111/cdev.12237

Di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: a neurophysiological study. *Experimental Brain Research*, *91*(1), 176–180.

Dienes, Z., & Berry, D. C. (1997). Implicit learning: below the subject threshold, *4*(1), 3–23. Retrieved from http://sro.sussex.ac.uk/14463/

Dienes, Z., Broadbent, D., & Berry, D. C. (1991). Implicit and explicit knowledge bases in artificial grammar learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(5), 875.

Dienes, Z., & Perner, J. (1999). A theory of implicit and explicit knowledge. *Behavioral and Brain Sciences*, *22*(5), 735–808.

Dinstein, I., Thomas, C., Humphreys, K., Minshew, N. J., Behrmann, M., & Heeger, D. J. (2010). Normal movement selectivity in autism. *Neuron*, *66*(3), 461–469.

Draine, S. C., & Greenwald, A. G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General*. US: American Psychological Association. https://doi.org/10.1037/0096-3445.127.3.286

Driver, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). *Gaze Perception Triggers Reflexive Visuospatial Orienting*. *Visual Cognition* (Vol. 6). https://doi.org/10.1080/135062899394920

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., … Brooks-Gunn, J. (2007). School readiness and later achievement. *Developmental Psychology*, *43*(6), 1428.

Eisenbarth, H., & Alpers, G. W. (2011). Happy Mouth and Sad Eyes: Scanning Emotional Facial Expressions. *Emotion*, *11*(4), 860–865. https://doi.org/10.1037/a0022758

Ekman, P. (1997). Should we call it expression or communication? *Innovation: The European Journal of Social Science Research*, *10*(4), 333–344. https://doi.org/10.1080/13511610.1997.9968538

Ekman, P., Friesen, W. V., & Ancoli, S. (1980). Facial Signs of Emotional Experience. *Journal of Personality and Social Psychology*, *39*(6), 1125–1134.

Ekman, P., & Oster, H. (1979). Facial Expressions of Emotion. *Annual Review of Psychology*, *30*, 527–554. https://doi.org/10.2307/1423637

Elison, J. T., Sasson, N. J., Turner-Brown, L. M., Dichter, G. S., & Bodfish, J. W. (2012). Age trends in visual exploration of social and nonsocial information in children with autism. *Research in Autism Spectrum Disorders*, *6*(2), 842–851.

Elsabbagh, M., Fernandes, J., Webb, S. J., Dawson, G., Charman, T., & Johnson, M. H. (2013). Disengagement of visual attention in infancy is associated with emerging autism in toddlerhood. *Biological Psychiatry*, *74*(3), 189–194.

Elsabbagh, M., Holmboe, K., Gliga, T., Mercure, E., Hudry, K., Charman, T., … Johnson, M. H. (2011). Social and attention factors during infancy and the later emergence of autism characteristics. *Progress in Brain Research*, *189*(June 2015), 195–207. https://doi.org/10.1016/B978-0-444-53884-0.00025-7

Elsabbagh, M., Volein, A., Holmboe, K., Tucker, L., Csibra, G., Baron-Cohen, S., … Johnson, M. H. (2009). Visual orienting in the early broader autism phenotype: disengagement and facilitation. *Journal of Child Psychology and Psychiatry*, *50*(5), 637–642.

Elsner, B. (2007). Infants’ imitation of goal-directed actions: The role of movements and action effects. *Acta Psychologica*, *124*(1), 44–59.

Endo, N., Endo, M., Kirita, T., & Maruyama, K. (1992). The effects of expression on face recognition. *Tohoku Psychol. Folia*, *51*, 37–44.

Evans, J. S. B. T. (2008). Dual-processing accounts of reasoning, judgment, and social cognition. *Annu. Rev. Psychol.*, *59*, 255–278.

Evers, K., Kerkhof, I., Steyaert, J., Noens, I., & Wagemans, J. (2014). No Differences in Emotion Recognition Strategies in Children with Autism Spectrum Disorder: Evidence from Hybrid Faces. *Autism Research and Treatment*, *2014*, 1–8. https://doi.org/10.1155/2014/345878

Fadiga, L., Fogassi, L., Pavesi, G., & Rizzolatti, G. (1995). Motor facilitation during action observation: a magnetic stimulation study. *Journal of Neurophysiology*, *73*(6), 2608–2611.

Falck-Ytter, T., & von Hofsten, C. (2011). How special is social looking in ASD: a review. In *Progress in brain research* (Vol. 189, pp. 209–222). Elsevier.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191.

Fazio, R. H. (2001). On the automatic activation of associated evaluations: An overview. *Cognition & Emotion*, *15*(2), 115–141. https://doi.org/10.1080/02699930125908

Fazio, R. H., Jackson, J. R., Dunton, B. C., & Williams, C. J. (1995). Variability in automatic activation as an unobtrusive measure of racial attitudes: A bona fide pipeline?. *Journal of Personality and Social Psychology*, *69*(6), 10–13. https://doi.org/10.1016/j.jfluchem.2016.06.019

Fazio, R. H., Sanbonmatsu, D. M., Powell, M. C., & Kardes, F. R. (1986). On the Automatic Activation of Attitudes. *Journal of Personality and Social Psychology*, *50*(2), 229–238. https://doi.org/10.1037/0022-3514.50.2.229

Fazio, R. H., & Towles-Schwen, T. (1999). The MODE model of attitude-behavior processes. In *Dual-process theories in social psychology.* (pp. 97–116). New York, NY, US: Guilford Press.

Ferguson, M. J., & Bargh, J. a. (2004). How social perception can automatically influence behavior. *Trends in Cognitive Sciences*, *8*(1), 33–39. https://doi.org/10.1016/j.tics.2003.11.004

Ferguson, M. J., Bargh, J. a., & Nayak, D. a. (2005). After-affects: How automatic evaluations influence the interpretation of subsequent, unrelated stimuli. *Journal of Experimental Social Psychology*, *41*(2), 182–191. https://doi.org/10.1016/j.jesp.2004.05.008

Fletcher-Watson, S., Leekam, S. R., Benson, V., Frank, M. C., & Findlay, J. M. (2009). Eye-movements reveal attention to social information in autism spectrum disorder. *Neuropsychologia*, *47*(1), 248–257. https://doi.org/10.1016/j.neuropsychologia.2008.07.016

Forkstam, C., & Petersson, K. M. (2005). Towards an explicit account of implicit learning. *Current Opinion in Neurology*, *18*(4), 435–441.

Forman, D. R., Aksan, N., & Kochanska, G. (2004). Toddlers' responsive imitation predicts preschool-age conscience. *Psychological Science*, *15*(10), 699–704.

Foti, F., Crescenzo, F. De, Vivanti, G., Menghini, D., & Vicari, S. (2014). Implicit learning in individuals with autism spectrum disorders : a meta-analysis. https://doi.org/10.1017/S0033291714001950

Frank, M. C., Vul, E., & Saxe, R. (2012). Measuring the development of social attention using free-viewing. *Infancy*, *17*(4), 355–375.

Freeth, M., Foulsham, T., & Kingstone, A. (2013). What Affects Social Attention? Social Presence, Eye Contact and Autistic Traits. *PLoS ONE*, *8*(1). https://doi.org/10.1371/journal.pone.0053286

Freire, A., Eskritt, M., & Lee, K. (2004). Are eyes windows to a deceiver's soul? Children's use of another's eye gaze cues in a deceptive situation. *Developmental Psychology*, *40*(6), 1093–1104. https://doi.org/10.1037/0012-1649.40.6.1093

Frensch, P. A., Lin, J., & Buchner, A. (1998). Learning versus behavioral expression of the learned: The effects of a secondary tone-counting task on implicit learning in the serial reaction task. *Psychological Research*, *61*(2), 83–98.

Frensch, P. A., & Miner, C. S. (1994). Effects of presentation rate and individual differences in short-term memory capacity on an indirect measure of serial learning. *Memory & Cognition*, *22*(1), 95–110.

Frensch, P. A., & Rünger, D. (2003). Implicit learning. *Current Directions in Psychological Science*, *12*(1), 13–18. https://doi.org/10.1111/1467-8721.01213

Freyd, J. J., & Finke, R. A. (1984). Representational momentum. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*(1), 126.

Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic Bulletin & Review*, *5*(3), 490–495. https://doi.org/10.3758/BF03208827

Frischen, A., Bayliss, A. P., & Tipper, S. P. (2007). Gaze cueing of attention: visual attention, social cognition, and individual differences. *Psychological Bulletin*, *133*(4), 694–724. https://doi.org/10.1037/0033-2909.133.4.694

Friston, K. J. (2010). The free-energy principle: a unified brain theory? *Nature Reviews Neuroscience*, *11*(2), 127.

Frith, C. D., & Frith, U. (1999). Interacting Minds--A Biological Basis. *Science*, *286*(5445), 1692–1695. https://doi.org/10.1126/science.286.5445.1692

Frith, C. D., & Frith, U. (2006). The Neural Basis of Mentalizing. *Neuron*, *50*(4), 531–534. https://doi.org/10.1016/j.neuron.2006.05.001

Frith, C. D., & Frith, U. (2008). Implicit and Explicit Processes in Social Cognition. *Neuron*, *60*(3), 503–510. https://doi.org/10.1016/j.neuron.2008.10.032

Frith, C. D., & Frith, U. (2012). Mechanisms of Social Cognition. *Annual Review of Psychology*, *63*(1), 287–313. https://doi.org/10.1146/annurev-psych-120710-100449

Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalizing. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *358*(1431), 459–473.

Funder, D. C., & Colvin, C. R. (1988). Friends and strangers: Acquaintanceship, agreement, and the accuracy of personality judgment. *Journal of Personality and Social Psychology*, *55*(1), 149.

Funder, D. C., Kolar, D. C., & Blackman, M. C. (1995). Agreement among judges of personality: Interpersonal relations, similarity, and acquaintanceship. *Journal of Personality and Social Psychology*, *69*(4), 656.

Furlanetto, T., Becchio, C., Samson, D., & Apperly, I. A. (2016). Altercentric interference in level 1 visual perspective taking reflects the ascription of mental states, not submentalizing. *Journal of Experimental Psychology: Human Perception and Performance*. Apperly, Ian: School of Psychology, University of Birmingham, Birmingham, United Kingdom, B15 2TT, i.a.apperly@bham.ac.uk: American Psychological Association. https://doi.org/10.1037/xhp0000138

Gallegos, D. R., & Tranel, D. (2005). Positive facial affect facilitates the identification of famous faces. *Brain and Language*, *93*(3), 338–348. https://doi.org/10.1016/j.bandl.2004.11.001

Gallese, V. (2001). The'shared manifold'hypothesis. From mirror neurons to empathy. *Journal of Consciousness Studies*, *8*(5–6), 33–50.

Gallese, V. (2007). Embodied simulation: from mirror neuron systems to interpersonal relations. In *Novartis Found Symp* (Vol. 278, pp. 3–12).

Gallese, V., & Goldman, A. (1998). Mirror neurons and the simulation theory of mind-reading. *Trends in Cognitive Sciences*, *2*(12), 493–501. https://doi.org/https://doi.org/10.1016/S1364-6613(98)01262-5

Gangopadhyay, N., & Schilbach, L. (2012). Seeing minds: a neurophilosophical investigation of the role of perception-action coupling in social perception. *Social Neuroscience*, *7*(4), 410–423.

Garner, M., Mogg, K., & Bradley, B. P. (2006). Orienting and maintenance of gaze to facial expressions in social anxiety. *Journal of Abnormal Psychology*, *115*(4), 760.

Gebauer, G. F., & Mackintosh, N. J. (2007). Psychometric intelligence dissociates implicit and explicit learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(1), 34.

Gebauer, L., Skewes, J. C., Westphael, G., Heaton, P., & Vuust, P. (2014). Intact brain processing of musical emotions in autism spectrum disorder, but more cognitive load and arousal in happy vs. sad music. *Frontiers in Neuroscience*, *8*, 192. https://doi.org/10.3389/fnins.2014.00192

George, N., & Conty, L. (2008). Facing the gaze of others. *Neurophysiologie Clinique, 38*(3), 197–207. https://doi.org/10.1016/j.neucli.2008.03.001

Ghaziuddin, M., & Mountain-Kimchi, K. (2004). Defining the intellectual profile of Asperger syndrome: Comparison with high-functioning autism. *Journal of Autism and Developmental Disorders*, *34*(3), 279–284.

Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development*. Oxford University Press, USA.

Gliga, T., & Csibra, G. (2007). Seeing the face through the eyes: a developmental perspective on face expertise. In C. von Hofsten & K. B. T.-P. in B. R. Rosander (Eds.), *From Action to Cognition* (Vol. 164, pp. 323–339). Elsevier. https://doi.org/https://doi.org/10.1016/S0079-6123(07)64018-7

Goerlich, K. S., Witteman, J., Schiller, N. O., Van Heuven, V. J., Aleman, A., & Martens, S. (2012). The nature of affective priming in music and speech. *Journal of Cognitive Neuroscience*, *24*(8), 1725–1741. https://doi.org/10.1162/jocn_a_00213

Golan, O., Baron-Cohen, S., Hill, J. J., & Rutherford, M. D. (2007). The "Reading the Mind in the Voice" test-revised: A study of complex emotion recognition in adults with and without autism spectrum conditions. *Journal of Autism and Developmental Disorders*, *37*, 1096–1106. https://doi.org/10.1007/s10803-006-0252-5

Goldman, A. (2006). *Simulating Minds: The Philosophy, Psychology, and Neuroscience of Mindreading*. *Philosophy of Mind Series*. New York: Oxford University Press. https://doi.org/10.1093/0195138929.001.0001

Goldman, A. (2009). Mirroring, Simulating and Mindreading. *Mind & Language*, *24*(2), 235–252. https://doi.org/10.1111/j.1468-0017.2008.01361.x

Gopnik, A. (2003). The theory theory as an alternative to the innateness hypothesis. *Chomsky and His Critics*, 238–254.

Gopnik, A., & Wellman, H. M. (1994). 10 The theory theory. *Mapping the Mind: Domain Specificity in Cognition and Culture*, 257.

Gopnik, A., & Wellman, H. M. (2012). Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. *Psychological Bulletin*, *138*(6), 1085.

Gordon, B., & Stark, S. (2007). Procedural learning of a visional sequence in indiviudals with Autism. *Focus on Autism and Other Developmental Disabilities*, *22*(1), 14–22. https://doi.org/10.1177/10883576070220010201

Gordon, R. M. (1986). Folk psychology as simulation. *Mind & Language*, *1*(2), 158–171.

Goren, C. C., Sarty, M., & Wu, P. Y. K. (1975). Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics*, *56*(4), 544–549.

Gottlieb, J. P., Kusunoki, M., & Goldberg, M. E. (1998). The representation of visual salience in monkey parietal cortex. *Nature*, *391*(6666), 481.

Grafton, S. T., Arbib, M. A., Fadiga, L., & Rizzolatti, G. (1996). Localization of grasp representations in humans by positron emission tomography. *Experimental Brain Research*, *112*(1), 103–111.

Grafton, S. T., & Hamilton, A. (2007). Evidence for a distributed hierarchy of action representation in the brain. *Human Movement Science*, *26*(4), 590–616. https://doi.org/10.1016/j.humov.2007.05.009

Grecucci, A., Brambilla, P., Siugzdaite, R., Londero, D., Fabbro, F., & Rumiati, R. I. (2013). Emotional Resonance Deficits in Autistic Children. *Journal of Autism and Developmental Disorders*, *43*(3), 616–628. https://doi.org/10.1007/s10803-012-1603-z

Green, M., Williams, L. M., & Davidson, D. (2003). BRIEF REPORT. *Cognition and Emotion*, *17*(5), 779–786. https://doi.org/10.1080/02699930302282

Greene, A. J., Gross, W. L., Elsinger, C. L., & Rao, S. M. (2007). Hippocampal differentiation without recognition: an fMRI analysis of the contextual cueing task. *Learning & Memory*, *14*(8), 548–553.

Grelotti, D. J., Gauthier, I., & Schultz, R. T. (2002). Social interest and the development of cortical face specialization: What autism teaches us about face processing. *Developmental Psychobiology*, *40*(3), 213–225. https://doi.org/10.1002/dev.10028

Grèzes, J., Wicker, B., Berthoz, S., & De Gelder, B. (2009). A failure to grasp the affective meaning of actions in autism spectrum disorder subjects. *Neuropsychologia*, *47*(8–9), 1816–1825.

Grice, S. J., Halit, H., Farroni, T., Baron-Cohen, S., Bolton, P., & Johnson, M. H.

(2005). Neural correlates of eye-gaze detection in young children with autism. *Cortex*, *41*(3), 342–353.

Grinter, E. J., Maybery, M. T., Van Beek, P. L., Pellicano, E., Badcock, J. C., & Badcock, D. R. (2009). Global visual processing and self-rated autistic-like traits. *Journal of Autism and Developmental Disorders*, *39*(9), 1278–1290.

Groner, R., Walder, F., & Groner, M. (1984). Looking at faces: Local and global aspects of scanpaths. In *Advances in Psychology* (Vol. 22, pp. 523–533). Elsevier.

Grossman, J. B., Klin, A., Carter, A. S., & Volkmar, F. (2003). Verbal Bias in Recognition of Facial Emotions in Children with Asperger Syndrome. *Journal of Child Psychology and Psychiatry*, *41*(3), 369–379. https://doi.org/10.1111/1469-7610.00621

Guillon, Q., Hadjikhani, N., Baduel, S., & Rogé, B. (2014). Visual social attention in autism spectrum disorder: Insights from eye tracking studies. *Neuroscience and Biobehavioral Reviews*, *42*, 279–297. https://doi.org/10.1016/j.neubiorev.2014.03.013

Haffey, A., Press, C., O'Connell, G., & Chakrabarti, B. (2013). Autistic traits modulate mimicry of social but not nonsocial rewards. *Autism Research*, *6*(6), 614–620. https://doi.org/10.1002/aur.1323

Haker, H., Schneebeli, M., & Stephan, K. E. (2016). Can Bayesian theories of autism spectrum disorder help improve clinical practice? *Frontiers in Psychiatry*, *7*(JUN), 1–17. https://doi.org/10.3389/fpsyt.2016.00107

Hall, J. A., & Schmid Mast, M. (2007). Sources of accuracy in the empathic accuracy paradigm. *Emotion*, *7*(2), 438.

Halliday, D. W. R., MacDonald, S. W. S., Sherf, S. K., & Tanaka, J. W. (2014). A reciprocal model of face recognition and autistic traits: evidence from an individual differences perspective. *PloS One*, *9*(5), e94013.

Hamilton, A. (2013). Reflecting on the mirror neuron system in autism: A systematic review of current theories. *Developmental Cognitive Neuroscience*, *3*(1), 91–105. https://doi.org/10.1016/j.dcn.2012.09.008

Hamilton, A., Brindley, R. M., & Frith, U. (2007). Imitation and action understanding in autistic spectrum disorders: how valid is the hypothesis of a deficit in the mirror neuron system? *Neuropsychologia*, *45*(8), 1859–1868.

Happé, F. (1994). An advanced test of theory of mind: Understanding of story characters' thoughts and feelings by able autistic, mentally handicapped, and normal children and adults. *Journal of Autism and Developmental Disorders*, *24*(2), 129–154. https://doi.org/10.1007/BF02172093

Happé, F. (1995). The role of age and verbal ability in the theory of mind task performance of subjects with autism. *Child Development*, *66*(3), 843–855.

Happé, F., & Frith, U. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *36*(1), 5–25.

Harms, M. B., Martin, A., & Wallace, G. L. (2010). Facial emotion recognition in autism spectrum disorders: A review of behavioral and neuroimaging studies. *Neuropsychology Review*, *20*(3), 290–322. https://doi.org/10.1007/s11065-010-9138-6

Hauck, M., Fein, D., Maltby, N., Waterhouse, L., & Feinstein, C. (1998). Memory for Faces in Children with Autism. *Child Neuropsychology (Neuropsychology, Development and Cognition: Section C)*, *4*(March 2015), 187–198. https://doi.org/10.1076/chin.4.3.187.3174

Hauf, P., & Aschersleben, G. (2008). Action–effect anticipation in infant action control. *Psychological Research*, *72*(2), 203–210.

Havet-Thomassin, V., Allain, P., Etcharry-Bouyx, F., & Le Gall, D. (2006). What about theory of mind after severe brain injury? *Brain Injury*, *20*(1), 83–91. https://doi.org/10.1080/02699050500340655

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*(6), 223–233. https://doi.org/10.1016/S1364-6613(00)01482-0

Heaton, P. (2005). Interval and contour processing in autism. *Journal of Autism and Developmental Disorders*, *35*(6), 787.

Heaton, P., Pring, L., & Hermelin, B. (1999). A pseudo-savant: A case of exceptional musical splinter skills. *Neurocase*, *5*(6), 503–509.

Heerey, E. A., & Velani, H. (2010). Implicit learning of social predictions. *Journal of*

Experimental Social Psychology, *46*(3), 577–581. https://doi.org/10.1016/j.jesp.2010.01.003

Heider, F., & Simmel, M. (1944). An Experimental Study of Apparent Behavior. *The American Journal of Psychology*, *57*(2), 243–259. https://doi.org/10.2307/1416950

Hellendoorn, A., Wijnroks, L., & Leseman, P. P. M. (2015). Unraveling the nature of autism: Finding order amid change. *Frontiers in Psychology*, *6*(MAR), 1–16. https://doi.org/10.3389/fpsyg.2015.00359

Helminen, T. M., Leppänen, J. M., Eriksson, K., Luoma, A., Hietanen, J. K., & Kylliäinen, A. (2017). Atypical physiological orienting to direct gaze in low-functioning children with autism spectrum disorder. *Autism Research*, *10*(5), 810–820. https://doi.org/10.1002/aur.1738

Henderson, J. M., Williams, C. C., & Falk, R. J. (2005). Eye movements are functional during face learning. *Memory & Cognition*, *33*(1), 98–106. https://doi.org/10.3758/BF03195300

Hernandez, N., Metzger, A., Magné, R., Bonnet-Brilhault, F., Roux, S., Barthelemy, C., & Martineau, J. (2009). Exploration of core features of a human face by healthy and autistic adults analyzed by visual scanning. *Neuropsychologia*, *47*(4), 1004–1012. https://doi.org/10.1016/j.neuropsychologia.2008.10.023

Heyes, C. M., & Frith, C. D. (2014). The cultural evolution of mind reading. *Science*, *344*(6190). Retrieved from http://science.sciencemag.org/content/344/6190/1243091.abstract

Hikosaka, O., Nakamura, K., Sakai, K., & Nakahara, H. (2002). Central mechanisms of motor skill learning. *Current Opinion in Neurobiology*, *12*(2), 217–222.

Hill, T., Lewicki, P., Czyzewska, M., & Schuller, G. (1990). The role of learned inferential encoding rules in the perception of faces: Effects of nonconscious self-perpetuation of a bias. *Journal of Experimental Social Psychology*, *26*(4), 350–371. https://doi.org/10.1016/0022-1031(90)90044-M

Hobson, R. P. (1986a). THE AUTISTIC CHILD'S APPRAISAL OF EXPRESSIONS OF EMOTION: A FURTHER STUDY. *Journal of Child Psychology and Psychiatry*, *27*(5), 671–680. https://doi.org/10.1111/j.1469-7610.1986.tb00191.x

Hobson, R. P. (1986b). THE AUTISTIC CHILD'S APPRAISAL OF EXPRESSIONS

OF EMOTION. *Journal of Child Psychology and Psychiatry*, *27*(3), 321–342. https://doi.org/10.1111/j.1469-7610.1986.tb01836.x

Hobson, R. P., Ouston, J., & Lee, A. Y. (1988). Emotion recognition in autism: coordinating faces and voices. *Psychological Medicine*, *18*, 911–923. https://doi.org/10.1017/S0033291700009843

Hodgkinson, G. P., Langan-Fox, J., & Sadler-Smith, E. (2008). Intuition: A fundamental bridging construct in the behavioural sciences. *British Journal of Psychology*, *99*(1), 1–27. https://doi.org/10.1348/000712607X216666

Hoekstra, R. A., Bartels, M., Cath, D. C., & Boomsma, D. I. (2008). Factor structure, reliability and criterion validity of the Autism-Spectrum Quotient (AQ): a study in Dutch population and patient groups. *Journal of Autism and Developmental Disorders*, *38*(8), 1555–1566.

Hohwy, J., & Palmer, C. J. (2014). Social Cognition as Causal Inference: Implications for Common Knowledge and Autism BT - Perspectives on Social Ontology and Social Cognition. In M. Gallotti & J. Michael (Eds.) (pp. 167–189). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-9147-2_12

Honda, M., Deiber, M.-P., Ibánez, V., Pascual-Leone, A., Zhuang, P., & Hallett, M. (1998). Dynamic cortical involvement in implicit and explicit motor sequence learning. A PET study. *Brain: A Journal of Neurology*, *121*(11), 2159–2173.

Howard Jr, J. H., Howard, D. V, Japikse, K. C., & Eden, G. F. (2006). Dyslexics are impaired on implicit higher-order sequence learning, but not on implicit spatial context learning. *Neuropsychologia*, *44*(7), 1131–1144.

Howlin, P., Goode, S., Hutton, J., & Rutter, M. (2004). Adult outcome for children with autism. *Journal of Child Psychology and Psychiatry*, *45*(2), 212–229.

Hsiao, J. H., & Cottrell, G. W. (2008). Two fixations suffice in face recognition. *Psychological Science*, *19*(10), 998–1006.

Hudson, M., Burnett, H. G., & Jellema, T. (2012). Anticipation of Action Intentions in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *42*(8), 1684–1693. https://doi.org/10.1007/s10803-011-1410-y

Hudson, M., & Jellema, T. (2011). Resolving ambiguous behavioral intentions by means of involuntary prioritization of gaze processing. *Emotion*. Hudson, Matthew: Department of Psychology, University of Hull, Cottingham Road, East Yorkshire, Hull, United Kingdom, HU6 7RX, matthudson50@gmail.com: American Psychological Association. https://doi.org/10.1037/a0023264

Hudson, M., Jellema, T., & Liu, H. (2009). The Role of Social Cues in the Involuntary Attribution of Intentionality. *Psychology*, *Doctor of*(December), 229.

Hudson, M., Liu, C. H., & Jellema, T. (2009). Anticipating intentional actions: The effect of eye gaze direction on the judgment of head rotation. *Cognition*, *112*(3), 423–434. https://doi.org/https://doi.org/10.1016/j.cognition.2009.06.011

Hudson, M., Nicholson, T., Simpson, W. A., Ellis, R., & Bach, P. (2016). One step ahead: The perceived kinematics of others' actions are biased toward expected goals. *Journal of Experimental Psychology: General*, *145*(1), 1–7. https://doi.org/10.1037/xge0000126

Hudson, M., Nijboer, T. C. W., & Jellema, T. (2012). Implicit social learning in relation to autistic-like traits. *Journal of Autism and Developmental Disorders*, *42*(12), 2534–2545. https://doi.org/10.1007/s10803-012-1510-3

Humphreys, K., Minshew, N. J., Leonard, G. L., & Behrmann, M. (2007). A fine-grained analysis of facial expression processing in high-functioning adults with autism. *Neuropsychologia*, *45*(4), 685–695. https://doi.org/10.1016/j.neuropsychologia.2006.08.003

Humphreys, L. G. (1978). Doing research the hard way: Substituting analysis of variance for a problem in correlational analysis. *Journal of Educational Psychology*. US: American Psychological Association. https://doi.org/10.1037/0022-0663.70.6.873

Hunnius, S., De Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition and Emotion*, *25*(2), 193–205.

Hunnius, S., & Geuze, R. H. (2004). Developmental changes in visual scanning of dynamic faces and abstract stimuli in infants: A longitudinal study. *Infancy*, *6*(2), 231–255.

Hus, V., & Lord, C. (2014). The autism diagnostic observation schedule, module 4: revised algorithm and standardized severity scores. *Journal of Autism and*

Developmental Disorders, *44*(8), 1996–2012. https://doi.org/10.1007/s10803-014-2080-3

Iacoboni, M., Molnar-Szakacs, I., Gallese, V., Buccino, G., Mazziotta, J. C., & Rizzolatti, G. (2005). Grasping the intentions of others with one's own mirror neuron system. *PLoS Biology*, *3*(3), e79.

Iacobucci, D., Posavac, S. S., Kardes, F. R., Schneider, M. J., & Popovich, D. L. (2015). Toward a more nuanced understanding of the statistical properties of a median split. *Journal of Consumer Psychology*, *25*(4), 652–665. https://doi.org/10.1016/j.jcps.2014.12.002

Ilie, G., & Thompson, W. F. (2006). A comparison of acoustic cues in music and speech for three dimensions of affect. *Music Perception: An Interdisciplinary Journal*, *23*(4), 319–330.

Ingersoll, B., & Gergans, S. (2007). The effect of a parent-implemented imitation intervention on spontaneous imitation skills in young children with autism. *Research in Developmental Disabilities*, *28*(2), 163–175.

Ipser, A., & Cook, R. (2016). Inducing a concurrent motor load reduces categorization precision for facial expressions. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(5), 706.

Jackson, M. C. (2018). Eye gaze influences working memory for happy but not angry faces. *Cognition and Emotion*, *32*(4), 719-728.

Janacsek, K., Fiser, J., & Nemeth, D. (2012). The best time to acquire new skills: Age-related differences in implicit sequence learning across the human lifespan. *Developmental Science*, *15*, 496–505. https://doi.org/10.1111/j.1467-7687.2012.01150.x

Janacsek, K., & Nemeth, D. (2012). Predicting the future: From implicit learning to consolidation. *International Journal of Psychophysiology*, *83*(2), 213–221. https://doi.org/10.1016/j.ijpsycho.2011.11.012

Jellema, T., Lorteije, J., Van Rijn, S., van T'Wout, M., De Haan, E., Van Engeland, H., & Kemner, C. (2009). Involuntary interpretation of social cues is compromised in autism spectrum disorders. *Autism Research*, *2*(July), 192–204. https://doi.org/10.1002/aur.83

Jellema, T., Pecchinenda, A., Palumbo, L., & Tan, E. G. (2011). Biases in the perception and affective valence of neutral facial expressions induced by the immediate perceptual history. *Visual Cognition*, *19*(930967795), 616–634. https://doi.org/10.1080/13506285.2011.569775

Jellema, T., & Perrett, D. I. (2002). *Coding of visible and hidden actions*. *Common mechanisms in perception an action* (Vol. 19).

Jellema, T., & Perrett, D. I. (2006). Neural representations of perceived bodily actions using a categorical frame of reference. *Neuropsychologia*, *44*(9), 1535–1546. https://doi.org/https://doi.org/10.1016/j.neuropsychologia.2006.01.020

Jellema, T., & Perrett, D. I. (2007). Neural pathways of social cognition. *The Oxford Handbook of Evolutionary Psychology*, (June 2015). https://doi.org/10.1093/oxfordhb/9780198568308.013.0013

Jellema, T., & Perrett, D. I. (2012). Neural pathways of social cognition. *Oxford Handbook of Evolutionary Psychology*, (September). https://doi.org/10.1093/oxfordhb/9780198568308.013.0013

Jiménez, L., & Vázquez, G. A. (2011). Implicit sequence learning and contextual cueing do not compete for central cognitive resources. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(1), 222.

Johnson, M. H. (2005). Subcortical face processing. *Nature Reviews Neuroscience*, *6*(10), 766.

Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, *40*(1–2), 1–19.

Jones, W., Carr, K., & Klin, A. (2008). Absence of preferential looking to the eyes of approaching adults predicts level of social disability in 2-year-old toddlers with autism spectrum disorder. *Archives of General Psychiatry*, *65*(8), 946–954.

Jones, W., & Klin, A. (2013). Attention to eyes is present but in decline in 2–6-month-old infants later diagnosed with autism. *Nature*, *504*(7480), 427.

Joseph, R. M., Ehrman, K., McNally, R., & Keehn, B. (2008). Affective response to eye contact and face recognition ability in children with ASD. *Journal of the International Neuropsychological Society*, *14*(06), 947.

https://doi.org/10.1017/S1355617708081344

Joseph, R. M., Keehn, B., Connolly, C., Wolfe, J. M., & Horowitz, T. S. (2009). Why is visual search superior in autism spectrum disorder? *Developmental Science*, *12*(6), 1083–1096.

Joseph, R. M., & Tager-Flusberg, H. (2004). The relationship of theory of mind and executive functions to symptom type and severity in children with autism. *Development and Psychopathology*, *16*(1), 137–155. https://doi.org/10.1017/S095457940404444X

Joseph, R. M., & Tanaka, J. W. (2003). Holistic and part-based face recognition in children with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *44*(4), 529–542. https://doi.org/10.1111/1469-7610.00142

Just, M. A., Cherkassky, V. L., Keller, T. A., Kana, R. K., & Minshew, N. J. (2006). Functional and anatomical cortical underconnectivity in autism: evidence from an FMRI study of an executive function task and corpus callosum morphometry. *Cerebral Cortex*, *17*(4), 951–961.

Just, M. A., Cherkassky, V. L., Keller, T. A., & Minshew, N. J. (2004). Cortical activation and synchronization during sentence comprehension in high-functioning autism: evidence of underconnectivity. *Brain*, *127*(8), 1811–1821.

Kaartinen, M., Puura, K., Mäkelä, T., Rannisto, M., Lemponen, R., Helminen, M., … Hietanen, J. K. (2012). Autonomic arousal to direct gaze correlates with social impairments among children with ASD. *Journal of Autism and Developmental Disorders*, *42*(9), 1917–1927. https://doi.org/10.1007/s10803-011-1435-2

Kamio, Y., Wolf, J. M., & Fein, D. (2006). Automatic processing of emotional faces in high-functioning pervasive developmental disorders: An affective priming study. *Journal of Autism and Developmental Disorders*, *36*(2), 155–167. https://doi.org/10.1007/s10803-005-0056-z

Kampe, K. K. W., Frith, C. D., & Frith, U. (2003). “Hey John”: Signals conveying communicative intention toward the self activate brain regions associated with “mentalizing,” regardless of modality. *The Journal of Neuroscience*, *23*(12), 5258–5263. https://doi.org/10.1002/hbm.21164

Kana, R. K., Keller, T. A., Cherkassky, V. L., Minshew, N. J., & Just, M. A. (2006).

Sentence comprehension in autism: thinking in pictures with decreased functional connectivity. *Brain*, *129*(9), 2484–2493.

Kana, R. K., Patriquin, M. A., Black, B. S., Channell, M. M., & Wicker, B. (2016). Altered Medial Frontal and Superior Temporal Response to Implicit Processing of Emotions in Autism. *Autism Research*, *9*(1), 55–66. https://doi.org/10.1002/aur.1496

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: a module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience*, *17*(11), 4302–4311.

Kaufman, J., & Johnston, P. J. (2014). Facial motion engages predictive visual mechanisms. *PloS One*, *9*(3), e91038. https://doi.org/10.1371/journal.pone.0091038

Kaufman, S. B., DeYoung, C. G., Gray, J. R., Jiménez, L., Brown, J., & Mackintosh, N. J. (2010). Implicit learning as an ability. *Cognition*, *116*(3), 321–340. https://doi.org/10.1016/j.cognition.2010.05.011

Kaufmann, J. M., & Schweinberger, S. R. (2004). Expression influences the recognition of familiar faces. *Perception*, *33*(4), 399–408. https://doi.org/10.1068/p5083

Kawashima, R., Sugiura, M., Kato, T., Nakamura, A., Hatano, K., Ito, K., … Nakamura, K. (1999). The human amygdala plays an important role in gaze monitoring: A PET study. *Brain*, *122*(4), 779–783. https://doi.org/10.1093/brain/122.4.779

Keele, S. W., Ivry, R. I., Mayr, U., Hazeltine, E., & Heuer, H. (2003). The cognitive and neural architecture of sequence representation. *Psychological Review*, *110*(2), 316.

Keltner, D., Ekman, P., Gonzaga, G. C., & Beer, J. S. (2003). *Handbook of affective sciences*. New York, NY.

Kennedy, D. P., & Adolphs, R. (2012). Perception of emotions from facial expressions in high-functioning adults with autism. *Neuropsychologia*, *50*(14), 3313–3319. https://doi.org/10.1016/j.neuropsychologia.2012.09.038

Keysers, C., & Gazzola, V. (2007). Integrating simulation and theory of mind: from self to social cognition. *Trends in Cognitive Sciences*, *11*(5), 194–196.

Kilner, J. M., Neal, A., Weiskopf, N., Friston, K. J., & Frith, C. D. (2009). Evidence of mirror neurons in human inferior frontal gyrus. *Journal of Neuroscience*, *29*(32), 10153–10159.

Kirita, T., & Endo, M. (1995). Happy face advantage in recognizing facial expressions. *Acta Psychologica*, *89*(2), 149–163. https://doi.org/10.1016/0001-6918(94)00021-8

Klauer, K. C., & Musch, J. (2003). Affective priming: Findings and theories. In *The psychology of evaluation: Affective processes in cognition and emotion.* (pp. 7–49). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Kleinhans, N. M., Richards, T., Johnson, L. C., Weaver, K. E., Greenson, J., Dawson, G., & Aylward, E. (2011). fMRI evidence of neural abnormalities in the subcortical face processing system in ASD. *NeuroImage*, *54*(1), 697–704. https://doi.org/https://doi.org/10.1016/j.neuroimage.2010.07.037

Kliemann, D., Dziobek, I., Hatri, A., Baudewig, J., & Heekeren, H. R. (2012). The role of the amygdala in atypical gaze on emotional faces in autism spectrum disorders. *Journal of Neuroscience*, *32*(28), 9469–9476.

Kliemann, D., Dziobek, I., Hatri, A., Steimke, R., & Heekeren, H. R. (2010). Atypical Reflexive Gaze Patterns on Emotional Faces in Autism Spectrum Disorders. *Journal of Neuroscience*, *30*(37), 12281–12287. https://doi.org/10.1523/JNEUROSCI.0688-10.2010

Klin, A., Jones, W., Schultz, R. T., & Volkmar, F. (2003). The enactive mind, or from actions to cognition: lessons from autism. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *358*(1430), 345–360.

Klin, A., Jones, W., Schultz, R. T., Volkmar, F., & Cohen, D. (2002). Visual Fixation Patterns During Viewing of Naturalistic Social Situations as Predictors of Social Competence in Individuals With Autism. *Archives of General Psychiatry*, *59*(9), 809. https://doi.org/10.1001/archpsyc.59.9.809

Klinger, L. G., & Dawson, G. (2001). Prototype formation in autism. *Development and Psychopathology*, *13*(1), 111–124.

Klinger, L. G., Klinger, M. R., & Pohlig, R. L. (2007). Implicit learning impairments in autism spectrum disorders. *New Developments in Autism: The Future Is Today*, 76–103.

Koelsch, S. (2006). Significance of Broca's area and ventral premotor cortex for music-syntactic processing. *Cortex*, *42*(4), 518–520.

Koelsch, S. (2011). Toward a neural basis of music perception–a review and updated model. *Frontiers in Psychology*, *2*, 110.

Koelsch, S., Gunter, T., Friederici, A. D., & Schröger, E. (2000). Brain indices of music processing:"nonmusicians" are musical. *Journal of Cognitive Neuroscience*, *12*(3), 520–541.

Koelsch, S., & Siebel, W. A. (2005). Towards a neural basis of music perception. *Trends in Cognitive Sciences*, *9*(12), 578–584.

Korb, S., Grandjean, D., & Scherer, K. R. (2010). Timing and voluntary suppression of facial mimicry to smiling faces in a Go/NoGo task—An EMG study. *Biological Psychology*, *85*(2), 347–349. https://doi.org/https://doi.org/10.1016/j.biopsycho.2010.07.012

Korkmaz, B. (2011). Theory of Mind and Neurodevelopmental Disorders of Childhood. *Pediatric Research*, *69*, 101R. Retrieved from https://doi.org/10.1203/PDR.0b013e318212c177

Kourkoulou, A., Kuhn, G., Findlay, J. M., & Leekam, S. R. (2013). Eye Movement Difficulties in Autism Spectrum Disorder: Implications for Implicit Contextual Learning. *Autism Research*, *6*(3), 177–189. https://doi.org/10.1002/aur.1274

Kourkoulou, A., Leekam, S. R., & Findlay, J. M. (2012). Implicit Learning of Local Context in Autism Spectrum Disorder, 244–256. https://doi.org/10.1007/s10803-011-1237-6

Kowler, E., Anderson, E., Dosher, B., & Blaser, E. (1995). The role of attention in the programming of saccades. *Vision Research*, *35*(13), 1897–1916. https://doi.org/https://doi.org/10.1016/0042-6989(94)00279-U

Kret, M. E., & De Gelder, B. (2012). A review on sex differences in processing emotional signals. *Neuropsychologia*, *50*(7), 1211–1221. https://doi.org/10.1016/j.neuropsychologia.2011.12.022

Krol, M. A., Schutter, D. J. L. G., & Jellema, T. (2018). Mu Suppression during

Anticipation of Predictable Actions Performed by Other Agents.

Krumhuber, E. G., Likowski, K. U., & Weyers, P. (2014). Facial mimicry of spontaneous and deliberate Duchenne and non-Duchenne smiles. *Journal of Nonverbal Behavior*, *38*(1), 1–11.

Krumhuber, E. G., Manstead, A. S. R., Cosker, D., Marshall, D., Rosin, P. L., & Kappas, A. (2007). Facial Dynamics as Indicators of Trustworthiness and Cooperative Behavior. *Emotion*, *7*(4), 730–735. https://doi.org/10.1037/1528-3542.7.4.730

Kuusikko, S., Pollock-Wurman, R., Jussila, K., Carter, A. S., Mattila, M. L., Ebeling, H., … Moilanen, I. (2008). Social anxiety in high-functioning children and adolescents with autism and {A}sperger syndrome. *Journal of Autism and Developmental Disorders*, *38*(9), 1697–1709. https://doi.org/10.1007/s10803-008-0555-9

Kylliäinen, A., & Hietanen, J. K. (2006). Skin conductance responses to another person's gaze in children with autism. *Journal of Autism and Developmental Disorders*, *36*(4), 517–525. https://doi.org/10.1007/s10803-006-0091-4

Kylliäinen, A., Wallace, S., Coutanche, M. N., Leppänen, J. M., Cusack, J., Bailey, A. J., & Hietanen, J. K. (2012). Affective-motivational brain responses to direct gaze in children with autism spectrum disorder. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *53*(7), 790–797. https://doi.org/10.1111/j.1469-7610.2011.02522.x

Larøi, F., D'Argembeau, A., & Van der Linden, M. (2006). The effects of angry and happy expressions on recognition memory for unfamiliar faces in delusion-prone individuals. *Journal of Behavior Therapy and Experimental Psychiatry*, *37*(4), 271–282. https://doi.org/10.1016/j.jbtep.2005.11.001

Larson, J. C. G., & Mostofsky, S. H. (2008). Evidence That the Pattern of Visuomotor Sequence Learning Is Aotered in Children With Autism. *Autism Research*, *1*(6), 341–353. https://doi.org/10.1002/aur.54.Evidence

Law Smith, M. J., Montagne, B., Perrett, D. I., Gill, M., & Gallagher, L. (2010). Detecting subtle facial emotion recognition deficits in high-functioning Autism using dynamic stimuli of varying intensities. *Neuropsychologia*, *48*(9), 2777–

2781. https://doi.org/https://doi.org/10.1016/j.neuropsychologia.2010.03.008

LeDoux, J. E. (1996). *The emotional brain: The mysterious underpinnings of emotional life. The emotional brain: The mysterious underpinnings of emotional life.* New York, NY, US: Simon & Schuster.

Lee, I.-S., Yoon, S.-S., Lee, S.-H., Lee, H., Park, H.-J., Wallraven, C., & Chae, Y. (2013). An amplification of feedback from facial muscles strengthened sympathetic activations to emotional facial cues. *Autonomic Neuroscience: Basic and Clinical*, *179*(1), 37–42. https://doi.org/10.1016/j.autneu.2013.06.009

Leekam, S. R., Baron-Cohen, S., Perrett, D. I., Milders, M., & Brown, S. (1997). Eye-direction detection: A dissociation between geometric and joint attention skills in autism. *British Journal of Developmental Psychology*, *15*(1), 77–95.

Leekam, S. R., & Perner, J. (1991). Does the autistic child have a metarepresentational deficit? *Cognition*, *40*(3), 203–218.

Legerstee, M., Barna, J., & DiAdamo, C. (2000). Precursors to the development of intention at 6 months: Understanding people and their actions. *Developmental Psychology*, *36*(5), 627.

Leppänen, J. M., & Hietanen, J. K. (2004). Positive facial expressions are recognized faster than negative facial expressions, but why? *Psychological Research*, *69*(1–2), 22–29. https://doi.org/10.1007/s00426-003-0157-2

Leslie, A. M., Friedman, O., & German, T. P. (2004). Core mechanisms in 'theory of mind.' *Trends in Cognitive Sciences*, *8*(12), 528–533.

Lewicki, P. (1986). Processing information about covariations that cannot be articulated. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *12*(1), 135.

Lewicki, P., Hill, T., & Czyzewska, M. (1992). Nonconscious acquisition of information. *American Psychologist*, *47*(6), 796.

Lewicki, P., Hill, T., & Czyzewska, M. (1994). Nonconscious indirect inferences in encoding. *General Journal Of Experimental Psycgology*, *123*(3), 257–263.

Liddell, B. J., Brown, K. J., Kemp, A. H., Barton, M. J., Das, P., Peduto, A., … Williams, L. M. (2005). A direct brainstem-amygdala-cortical "alarm" system for subliminal signals of fear. *NeuroImage*, *24*(1), 235–243.

https://doi.org/10.1016/j.neuroimage.2004.08.016

Lieberman, M. D. (2000). Intuition: a social cognitive neuroscience approach. *Psychological Bulletin*, *126*(1), 109–137. https://doi.org/10.1037/0033-2909.126.1.109

Lieberman, M. D. (2003). A social cognitive neuroscience approach. *Social Judgments: Implicit and Explicit Processes*, *5*, 44.

Lieberman, M. D. (2007). The X-and C-systems. *Social Neuroscience: Integrating Biological and Psychological Explanations of Social Behavior*, 290–315.

Lind, S. E. (2010). Memory and the self in autism: A review and theoretical framework. *Autism*, *14*(5), 430–456. https://doi.org/10.1177/1362361309358700

Lindner, J. L., & Rosén, L. A. (2006). Decoding of Emotion through Facial Expression, Prosody and Verbal Content in Children and Adolescents with Asperger's Syndrome. *Journal of Autism and Developmental Disorders*, *36*(6), 769–777. https://doi.org/10.1007/s10803-006-0105-2

Liu, C. H., Chen, W., & Ward, J. (2014). Remembering faces with emotional expressions. *Frontiers in Psychology*, *5*(DEC), 1–7. https://doi.org/10.3389/fpsyg.2014.01439

Lobmaier, J. S., Tiddeman, B. P., & Perrett, D. I. (2008). Emotional expression modulates perceived gaze direction. *Emotion*, *8*(4), 573–577. https://doi.org/10.1037/1528-3542.8.4.573

Lombardo, M. V., Barnes, J. L., Wheelwright, S., & Baron-Cohen, S. (2007). Self-referential cognition and empathy in austism. *PLoS ONE*, *2*(9). https://doi.org/10.1371/journal.pone.0000883

Lord, C., Rutter, M., DiLavore, P., & Risi, S. (2008). *Autism Diagnostic Observation Schedule: Manual* (5th ed.). Los Angeles, CA: Western Psychological Services.

Losh, M., & Capps, L. (2003). Narrative ability in high-functioning children with autism or Asperger's Syndrome. *Journal of Autism and Developmental Disorders*, *33*(3), 239–251. https://doi.org/10.1023/A:1024446215446

Louwerse, A., Van der Geest, J. N., Tulen, J. H. M., Van der Ende, J., Van Gool, A. R., Verhulst, F. C., & Greaves-Lord, K. (2013). Effects of eye gaze directions of facial images on looking behaviour and autonomic responses in adolescents with autism spectrum disorders. *Research in Autism Spectrum Disorders*, *7*(9), 1043–1053. https://doi.org/10.1016/j.rasd.2013.04.013

Low, J., & Perner, J. (2012). Implicit and explicit theory of MD: State of the art. *British Journal of Developmental Psychology*, *30*(1), 1–13. https://doi.org/10.1111/j.2044-835X.2011.02074.x

Luo, Y. (2011). Do 10-month-old infants understand others' false beliefs? *Cognition*, *121*(3), 289–298. https://doi.org/https://doi.org/10.1016/j.cognition.2011.07.011

Luo, Y., & Johnson, S. C. (2008). Recognizing the role of perception in action at 6 months. *Developmental Science*, *12*(1), 142–149. https://doi.org/10.1111/j.1467-7687.2008.00741.x

Magiati, I., Tay, X. W., & Howlin, P. (2014). Cognitive, language, social and behavioural outcomes in adults with autism spectrum disorders: a systematic review of longitudinal follow-up studies in adulthood. *Clinical Psychology Review*, *34*(1), 73–86.

Manor, B. R., & Gordon, E. (2003). Defining the temporal threshold for ocular fixation in free-viewing visuocognitive tasks. *Journal of Neuroscience Methods*, *128*(1–2), 85–93.

Marsh, A. A., Ambady, N., & Kleck, R. E. (2005). The Effects of Fear and Anger Facial Expressions on Approach- and Avoidance-Related Behaviors. *Emotion*, *5*(1), 119–124. https://doi.org/10.1037/1528-3542.5.1.119

Marsh, L. E., & Hamilton, A. (2011). Dissociation of mirroring and mentalising systems in autism. *Neuroimage*, *56*(3), 1511–1519.

Mason, M. F., Hood, B. M., & Macrae, C. N. (2004). Look into my eyes: gaze direction and person memory. *Memory (Hove, England)*, *12*(5), 637–643. https://doi.org/10.1080/09658210344000152

Maxwell, S. E., & Delaney, H. D. (1993). Bivariate median splits and spurious statistical significance. *Psychological Bulletin*. US: American Psychological Association. https://doi.org/10.1037/0033-2909.113.1.181

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, *38*(1), 43–52.

Mayo, J., & Eigsti, I.-M. (2012). Brief Report: A Comparison of Statistical Learning in

School-Aged Children with High Functioning Autism and Typically Developing Peers. *Journal of Autism and Developmental Disorders*, *42*(11), 2476–2485. https://doi.org/10.1007/s10803-012-1493-0

McClure, E. B. (2000). A meta-analytic review of sex differences in facial expression processing and their development in infants, children, and adolescents. *Psychological Bulletin*. US: American Psychological Association. https://doi.org/10.1037/0033-2909.126.3.424

McConnell, A. R., & Leibold, J. M. (2001). Relations among the Implicit Association Test, discriminatory behavior, and explicit measures of racial attitudes. *Journal of Experimental Social Psychology*, *37*(5), 435–442. https://doi.org/10.1006/jesp.2000.1470

McGaugh, J. L. (2000). Memory--a Century of Consolidation. *Science*, *287*(5451), 248–251. https://doi.org/10.1126/science.287.5451.248

McIntosh, D. N., Reichmann-Decker, A., Winkielman, P., & Wilbarger, J. L. (2006). When the social mirror breaks: deficits in automatic, but not voluntary, mimicry of emotional facial expressions in autism. *Developmental Science*, *9*(3), 295–302.

McPartland, J. C., Webb, S. J., Keehn, B., & Dawson, G. (2011). Patterns of visual attention to faces and objects in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *41*(2), 148–157. https://doi.org/10.1007/s10803-010-1033-8

Meier, B., Weiermann, B., Gutbrod, K., Stephan, M. A., Cock, J., Müri, R. M., & Kaelin-Lang, A. (2013). Implicit task sequence learning in patients with Parkinson's disease, frontal lesions and amnesia: The critical role of fronto-striatal loops. *Neuropsychologia*, *51*(14), 3014–3024. https://doi.org/10.1016/j.neuropsychologia.2013.10.009

Merrell, C., Sayal, K., Tymms, P., & Kasim, A. (2017). A longitudinal study of the association between inattention, hyperactivity and impulsivity and children's academic attainment at age 11. *Learning and Individual Differences*, *53*, 156–161. https://doi.org/https://doi.org/10.1016/j.lindif.2016.04.003

Meyer, M. L., & Lieberman, M. D. (2015). Social Working Memory Training

Improves Perspective-Taking Accuracy. *Social Psychological and Personality Science*, *7*(4), 381–389. https://doi.org/10.1177/1948550615624143

Meyer, M. L., Taylor, S. E., & Lieberman, M. D. (2015). Social working memory and its distinctive link to social cognitive ability: An fMRI study. *Social Cognitive and Affective Neuroscience*, *10*(10), 1338–1347. https://doi.org/10.1093/scan/nsv065

Meyers, J. E., Zellinger, M. M., Kockler, T., Wagner, M., & Miller, R. M. (2013). A Validated Seven-Subtest Short Form for the WAIS-IV. *Applied Neuropsychology: Adult*, *20*(4), 249–256. https://doi.org/10.1080/09084282.2012.710180

Milders, M., Hietanen, J. K., Leppänen, J. M., & Braun, M. (2011). Detection of emotional faces is modulated by the direction of eye gaze. *Emotion*, *11*(6), 1456.

Minati, L., Rosazza, C., D'incerti, L., Pietrocini, E., Valentini, L., Scaioli, V., … Bruzzone, M. G. (2009). Functional MRI/event-related potential study of sensory consonance and dissonance in musicians and nonmusicians. *Neuroreport*, *20*(1), 87–92.

Minio-Paluello, I., Baron-Cohen, S., Avenanti, A., Walsh, V., & Aglioti, S. M. (2009). Absence of embodied empathy during pain observation in Asperger syndrome. *Biological Psychiatry*, *65*(1), 55–62.

Minshew, N. J., Goldstein, G., & Siegel, D. J. (1997). Neuropsychologic functioning in autism: Profile of a complex information processing disorder. *Journal of the International Neuropsychological Society*, *3*(4), 303–316.

Minshew, N. J., & Williams, D. L. (2007). The new neurobiology of autism: cortex, connectivity, and neuronal organization. *Archives of Neurology*, *64*(7), 945–950.

Mitchell, J. P. (2005). The false dichotomy between simulation and theory-theory: the argument's error. *Trends in Cognitive Sciences*, *9*(8), 363–364.

Mitchell, P., Currie, G., & Ziegler, F. (2009). Two routes to perspective: Simulation and rule-use as approaches to mentalizing. *British Journal of Developmental Psychology*, *27*(3), 513–543.

Molenberghs, P., Johnson, H., Henry, J. D., & Mattingley, J. B. (2016). Understanding the minds of others: A neuroimaging meta-analysis. *Neuroscience and Biobehavioral Reviews*, *65*, 276–291.

https://doi.org/10.1016/j.neubiorev.2016.03.020

Molesworth, C. J., Bowler, D. M., & Hampton, J. A. (2005). The prototype effect in recognition memory: Intact in autism? *Journal of Child Psychology and Psychiatry*, *46*(6), 661–672.

Moore, A., Gorodnitsky, I., & Pineda, J. A. (2012). EEG mu component responses to viewing emotional faces. *Behavioural Brain Research*, *226*(1), 309–316.

Morris, J. S., Öhman, A., & Dolan, R. J. (1998). Conscious and unconscious emotional learning in the human amygdala. *Nature*, *393*, 467. Retrieved from https://doi.org/10.1038/30976

Morris, J. S., Öhman, A., & Dolan, R. J. (1999). A subcortical pathway to the right amygdala mediating "unseen" fear. *Proceedings of the National Academy of Sciences*, *96*(4), 1680 LP-1685. Retrieved from http://www.pnas.org/content/96/4/1680.abstract

Mostofsky, S. H., Goldberg, M. C., Landa, R. J., & Denckla, M. B. (2000). Evidence for a deficit in procedural learning in children and adolescents with autism: implications for cerebellar contribution. *Journal of the International Neuropsychological Society*, *6*(7), 752–759.

Mottron, L., Peretz, I., & Menard, E. (2000). Local and global processing of music in high-functioning persons with autism: beyond central coherence? *The Journal of Child Psychology and Psychiatry and Allied Disciplines*, *41*(8), 1057–1065.

Müller, R. A., Cauich, C., Rubio, M. A., Mizuno, A., & Courchesne, E. (2004). Abnormal activity patterns in premotor cortex during sequence learning in autistic patients. *Biological Psychiatry*, *56*(5), 323–332. https://doi.org/10.1016/j.biopsych.2004.06.007

Mumenthaler, C., & Sander, D. (2012). Social appraisal influences recognition of emotions. *Journal of Personality and Social Psychology*, *102*(6), 1118–1135. https://doi.org/10.1037/a0026885

Murphy, C. M., Wilson, C. E., Robertson, D. M., Ecker, C., Daly, E. M., Hammond, N., … McAlonan, G. M. (2016). Autism spectrum disorder in adults: diagnosis, management, and health services development. *Neuropsychiatric Disease and Treatment*, *12*, 1669–1686. https://doi.org/10.2147/NDT.S65455

Musser, G. (2018). How autism may stem from problems with prediction. *Spectrum*, (March), 1–10. Retrieved from https://spectrumnews.org/features/deep-dive/autism-may-stem-problems-prediction/

N'Diaye, K., Sander, D., & Vuilleumier, P. (2009). Self-Relevance Processing in the Human Amygdala: Gaze Direction, Facial Expression, and Emotion Intensity. *Emotion*, *9*(6), 798–806. https://doi.org/10.1037/a0017845

Nakashima, S. F., Langton, S. R. H., & Yoshikawa, S. (2012). The effect of facial expression and gaze direction on memory for unfamiliar faces. *Cognition & Emotion*, *26*(7), 1316–1325. https://doi.org/10.1080/02699931.2011.619734

Neelamegham, R. (2001). Treating an individual difference predictor as continuous or categorical. LAWRENCE ERLBAUM ASSOC INC 10 INDUSTRIAL AVE, MAHWAH, NJ 07430-2262 USA.

Negash, S., Boeve, B. F., Geda, Y. E., Smith, G. E., Knopman, D. S., Ivnik, R. J., … Petersen, R. C. (2007). Implicit learning of sequential regularities and spatial contexts in corticobasal syndrome. *Neurocase*, *13*(3), 133–143.

Nemeth, D., Janacsek, K., Balogh, V., Londe, Z., Mingesz, R., Fazekas, M., … Vetro, A. (2010). Learning in autism: Implicitly superb. *PLoS ONE*, *5*(7). https://doi.org/10.1371/journal.pone.0011731

Nemeth, D., Janacsek, K., Csifcsak, G., Szvoboda, G., Howard Jr, J. H., & Howard, D. V. (2011). Interference between sentence processing and probabilistic implicit sequence learning. *PLoS One*, *6*(3), e17577.

Nemeth, D., Janacsek, K., Polner, B., & Kovacs, Z. A. (2013). Boosting human learning by hypnosis. *Cerebral Cortex*, *23*(4), 801–805.

Nemiah, J. C. (1976). Alexithymia: a view of the psychosomatic process. *Modern Trends in Psychosomatic Medicine*, *3*, 430–439.

Neuhaus, E., Bernier, R. A., & Beauchaine, T. P. (2015). Electrodermal response to reward and non-reward among children with autism. *Autism Research*, *8*(4), 357–370.

Neumann, D., Spezio, M. L., Piven, J., & Adolphs, R. (2006). Looking you in the mouth: abnormal gaze in autism resulting from impaired top-down modulation of visual attention. *Social Cognitive and Affective Neuroscience*, *1*(3), 194–202. https://doi.org/10.1093/scan/nsl030

Niedenthal, P. M., & Brauer, M. (2012). Social functionality of human emotion. *Annual Review of Psychology*, *63*, 259–285.

Niedenthal, P. M., Mermillod, M., Maringer, M., & Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and Brain Sciences*, *33*(6), 417–433.

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology*, *19*(1), 1–32.

Norman, E., & Price, M. C. (2012). Social intuition as a form of implicit learning: Sequences of body movements are learned less explicitly than letter sequences. *Advances in Cognitive Psychology*, *8*(121), 121–131. https://doi.org/10.2478/v10053-008-0109-x

Northrup, J. B. (2017). Contingency detection in a complex world: A developmental model and implications for atypical development. *International Journal of Behavioral Development*, *41*(6), 723–734.

Nuske, H. J., Vivanti, G., & Dissanayake, C. (2013). Are emotion impairments unique to, universal, or specific in autism spectrum disorder? A comprehensive review. *Cognition & Emotion*, *27*(August 2014), 1042–1061. https://doi.org/10.1080/02699931.2012.762900

Nuske, H. J., Vivanti, G., & Dissanayake, C. (2014). Reactivity to fearful expressions of familiar and unfamiliar people in children with autism: an eye-tracking pupillometry study. *Journal of Neurodevelopmental Disorders*, *6*(1), 14. https://doi.org/10.1186/1866-1955-6-14

Nuske, H. J., Vivanti, G., & Dissanayake, C. (2015). No Evidence of Emotional Dysregulation or Aversion to Mutual Gaze in Preschoolers with Autism Spectrum Disorder: An Eye-Tracking Pupillometry Study. *Journal of Autism and Developmental Disorders*, *45*(11), 3433–3445. https://doi.org/10.1007/s10803-015-2479-5

O'Connor, K., Hamm, J. P., & Kirk, I. J. (2005). The neurophysiological correlates of face processing in adults and children with Asperger's syndrome. *Brain and Cognition*, *59*(1), 82–95.

https://doi.org/https://doi.org/10.1016/j.bandc.2005.05.004

O'Riordan, M., & Plaisted, K. (2001). Enhanced discrimination in autism. *The Quarterly Journal of Experimental Psychology: Section A*, *54*(4), 961–979.

Oberman, L. M., Hubbard, E. M., McCleery, J. P., Altschuler, E. L., Ramachandran, V. S., & Pineda, J. A. (2005). EEG evidence for mirror neuron dysfunction in autism spectrum disorders. *Cognitive Brain Research*, *24*(2), 190–198. https://doi.org/https://doi.org/10.1016/j.cogbrainres.2005.01.014

Oberman, L. M., Ramachandran, V. S., & Pineda, J. A. (2008). Modulation of mu suppression in children with autism spectrum disorders in response to familiar or unfamiliar stimuli: the mirror neuron hypothesis. *Neuropsychologia*, *46*(5), 1558–1565.

Oberman, L. M., Winkielman, P., & Ramachandran, V. S. (2007). Face to face: Blocking facial mimicry can selectively impair recognition of emotional expressions. *Social Neuroscience*, *2*(3–4), 167–178.

Öhman, A., Lundqvist, D., & Esteves, F. (2001). The face in the crowd revisited: A threat advantage with schematic stimuli. *Journal of Personality and Social Psychology*, *80*(3), 381–396. https://doi.org/10.1037/0022-3514.80.3.381

Olszanowski, M., Pochwatko, G., Kuklinski, K., Scibor-Rylski, M., Lewinski, P., & Ohme, R. K. (2015). Warsaw set of emotional facial expression pictures: a validation study of facial display photographs. *Frontiers in Psychology*, *5*, 1516. https://doi.org/10.3389/fpsyg.2014.01516

Onishi, K. H., & Baillargeon, R. (2005). Do 15-month-old infants understand false beliefs? *Science (New York, N.Y.)*, *308*(5719), 255–258. https://doi.org/10.1126/science.1107621

Oosterling, I., Roos, S., de Bildt, A., Rommelse, N., de Jonge, M., Visser, J., … Buitelaar, J. (2010). Improved diagnostic validity of the ADOS revised algorithms: a replication study in an independent sample. *Journal of Autism and Developmental Disorders*, *40*(6), 689–703. https://doi.org/10.1007/s10803-009-0915-0

Otten, M., Seth, A. K., & Pinto, Y. (2017). A social Bayesian brain: How social knowledge can shape visual perception. *Brain and Cognition*, *112*, 69–77.

https://doi.org/10.1016/j.bandc.2016.05.002

Ozonoff, S., Iosif, A.-M., Baguio, F., Cook, I. C., Hill, M. M., Hutman, T., … Sigman, M. (2010). A prospective study of the emergence of early behavioral signs of autism. *Journal of the American Academy of Child & Adolescent Psychiatry*, *49*(3), 256–266.

Ozonoff, S., Macari, S., Young, G. S., Goldring, S., Thompson, M., & Rogers, S. J. (2008). Atypical object exploration at 12 months of age is associated with autism in a prospective sample. *Autism*, *12*(5), 457–472.

Ozonoff, S., & Miller, J. N. (1995). Teaching theory of mind: A new approach to social skills training for individuals with autism. *Journal of Autism and Developmental Disorders*, *25*(4), 415–433.

Palmer, C. J., Seth, A. K., & Hohwy, J. (2015). The felt presence of other minds: Predictive processing, counterfactual predictions, and mentalising in autism. *Consciousness and Cognition*, *36*, 376–389. https://doi.org/10.1016/j.concog.2015.04.007

Palumbo, L., Burnett, H. G., & Jellema, T. (2015). Atypical emotional anticipation in high-functioning autism. *Molecular Autism*, *6*(1), 1–17. https://doi.org/10.1186/s13229-015-0039-7

Palumbo, L., & Jellema, T. (2013). Beyond face value: does involuntary emotional anticipation shape the perception of dynamic facial expressions? *PloS One*, *8*(2), e56003–e56003. https://doi.org/10.1371/journal.pone.0056003

Palumbo, L., Macinska, S. T., & Jellema, T. (2018). The Role of Pattern Extrapolation in the Perception of Dynamic Facial Expressions in Autism Spectrum Disorder. *Frontiers in Psychology*, *9*, 1918. https://doi.org/10.3389/fpsyg.2018.01918

Paulus, M., Hunnius, S., & Bekkering, H. (2012). Neurocognitive mechanisms underlying social learning in infancy: infants' neural processing of the effects of others' actions. *Social Cognitive and Affective Neuroscience*, *8*(7), 774–779.

Pawling, R., Kirkham, A. J., Hayes, A. E., & Tipper, S. P. (2017). Incidental retrieval of prior emotion mimicry. *Experimental Brain Research*, *235*(4), 1173–1184.

Pellicano, E., & Burr, D. (2012). When the world becomes "too real": A Bayesian explanation of autistic perception. *Trends in Cognitive Sciences*, *16*(10), 504–510.

https://doi.org/10.1016/j.tics.2012.08.009

Pelphrey, K. A., Morris, J. P., McCarthy, G., & Labar, K. S. (2007). Perception of dynamic changes in facial affect and identity in autism. *Social Cognitive and Affective Neuroscience*, *2*(2), 140–149. https://doi.org/10.1093/scan/nsm010

Pelphrey, K. A., Sasson, N. J., Reznick, J. S., Gregory, P., Goldman, B., & Piven, J. (2002). Visual scanning of faces in autism. *Journal Of Autism And Developmental Disorders*, *32*(4), 249–261.

Peretz, I., & Zatorre, R. J. (2005). Brain organization for music processing. *Annu. Rev. Psychol.*, *56*, 89–114.

Perkins, T., Stokes, M., McGillivray, J., & Bittar, R. (2010). Mirror neuron dysfunction in autism spectrum disorders. *Journal of Clinical Neuroscience*, *17*(10), 1239–1243. https://doi.org/https://doi.org/10.1016/j.jocn.2010.01.026

Perner, J., Frith, U., Leslie, A. M., & Leekam, S. R. (1989). Exploration of the autistic child's theory of mind: Knowledge, belief, and communication. *Child Development*, 689–700.

Perrett, D. I., May, K. A., & Yoshikawa, S. (1994). Facial shape and judgements of female attractiveness. *Nature*, *368*(6468), 239.

Perruchet, P., & Pacton, S. (2006). Implicit learning and statistical learning: One phenomenon, two approaches. *Trends in Cognitive Sciences*, *10*(5), 233–238.

Peterson, M. F., & Eckstein, M. P. (2011). Fixating the eyes is an optimal strategy across important face (related) tasks. *Journal of Vision*, *11*(11), 662.

Pierce, K. (2001). Face processing occurs outside the fusiform `face area' in autism: evidence from functional MRI. *Brain*, *124*(10), 2059–2073. https://doi.org/10.1093/brain/124.10.2059

Pitskel, N. B., Bolling, D. Z., Hudac, C. M., Lantz, S. D., Minshew, N. J., Vander Wyk, B. C., & Pelphrey, K. A. (2011). Brain mechanisms for processing direct and averted gaze in individuals with autism. *Journal of Autism and Developmental Disorders*, *41*(12), 1686–1693. https://doi.org/10.1007/s10803-011-1197-x

Piven, J., Rabins, P., & Group, A. A. W. (2011). Autism spectrum disorders in older adults: toward defining a research agenda. *Journal of the American Geriatrics*

Society, *59*(11), 2151–2155.

Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998). Enhanced discrimination of novel, highly similar stimuli by adults with autism during a perceptual learning task. *The Journal of Child Psychology and Psychiatry and Allied Disciplines*, *39*(5), 765–775.

Plomp, R., & Levelt, W. J. M. (1965). Tonal consonance and critical bandwidth. *The Journal of the Acoustical Society of America*, *38*(4), 548–560.

Poldrack, R. A., Sabb, F. W., Foerde, K., Tom, S. M., Asarnow, R. F., Bookheimer, S. Y., & Knowlton, B. J. (2005). The neural correlates of motor skill automaticity. *Journal of Neuroscience*, *25*(22), 5356–5364.

Poljac, E., Poljac, E., & Wagemans, J. (2013). Reduced accuracy and sensitivity in the perception of emotional facial expressions in individuals with high autism spectrum traits. *Autism*, *17*(6), 668–680. https://doi.org/10.1177/1362361312455703

Ponari, M., Conson, M., D'amico, N. P., Grossi, D., & Trojano, L. (2012). Mapping correspondence between facial mimicry and emotion recognition in healthy subjects. *Emotion*, *12*(6), 1398.

Posamentier, M. T., & Abdi, H. (2003). Processing Faces and Facial Expressions. *Neuropsychology Review*, *13*(3), 113–143. https://doi.org/10.1023/A:1025519712569

Powell, P. S., Travers, B. G., Klinger, L. G., & Klinger, M. R. (2016). Difficulties with multi-sensory fear conditioning in individuals with autism spectrum disorder. *Research in Autism Spectrum Disorders*, *25*(October), 137–146. https://doi.org/10.1016/j.rasd.2016.02.008

Premack, D., & Woodruff, G. (1978). Does the chimpanzee have a theory of mind? *The Behavioral and Brain Sciences*, *4*, 515–526.

Price, T. F., & Harmon-Jones, E. (2015). Embodied emotion: the influence of manipulated facial and bodily states on emotive responses. *Wiley Interdisciplinary Reviews: Cognitive Science*, *6*(6), 461–473. https://doi.org/10.1002/wcs.1370

Pugliese, C. E., Kenworthy, L., Bal, V. H., Wallace, G. L., Yerys, B. E., Maddox, B. B.,

… Anthony, L. G. (2015). Replication and Comparison of the Newly Proposed ADOS-2, Module 4 Algorithm in ASD Without ID: A Multi-site Study. *Journal of Autism and Developmental Disorders*, *45*(12), 3919–3931. https://doi.org/10.1007/s10803-015-2586-3

Quintin, E.-M., Bhatara, A., Poissant, H., Fombonne, E., & Levitin, D. J. (2011). Emotion Perception in Music in High-Functioning Adolescents With Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *41*(9), 1240–1255. https://doi.org/10.1007/s10803-010-1146-0

Qureshi, A. W., Apperly, I. A., & Samson, D. (2010). Executive function is necessary for perspective selection, not Level-1 visual perspective calculation: Evidence from a dual-task study of adults. *Cognition*, *117*(2), 230–236. https://doi.org/https://doi.org/10.1016/j.cognition.2010.08.003

Ramachandran, V. S., & Oberman, L. M. (2006). Broken mirrors: a theory of autism. *Scientific American*, *295*(5), 62–69.

Rauch, S. L., Whalen, P. J., Savage, C. R., Curran, T., Kendrick, A., Brown, H. D., … Rosen, B. R. (1997). Striatal recruitment during an implicit sequence learning task as measured by functional magnetic resonance imaging. *Human Brain Mapping*, *5*(2), 124–132.

Rausei, V., Makovski, T., & Jiang, Y. (2007). Attention dependency in implicit learning of repeated search context. *The Quarterly Journal of Experimental Psychology*, *60*(10), 1321–1328.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, *6*(6), 855–863.

Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General*, *118*(3), 219.

Reber, A. S. (1993). Implicit Learning and Tacit Knowledge: An Essay on the Cognitive Unconscious (Oxford Psychology Series, No 19). Oxford, Oxford University Press.

Reber, A. S., Walkenfeld, F. F., & Hernstadt, R. (1991). Implicit and explicit learning: Individual differences and IQ. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. US: American Psychological Association.

https://doi.org/10.1037/0278-7393.17.5.888

Reber, P. J. (2013). The neural basis of implicit learning and memory: A review of neuropsychological and neuroimaging research. *Neuropsychologia*, *51*(10), 2026–2042. https://doi.org/10.1016/j.neuropsychologia.2013.06.019

Reber, P. J., Batterink, L. J., Thompson, K. R., & Reuveni, B. (2017). Implicit Learning: History & Applications, (847), 1–26.

Rebuschat, P., Hamrick, P., Sachs, R., Riestenberg, K., & Ziegler, N. (2013). Implicit and explicit knowledge of form-meaning connections: Evidence from subjective measures of awareness. *Noticing and Second Language Acquisition: Studies in Honor of Richard Schmidt*, 249–269.

Reed, P., Lowe, C., & Everett, R. (2011). Perceptual learning and perceptual search are altered in male university students with higher Autism Quotient scores. *Personality and Individual Differences*, *51*(6), 732–736. https://doi.org/10.1016/j.paid.2011.06.016

Remington, A. M., Swettenham, J., Campbell, R., & Coleman, M. (2009). Selective Attention and Perceptual Load in Autism Spectrum Disorder. *Psychological Science*, *20*(11), 1388–1393. https://doi.org/10.1111/j.1467-9280.2009.02454.x

Remington, A. M., Swettenham, J., & Lavie, N. (2012). Lightening the load: Perceptual load impairs visual detection in typical adults but not in autism. *Journal of Abnormal Psychology*. Remington, Anna M.: Institute of Cognitive Neuroscience, University College London, 17 Queens Square, London, United Kingdom, WC1N 3AR, A.remington@ucl.ac.uk: American Psychological Association. https://doi.org/10.1037/a0027670

Riby, D. M., Doherty-Sneddon, G., & Bruce, V. (2009). The eyes or the mouth? Feature salience and unfamiliar face processing in Williams syndrome and autism. *The Quarterly Journal of Experimental Psychology*, *62*(1), 189–203. https://doi.org/10.1080/17470210701855629

Riby, D. M., & Hancock, P. J. B. (2008). Looking at Movies and Cartoons: Eye-tracking evidence from Williams syndrome and Autism. *Journal of Intellectual Disability Research*. https://doi.org/10.1111/j.1365-2788.2008.01142.x

Ridout, N., Astell, A., Reid, I., Glen, T., & O'Carroll, R. (2003). Memory bias for emotional facial expressions in major depression. *Cognition & Emotion*, *17*(1), 101–122. https://doi.org/10.1080/02699930302272

Ristic, J., Mottron, L., Friesen, C. K., Iarocci, G., Burack, J. A., & Kingstone, A. (2005). Eyes are special but not for everyone: The case of autism. *Cognitive Brain Research*, *24*(3), 715–718. https://doi.org/https://doi.org/10.1016/j.cogbrainres.2005.02.007

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annu. Rev. Neurosci.*, *27*, 169–192.

Rizzolatti, G., & Fabbri-Destro, M. (2008). The mirror system and its role in social cognition. *Current Opinion in Neurobiology*, *18*(2), 179–184. https://doi.org/10.1016/j.conb.2008.08.001

Rizzolatti, G., Fabbri-Destro, M., & Cattaneo, L. (2009). Mirror neurons and their clinical relevance. *Nature Reviews Neurology*, *5*(1), 24.

Rizzolatti, G., & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nature Reviews Neuroscience*, *11*(4), 264.

Rogers, R. D., Bayliss, A. P., Szepietowska, A., Dale, L., Reeder, L., Pizzamiglio, G., … Tipper, S. P. (2014). I want to help you, but I am not sure why: Gaze-cuing induces altruistic giving. *Journal of Experimental Psychology: General*, *143*(2), 763.

Rogers, S. J., Bennetto, L., McEvoy, R., & Pennington, B. F. (1996). Imitation and pantomime in high-functioning adolescents with autism spectrum disorders. *Child Development*, *67*(5), 2060–2073.

Rozga, A., Hutman, T., Young, G. S., Rogers, S. J., Ozonoff, S., Dapretto, M., & Sigman, M. (2011). Behavioral profiles of affected and unaffected siblings of children with autism: Contribution of measures of mother–infant interaction and nonverbal communication. *Journal of Autism and Developmental Disorders*, *41*(3), 287–301.

Ruffman, T., Garnham, W., & Rideout, P. (2001). Social understanding in autism: Eye gaze as a measure of core insights. *The Journal of Child Psychology and Psychiatry and Allied Disciplines*, *42*(8), 1083–1094.

Rutherford, M. D., Clements, K. A., & Sekuler, A. B. (2007). Differences in discrimination of eye and mouth displacement in autism spectrum disorders. *Vision Research*, *47*(15), 2099–2110.

Rutherford, M. D., & Towns, A. M. (2008a). Scan path differences and similarities during emotion perception in those with and without autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *38*(7), 1371–1381. https://doi.org/10.1007/s10803-007-0525-7

Rutherford, M. D., & Towns, A. M. (2008b). Scan Path Differences and Similarities During Emotion Perception in those With and Without Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *38*(7), 1371–1381. https://doi.org/10.1007/s10803-007-0525-7

Rychlowska, M., Cañadas, E., Wood, A., Krumhuber, E. G., Fischer, A., & Niedenthal, P. M. (2014). Blocking mimicry makes true and false smiles look the same. *PLoS One*, *9*(3), e90876.

Sabatos-DeVito, M., Schipul, S. E., Bulluck, J. C., Belger, A., & Baranek, G. T. (2016). Eye Tracking Reveals Impaired Attentional Disengagement Associated with Sensory Response Patterns in Children with Autism. *Journal of Autism and Developmental Disorders*, *46*(4), 1319–1333. https://doi.org/10.1007/s10803-015-2681-5

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*, *274*(5294), 1926–1928.

Salva, O. R., Farroni, T., Regolin, L., Vallortigara, G., & Johnson, M. H. (2011). The evolution of social orienting: evidence from chicks (Gallus gallus) and human newborns. *PLoS One*, *6*(4), e18802.

Samson, D., Apperly, I. A., Braithwaite, J. J., Andrews, B. J., & Bodley Scott, S. E. (2010). Seeing it their way: Evidence for rapid and involuntary computation of what other people see. *Journal of Experimental Psychology: Human Perception and Performance*. Samson, Dana: School of Psychology, University of Nottingham, University Park, Nottingham, United Kingdom, NG7 2RD, dana.samson@nottingham.ac.uk: American Psychological Association. https://doi.org/10.1037/a0018729

Sander, D., Grafman, J., & Zalla, T. (2003). The Human Amygdala: An Evolved

System for Relevance Detection. *Reviews in Neurosicnces*, *14*, 303–316.

Sander, D., Grandjean, D., Kaiser, S., Wehrle, T., & Scherer, K. R. (2007). Interaction effects of perceived gaze direction and dynamic facial expression: Evidence for appraisal theories of emotion. *European Journal of Cognitive Psychology*, *19*(3), 470–480. https://doi.org/10.1080/09541440600757426

Sasson, N. J. (2006). The development of face processing in autism. *Journal of Autism and Developmental Disorders*, *36*(3), 381–394.

Sasson, N. J., Nowlin, R. B., & Pinkham, A. E. (2013). Social cognition, social skill, and the broad autism phenotype. *Autism*, *17*(6), 655–667.

Sasson, N. J., Turner-Brown, L. M., Holtzclaw, T. N., Lam, K. S. L., & Bodfish, J. W. (2008). Children with autism demonstrate circumscribed attention during passive viewing of complex social and nonsocial picture arrays. *Autism Research*, *1*(1), 31–42.

Sato, W. (2014). Enhanced subliminal emotional responses to dynamic facial expressions, *5*(September), 1–7. https://doi.org/10.3389/fpsyg.2014.00994

Sato, W., Kochiyama, T., & Uono, S. (2015). Spatiotemporal neural network dynamics for the processing of dynamic facial expressions. *Scientific Reports*, *5*, 12432. Retrieved from https://doi.org/10.1038/srep12432

Sato, W., Kochiyama, T., Uono, S., & Yoshikawa, S. (2010). Amygdala integrates emotional expression and gaze direction in response to dynamic facial expressions. *NeuroImage*, *50*(4), 1658–1665. https://doi.org/10.1016/j.neuroimage.2010.01.049

Sato, W., Kochiyama, T., Yoshikawa, S., Naito, E., & Matsumura, M. (2004). Enhanced neural activity in response to dynamic facial expressions of emotion: an fMRI study. *Cognitive Brain Research*, *20*(1), 81–91. https://doi.org/https://doi.org/10.1016/j.cogbrainres.2004.01.008

Sato, W., Okada, T., & Toichi, M. (2007). Attentional shift by gaze is triggered without awareness. *Experimental Brain Research*, *183*(1), 87–94. https://doi.org/10.1007/s00221-007-1025-x

Satpute, A. B., & Lieberman, M. D. (2006). Integrating automatic and controlled processes into neurocognitive models of social cognition. *Brain Research*, *1079*(1), 86–97. https://doi.org/10.1016/j.brainres.2006.01.005

Sawyer, A. C. P., Williamson, P., & Young, R. L. (2012). Can gaze avoidance explain why individuals with Asperger's syndrome can't recognise emotions from facial expressions? *Journal of Autism and Developmental Disorders*, *42*(4), 606–618. https://doi.org/10.1007/s10803-011-1283-0

Saxe, R. (2006). Uniquely human social cognition. *Current Opinion in Neurobiology*, *16*(2), 235–239.

Saxe, R., & Wexler, A. (2005). Making sense of another mind: The role of the right temporo-parietal junction. *Neuropsychologia*, *43*(10), 1391–1399. https://doi.org/10.1016/j.neuropsychologia.2005.02.013

Schellenberg, E. G., & Trehub, S. E. (1994). Frequency ratios and the perception of tone patterns. *Psychonomic Bulletin & Review*, *1*(2), 191–201.

Schilbach, L., Eickhoff, S. B., Mojzisch, A., & Vogeley, K. (2008). What's in a smile? Neural correlates of facial embodiment during social interaction. *Social Neuroscience*, *3*(1), 37–50.

Schilbach, L., Timmermans, B., Reddy, V., Costall, A., Bente, G., Schlicht, T., & Vogeley, K. (2013). Toward a second-person neuroscience. *Behavioral and Brain Sciences*, *36*(4), 393–414. https://doi.org/10.1017/S0140525X12000660

Schmidt, R. W. (n.d.). Implicit learning and the cognitive unconscious.

Schneider, D., Bayliss, A. P., Becker, S. I., & Dux, P. E. (2012). Eye movements reveal sustained implicit processing of others' mental states. *Journal of Experimental Psychology: General*. Schneider, Dana: School of Psychology, University of Queensland, McElwain Building, St. Lucia, QLD, Australia, 4072, msdanaschneider@gmail.com: American Psychological Association. https://doi.org/10.1037/a0025458

Schneider, D., Slaughter, V. P., Bayliss, A. P., & Dux, P. E. (2013). A temporally sustained implicit theory of mind deficit in autism spectrum disorders. *Cognition*, *129*(2), 410–417. https://doi.org/https://doi.org/10.1016/j.cognition.2013.08.004

Schneider, D., Slaughter, V. P., Becker, S. I., & Dux, P. E. (2014). Implicit false-belief processing in the human brain. *NeuroImage*, *101*, 268–275.

https://doi.org/10.1016/j.neuroimage.2014.07.014

Schneider, D., Slaughter, V. P., & Dux, P. E. (2017). Current evidence for automatic Theory of Mind processing in adults. *Cognition*, *162*, 27–31. https://doi.org/10.1016/j.cognition.2017.01.018

Scholl, B. J., & Leslie, A. M. (1999). Modularity, development and "theory of mind." *Mind & Language*. United Kingdom: Blackwell Publishing. https://doi.org/10.1111/1468-0017.00106

Scholl, B. J., & Leslie, A. M. (2001). Minds, modules, and meta-analysis. Commentary on "Meta-analysis of theory-of-mind development: The truth about false belief." *Child Development*. United Kingdom: Blackwell Publishing. https://doi.org/10.1111/1467-8624.00308

Schultz, R. T. (2005). Developmental deficits in social perception in autism: The role of the amygdala and fusiform face area. *International Journal of Developmental Neuroscience*. https://doi.org/10.1016/j.ijdevneu.2004.12.012

Schultz, R. T., Gauthier, I., Klin, A., & Al, E. (2000). Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and asperger syndrome. *Archives of General Psychiatry*, *57*(4), 331–340. Retrieved from http://dx.doi.org/10.1001/archpsyc.57.4.331

Schurgin, M. W., Nelson, J., Iida, S., Ohira, H., Chiao, J. Y., & Franconeri, S. L. (2014). Eye movements during emotion recognition in faces. *Journal of Vision*, *14*(13), 1–16. https://doi.org/10.1167/14.13.14.doi

Schuwerk, T., Vuori, M., & Sodian, B. (2015). Implicit and explicit Theory of Mind reasoning in autism spectrum disorders: The impact of experience. *Autism*, *19*(4), 459–468. https://doi.org/10.1177/1362361314526004

Scott, R. M., He, Z., Baillargeon, R., & Cummins, D. (2012). False-belief understanding in 2.5-year-olds: evidence from two novel verbal spontaneous-response tasks. *Developmental Science*, *15*(2), 181–193. https://doi.org/10.1111/j.1467-7687.2011.01103.x

Seger, C. A. (1994). Implicit Learning, *115*(2), 163–196. https://doi.org/10.1111/1467-8721.01213

Seltzer, M. M., Shattuck, P., Abbeduto, L., & Greenberg, J. S. (2004). Trajectory of development in adolescents and adults with autism. *Mental Retardation and Developmental Disabilities Research Reviews*, *10*(4), 234–247.

Senju, A. (2013). Atypical development of spontaneous social cognition in autism spectrum disorders. *Brain & Development*, *35*(2), 96–101. https://doi.org/10.1016/j.braindev.2012.08.002

Senju, A., & Hasegawa, T. (2005). Direct gaze captures visuospatial attention. *Visual Cognition*, *12*(1), 127–144.

Senju, A., & Johnson, M. H. (2009). Atypical eye contact in autism: Models, mechanisms and development. *Neuroscience and Biobehavioral Reviews*, *33*(8), 1204–1214. https://doi.org/10.1016/j.neubiorev.2009.06.001

Senju, A., Southgate, V., White, S., & Frith, U. (2009). Mindblind eyes: an absence of spontaneous theory of mind in Asperger syndrome. *Science*, *325*(5942), 883–886. https://doi.org/10.1126/science.1176170

Senju, A., Tojo, Y., Dairoku, H., & Hasegawa, T. (2004). Reflexive orienting in response to eye gaze and an arrow in children with and without autism. *Journal of Child Psychology and Psychiatry*, *45*(3), 445–458.

Sepeta, L., Tsuchiya, N., Davies, M. S., Sigman, M., Bookheimer, S. Y., & Dapretto, M. (2012). Abnormal social reward processing in autism as indexed by pupillary responses to happy faces. *Journal of Neurodevelopmental Disorders*, *4*(1), 17. https://doi.org/10.1186/1866-1955-4-17

Sergerie, K., Lepage, M., & Armony, J. L. (2005). A face to remember: Emotional expression modulates prefrontal activity during memory formation. *NeuroImage*, *24*(2), 580–585. https://doi.org/10.1016/j.neuroimage.2004.08.051

Sergerie, K., Lepage, M., & Armony, J. L. (2007). Influence of Emotional Expression on Memory Recognition Bias: A Functional Magnetic Resonance Imaging Study. *Biological Psychiatry*, *62*(10), 1126–1133. https://doi.org/10.1016/j.biopsych.2006.12.024

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry*, *24*(4), 613–620.

Shanks, D. R., & Channon, S. (2002). Effects of a secondary task on" implicit" sequence learning: learning or performance? *Psychological Research*, *66*(2), 99–

109.

Shanks, D. R., Rowland, L. A., & Ranger, M. S. (2005). Attentional load and implicit sequence learning. *Psychological Research*, *69*(5–6), 369–382.

Shasteen, J. R., Sasson, N. J., & Pinkham, A. E. (2014). Eye tracking the face in the crowd task: Why are angry faces found more quickly? *PLoS ONE*, *9*(4). https://doi.org/10.1371/journal.pone.0093914

Shic, F., Bradshaw, J., Klin, A., Scassellati, B., & Chawarska, K. (2011). Limited activity monitoring in toddlers with autism spectrum disorder. *Brain Research*, *1380*, 246–254.

Shic, F., Macari, S., & Chawarska, K. (2014). Speech disturbs face scanning in 6-month-old infants who develop autism spectrum disorder. *Biological Psychiatry*, *75*(3), 231–237.

Shimamura, A. P., Ross, J. G., & Bennett, H. D. (2006). Memory for facial expressions: The power of a smile. *Psychonomic Bulletin & Review*, *13*(2), 217–222. https://doi.org/10.3758/BF03193833

Siegert, R. J., Taylor, K. D., Weatherall, M., & Abernethy, D. A. (2006). Is implicit sequence learning impaired in Parkinson's disease? A meta-analysis. *Neuropsychology*, *20*(4), 490.

Skewes, J. C., Jegindø, E.-M., & Gebauer, L. (2014). Perceptual inference and autistic traits. *Autism*, *19*(3), 301–307. https://doi.org/10.1177/1362361313519872

Smith, A. D., Hood, B. M., & Hector, K. (2006). Eye remember you two: Gaze direction modulates face recognition in a developmental study. *Developmental Science*, *9*(5), 465–472. https://doi.org/10.1111/j.1467-7687.2006.00513.x

Smith, E. G., & Bennetto, L. (2007). Audiovisual speech integration and lipreading in autism. *Journal of Child Psychology and Psychiatry*, *48*(8), 813–821.

Smith, M., Cottrell, G. W., Gosselin, F., & Schyns, P. G. (2005). Transmitting and Decoding Facial Expressions. *Psychological Science*, *16*(3), 184–189. https://doi.org/10.1111/j.0956-7976.2005.00801.x

Sodian, B. (2011). Theory of Mind in Infancy. *Child Development Perspectives*, *5*(1), 39–43. https://doi.org/10.1111/j.1750-8606.2010.00152.x

Sodian, B., Schuwerk, T., & Kristen, S. (2015). Implicit and Spontaneous Theory of

Mind Reasoning in Autism Spectrum Disorders.

Sollberge, B., Rebe, R., & Eckstein, D. (2003). Musical chords as affective priming context in a word-evaluation task. *Music Perception: An Interdisciplinary Journal*, *20*(3), 263–282.

Sommerville, J. A., & Woodward, A. L. (2005). Pulling out the intentional structure of action: the relation between action processing and action production in infancy. *Cognition*, *95*(1), 1–30.

Southgate, V., Senju, A., & Csibra, G. (2007). Action Anticipation Through Attribution of False Belief by 2-Year-Olds. *Psychological Science*, *18*(7), 587–592. https://doi.org/10.1111/j.1467-9280.2007.01944.x

Spezio, M. L., Adolphs, R., Hurley, R. S. E., & Piven, J. (2007). Abnormal use of facial information in high-functioning autism. *Journal of Autism and Developmental Disorders*, *37*(5), 929–939. https://doi.org/10.1007/s10803-006-0232-9

Spunt, R. P., & Lieberman, M. D. (2013). The busy social brain: evidence for automaticity and control in the neural systems supporting social cognition and action understanding. *Psychological Science*, *24*(1), 80–86. https://doi.org/10.1177/0956797612450884

Stadler, M. A. (1995). Role of attention in implicit learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(3), 674.

Stadler, M. A. (1997). Distinguishing implicit and explicit learning. *Psychonomic Bulletin & Review*, *4*(1), 56–62.

Stanutz, S., Wapnick, J., & Burack, J. A. (2012). Pitch discrimination and melodic memory in children with autism spectrum disorders. *Autism*, *18*(2), 137–147. https://doi.org/10.1177/1362361312462905

Steinbeis, N., & Koelsch, S. (2008). Comparing the processing of music and language meaning using EEG and fMRI provides evidence for similar and distinct neural representations. *PloS One*, *3*(5), e2226.

Steinbeis, N., & Koelsch, S. (2011). Affective priming effects of musical sounds on the processing of word meaning. *Journal of Cognitive Neuroscience*, *23*(3), 604–621. https://doi.org/10.1162/jocn.2009.21383

Stillman, C. M., Feldman, H., Wambach, C. G., Howard, J. H., & Howard, D. V. (2014). Dispositional mindfulness is associated with reduced implicit learning. *Consciousness and Cognition*, *28*, 141–150.

Stins, J. F., Roelofs, K., Villan, J., Kooijman, K., Hagenaars, M. A., & Beek, P. J. (2011). Walk to me when I smile, step back when I'm angry: Emotional faces modulate whole-body approach-avoidance behaviors. *Experimental Brain Research*, *212*(4), 603–611. https://doi.org/10.1007/s00221-011-2767-z

Stirrat, M., & Perrett, D. I. (2010). Valid Facial Cues to Cooperation and Trust: Male Facial Width and Trustworthiness. *Psychological Science*, *21*(3), 349–354. https://doi.org/10.1177/0956797610362647

Suda, M., Takei, Y., Aoyama, Y., Narita, K., Sakurai, N., Fukuda, M., & Mikuni, M. (2011). Autistic traits and brain activation during face-to-face conversations in typically developed adults. *PLoS ONE*, *6*(5). https://doi.org/10.1371/journal.pone.0020021

Sun, R., Merrill, E. C., & Peterson, T. (2001). *From implicit skills to explicit knowledge: A bottom-up model of skill learning*. *Cognitive Science* (Vol. 25). https://doi.org/10.1016/S0364-0213(01)00035-0

Svärd, J., Wiens, S., & Fischer, H. (2012). Superior recognition performance for happy masked and unmasked faces in both younger and older adults. *Frontiers in Psychology*, *3*(NOV), 1–11. https://doi.org/10.3389/fpsyg.2012.00520

Sweeny, T. D., Grabowecky, M., Suzuki, S., & Paller, K. A. (2009). Long-lasting effects of subliminal affective priming from facial expressions. *Consciousness and Cognition*, *18*(4), 929–938.

Swettenham, J. (1996). Can children with autism be taught to understand false belief using computers? *Journal of Child Psychology and Psychiatry*, *37*(2), 157–165.

Tanaka, J. W., & Sung, A. (2016). The "Eye Avoidance" Hypothesis of Autism Face Processing. *Journal of Autism and Developmental Disorders*, *46*(5), 1538–1552. https://doi.org/10.1007/s10803-013-1976-7

Tantam, D., Monaghan, L., Nicholson, H., & Stirling, J. (1989). Autistic Children's Ability to Interpret Faces: A Research Note. *Journal of Child Psychology and Psychiatry*, *30*(4), 623–630. https://doi.org/10.1111/j.1469-7610.1989.tb00274.x

Tardif, C., Lainé, F., Rodriguez, M., & Gepner, B. (2007). Slowing down presentation of facial movements and vocal sounds enhances facial expression recognition and induces facial-vocal imitation in children with autism. *Journal of Autism and Developmental Disorders*, *37*(8), 1469–1484. https://doi.org/10.1007/s10803-006-0223-x

Taylor, N., Isaac, C., & Milne, E. (2010). A comparison of the development of audiovisual integration in children with autism spectrum disorders and typically developing children. *Journal of Autism and Developmental Disorders*, *40*(11), 1403–1411.

Teufel, C., Alexis, D. M., Todd, H., Lawrance-Owen, A. J., Clayton, N. S., & Davis, G. (2009). Social Cognition Modulates the Sensory Coding of Observed Gaze Direction. *Current Biology*, *19*(15), 1274–1277. https://doi.org/10.1016/j.cub.2009.05.069

Teufel, C., Fletcher, P. C., & Davis, G. (2010). Seeing other minds: Attributed mental states influence perception. *Trends in Cognitive Sciences*, *14*(8), 376–382. https://doi.org/10.1016/j.tics.2010.05.005

Teunisse, J.-P., & De Gelder, B. (2001). Impaired Categorical Perception of Facial Expressions in High-Functioning Adolescents with Autism. *Child Neuropsychology*, *7*(1), 1–14. https://doi.org/10.1076/chin.7.1.1.3150

Thioux, M., Gazzola, V., & Keysers, C. (2008). Action understanding: how, what and why. *Current Biology*, *18*(10), R431–R434.

Thomas, L. A., De Bellis, M. D., Graham, R., & LaBar, K. S. (2007). Development of emotional facial recognition in late childhood and adolescence. *Developmental Science*, *10*(5), 547–558. https://doi.org/10.1111/j.1467-7687.2007.00614.x

Thompson, K. G., & Bichot, N. P. (2005). A visual salience map in the primate frontal eye field. *Progress in Brain Research*, *147*, 249–262.

Todorov, A., Gobbini, M. I., Evans, K. K., & Haxby, J. V. (2007). Spontaneous retrieval of affective person knowledge in face perception. *Neuropsychologia*, *45*(1), 163–173.

Todorov, A., Said, C. P., Engell, A. D., & Oosterhof, N. N. (2008). Understanding evaluation of faces on social dimensions. *Trends in Cognitive Sciences*, *12*(12),

455–460.
Toichi, M., & Kamio, Y. (2002). Long-term memory and levels-of-processing in autism. *Neuropsychologia*. Toichi, Motomi: Case Western Reserve U/University Hosps of Cleveland, Div of Child & Adolescent Psychiatry, Cleveland, OH, US, motomi@mbj.sphere.ne.jp: Elsevier Science. https://doi.org/10.1016/S0028-3932(01)00163-4
Tracy, J. L., Robins, R. W., Schriber, R. A., & Solomon, M. (2011). Is emotion recognition impaired in individuals with autism spectrum disorders? *Journal of Autism and Developmental Disorders*, *41*(1), 102–109. https://doi.org/10.1007/s10803-010-1030-y
Trainor, L. J., Tsang, C. D., & Cheung, V. H. W. (2002). Preference for sensory consonance in 2-and 4-month-old infants. *Music Perception: An Interdisciplinary Journal*, *20*(2), 187–194.
Travers, B. G., Klinger, M. R., Mussey, J. L., & Klinger, L. G. (2010). Motor-linked implicit learning in persons with autism spectrum disorders. *Autism Research*, *3*(2), 68–77.
Travers, B. G., Powell, P. S., Mussey, J. L., Klinger, L. G., Crisler, M. E., & Klinger, M. R. (2013). Spatial and identity cues differentially affect implicit contextual cueing in adolescents and adults with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *43*, 2393–2404. https://doi.org/10.1007/s10803-013-1787-x
Troiani, V., & Schultz, R. T. (2013). Amygdala, pulvinar, and inferior parietal cortex contribute to early processing of faces without awareness. *Frontiers in Human Neuroscience*. Retrieved from https://www.frontiersin.org/article/10.3389/fnhum.2013.00241
Turkstra, L. S. (2008). Conversation-based assessment of social cognition in adults with traumatic brain injury. *Brain Injury*, *22*(5), 397–409. https://doi.org/10.1080/02699050802027059
Turner-Brown, L. M., Baranek, G. T., Reznick, J. S., Watson, L. R., & Crais, E. R. (2013). The First Year Inventory: a longitudinal follow-up of 12-month-old to 3-year-old children. *Autism*, *17*(5), 527–540.

Uddin, L. Q., Iacoboni, M., Lange, C., & Keenan, J. P. (2007). The self and social cognition: the role of cortical midline structures and mirror neurons. *Trends in Cognitive Sciences*, *11*(4), 153–157.

Uljarevic, M., & Hamilton, A. (2013). Recognition of emotions in autism: A formal meta-analysis. *Journal of Autism and Developmental Disorders*, *43*(7), 1517–1526. https://doi.org/10.1007/s10803-012-1695-5

Uono, S., Sato, W., & Toichi, M. (2010). Brief Report: Representational Momentum for Dynamic Facial Expressions in Pervasive Developmental Disorder. *Journal of Autism and Developmental Disorders*, *40*(3), 371–377. https://doi.org/10.1007/s10803-009-0870-9

Vabalas, A., & Freeth, M. (2016). Brief Report: Patterns of Eye Movements in Face to Face Conversation are Associated with Autistic Traits: Evidence from a Student Sample. *Journal of Autism and Developmental Disorders*, *46*(1), 305–314. https://doi.org/10.1007/s10803-015-2546-y

van 't Wout, M., & Sanfey, A. G. (2008). Friend or foe: The effect of implicit trustworthiness judgments in social decision-making. *Cognition*, *108*(3), 796–803. https://doi.org/10.1016/j.cognition.2008.07.002

Van Belle, G., Ramon, M., Lefèvre, P., & Rossion, B. (2010). Fixation patterns during recognition of personally familiar and unfamiliar faces. *Frontiers in Psychology*, *1*, 20.

van Boxtel, J. J. A., & Lu, H. (2013). A predictive coding perspective on autism spectrum disorders. *Frontiers in Psychology*, *4*(JAN), 1–3. https://doi.org/10.3389/fpsyg.2013.00019

Van Der Geest, J. N., Kemner, C., Camfferman, G., Verbaten, M. N., & van Engeland, H. (2002). Looking at Images with Human Figures: Comparison between Autistic and Normal Children. *Journal of Autism and Developmental Disorders*, *32*(2), 69–75. https://doi.org/10.1023/A:1014832420206

van der Wel, R. P. R. D., Sebanz, N., & Knoblich, G. (2014). Do people automatically track others' beliefs? Evidence from a continuous measure. *Cognition*, *130*(1), 128–133. https://doi.org/10.1016/j.cognition.2013.10.004

Van Overwalle, F., & Baetens, K. (2009). Understanding others' actions and goals by mirror and mentalizing systems: a meta-analysis. *Neuroimage*, *48*(3), 564–584.

Verfaelllie, M., LaRocque, K. F., & Keane, M. M. (2012). Intact implicit verbal relational memory in medial temporal lobe amnesia. *Neuropsychologia*, *50*(8), 2100–2106.

Vernon, R. J. W., Sutherland, C. A. M., Young, A. W., & Hartley, T. (2014). Modeling first impressions from highly variable facial images. *Proceedings of the National Academy of Sciences*, *111*(32), E3353–E3361.

Verosky, S. C., & Todorov, A. (2010). Generalization of affective learning about faces to perceptually similar faces. *Psychological Science*, *21*(6), 779–785.

Verosky, S. C., & Todorov, A. (2013). When physical similarity matters: Mechanisms underlying affective learning generalization to the evaluation of novel faces. *Journal of Experimental Social Psychology*, *49*(4), 661–669.

Verschoor, S. A., Weidema, M., Biro, S., & Hommel, B. (2010). Where do action goals come from? Evidence for spontaneous action–effect binding in infants. *Frontiers in Psychology*, *1*, 201.

Virtala, P., Huotilainen, M., Partanen, E., Fellman, V., & Tervaniemi, M. (2013). Newborn infants' auditory system is sensitive to Western music chord categories. *Frontiers in Psychology*, *4*, 492.

Vivanti, G., & Dissanayake, C. (2014). Propensity to imitate in autism is not modulated by the model's gaze direction: An eye-tracking study. *Autism Research*, *7*(3), 392–399. https://doi.org/10.1002/aur.1376

Vivanti, G., & Hamilton, A. (2014). Imitation in autism spectrum disorders. *Handbook of Autism and Pervasive Developmental Disorders, Fourth Edition*.

Vivanti, G., McCormick, C., Young, G. S., Abucayan, F., Hatt, N., Nadig, A., … Rogers, S. J. (2011). Intact and impaired mechanisms of action understanding in autism. *Developmental Psychology*, *47*(3), 841–856. https://doi.org/10.1037/a0023105

Vivanti, G., Nadig, A., Ozonoff, S., & Rogers, S. J. (2008). What do children with autism attend to during imitation tasks? *Journal of Experimental Child Psychology*, *101*(3), 186–205.

Vivanti, G., & Rogers, S. J. (2014). Autism and the mirror neuron system: Insights from learning and teaching. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1644). https://doi.org/10.1098/rstb.2013.0184

Vivanti, G., Trembath, D., & Dissanayake, C. (2014). Atypical monitoring and responsiveness to goal-directed gaze in autism spectrum disorder. *Experimental Brain Research*, *232*(2), 695–701.

Vlamings, P. H. J. M., Stauder, J. E. A., van Son, I. A. M., & Mottron, L. (2005). Atypical visual orienting to gaze-and arrow-cues in adults with high functioning autism. *Journal of Autism and Developmental Disorders*, *35*(3), 267–277.

Vogel, E. K., & Machizawa, M. G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature*, *428*(6984), 748–751. https://doi.org/10.1038/nature02447

Von dem Hagen, E., Stoyanova, R. S., Rowe, J. B., Baron-Cohen, S., & Calder, A. J. (2014). Direct gaze elicits atypical activation of the theory-of-mind network in Autism spectrum conditions. *Cerebral Cortex*, *24*(6), 1485–1492. https://doi.org/10.1093/cercor/bht003

Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*. Harvard university press.

Wagner, J. B., Hirsch, S. B., Vogel-Farley, V. K., Redcay, E., & Nelson, C. a. (2013). Eye-tracking, autonomic, and electrophysiological correlates of emotional face processing in adolescents with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *43*(1), 188–199. https://doi.org/10.1007/s10803-012-1565-1

Walker-Smith, G. J., Gale, A. G., & Findlay, J. M. (1977). Eye movement strategies involved in face perception. *Perception*, *6*(3), 313–326.

Wallace, S., Coleman, M., & Bailey, A. J. (2008). Face and object processing in autism spectrum disorders. *Autism Research*, *1*(1), 43–51.

Wallace, S., Coleman, M., Pascalis, O., & Bailey, A. J. (2006). A study of impaired judgment of eye-gaze direction and related face-processing deficits in autism spectrum disorders. *Perception*, *35*(12), 1651–1664.

Wang, A. T., Dapretto, M., Hariri, A. R., Sigman, M., & Bookheimer, S. Y. (2004).

Neural Correlates of Facial Affect Processing in Children and Adolescents With Autism Spectrum Disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *43*(4), 481–490. https://doi.org/10.1097/00004583-200404000-00015

Wang, Y., & Hamilton, A. (2012). Social top-down response modulation (STORM): a model of the control of mimicry in social interaction. *Frontiers in Human Neuroscience*, *6*(June), 1–10. https://doi.org/10.3389/fnhum.2012.00153

Ward, L. C. (1990). Prediction of verbal, performance, and full scale IQs from seven subtests of the wais-r. *Journal of Clinical Psychology*, *46*(4), 436–440. https://doi.org/10.1002/1097-4679(199007)46:4<436::AID-JCLP2270460411>3.0.CO;2-M

Webb, S. J., Neuhaus, E., & Faja, S. (2017). Face perception and learning in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, *70*(5), 970–986.

Wechsler, D. (2008). *Wechsler adult intelligence scale-fourth*. San Antonio, TX: The Psychological Corporation Google Scholar.

Weigelt, S., Koldewyn, K., & Kanwisher, N. (2012). Face identity recognition in autism spectrum disorders: A review of behavioral studies. *Neuroscience and Biobehavioral Reviews*, *36*(3), 1060–1084. https://doi.org/10.1016/j.neubiorev.2011.12.008

Weisbuch, M., Lamer, S. A., & Ford, B. Q. (2013). Memory for Eye Gaze : Accuracy , Bias , and the Role of Facial Emotion. *Social Cognition*, *31*(6), 686–695. https://doi.org/10.1521/soco.2013.31.6.686

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development*, *72*(3), 655–684.

Wellman, H. M., & Liu, D. (2004). Scaling of Theory-of-Mind Tasks. *Child Development*, *75*(2), 523–541. https://doi.org/10.1111/j.1467-8624.2004.00691.x

Wentura, D. (1999). Activation and inhibition of affective information: Evidence for negative priming in the evaluation task. *Cognition and Emotion*. United Kingdom: Taylor & Francis. https://doi.org/10.1080/026999399379375

Whalen, P. J., Rauch, S. L., Etcoff, N. L., McInerney, S. C., Lee, M. B., & Jenike, M. A.

(1998). Masked Presentations of Emotional Facial Expressions Modulate Amygdala Activity without Explicit Knowledge. *The Journal of Neuroscience*, *18*(1), 411 LP-418. Retrieved from http://www.jneurosci.org/content/18/1/411.abstract

White, S., Hill, E., Happé, F., & Frith, U. (2009). Revisiting the strange stories: Revealing mentalizing impairments in autism. *Child Development*, *80*(4), 1097–1117.

White, S. W., Bray, B. C., & Ollendick, T. H. (2012). Examining shared and unique aspects of social anxiety disorder and autism spectrum disorder using factor analysis. *Journal of Autism and Developmental Disorders*, *42*(5), 874–884. https://doi.org/10.1007/s10803-011-1325-7

White, S. W., Ollendick, T. H., & Bray, B. C. (2011). College students on the autism spectrum: Prevalence and associated problems. *Autism*, *15*(6), 683–701. https://doi.org/10.1177/1362361310393363

Williams, B. T., & Gray, K. M. (2013). The relationship between emotion recognition ability and social skills in young children with autism. *Autism*, *17*(6), 762–768.

Williams, J. H. G., Whiten, A., & Singh, T. (2004). A systematic review of action imitation in autistic spectrum disorder. *Journal of Autism and Developmental Disorders*, *34*(3), 285–299.

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition*, *13*(1), 103–128. https://doi.org/https://doi.org/10.1016/0010-0277(83)90004-5

Witt, K., Nuhsman, A., & Deuschl, G. (2002). Dissociation of habit-learning in Parkinson's and cerebellar disease. *Journal of Cognitive Neuroscience*, *14*(3), 493–499.

Wolf, J. M., Tanaka, J. W., Klaiman, C., Cockburn, J., Herlihy, L., Brown, C., … Schultz, R. T. (2008). Specific impairment of face-processing abilities in children withautism spectrum disorder using the let's face it! skills battery. *Autism Research*, *1*(6), 329–340. https://doi.org/10.1002/aur.56

Wood, A., Rychlowska, M., Korb, S., & Niedenthal, P. M. (2016). Fashioning the

Face: Sensorimotor Simulation Contributes to Facial Expression Recognition. *Trends in Cognitive Sciences*, *20*(3), 227–240. https://doi.org/10.1016/j.tics.2015.12.010

Woodbury-Smith, M. R., Robinson, J., Wheelwright, S., & Baron-Cohen, S. (2005). Screening adults for Asperger Syndrome using the AQ: a preliminary study of its diagnostic validity in clinical practice. *Journal of Autism and Developmental Disorders*, *35*(3), 331–335. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16119474

Wright, S. D., Brooks, D. E., D'Astous, V., & Grandin, T. (2013). The challenge and promise of autism spectrum disorders in adulthood and aging: A systematic review of the literature (1990–2013). *Autism Insights*, *2013*(5), 21–73.

Yang, J., & Li, P. (2012). Brain Networks of Explicit and Implicit Learning. *PLoS ONE*, *7*(8). https://doi.org/10.1371/journal.pone.0042993

Yoshikawa, S., & Sato, W. (2008). Dynamic facial expressions of emotion induce representational momentum. *Cognitive, Affective, & Behavioral Neuroscience*, *8*(1), 25–31. https://doi.org/10.3758/CABN.8.1.25

Yoshimura, S., Sato, W., Uono, S., & Toichi, M. (2015). Impaired Overt Facial Mimicry in Response to Dynamic Facial Expressions in High-Functioning Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *45*(5), 1318–1328. https://doi.org/10.1007/s10803-014-2291-7

Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist*, *35*(2), 151–175. https://doi.org/10.1037/0003-066X.35.2.151

Zajonc, R. B. (1984). On the primacy of affect.

Zajonc, R. B. (2000). Feeling and thinking: Closing the debate over the independence of affect. In *Feeling and thinking: The role of affect in social cognition.* (pp. 31–58). New York, NY, US: Cambridge University Press.

Zaki, S. R., & Johnson, S. A. (2013). The role of gaze direction in face memory in autism spectrum disorder. *Autism Research*, *6*(4), 280–287. https://doi.org/10.1002/aur.1292

Zapata-Fonseca, L., Froese, T., Schilbach, L., Vogeley, K., & Timmermans, B. (2018). Sensitivity to Social Contingency in Adults with High-Functioning Autism during Computer-Mediated Embodied Interaction. *Behavioral Sciences*, *8*(2), 22. https://doi.org/10.3390/bs8020022

Zebrowitz, L. A. (2006). Finally, faces find favor. *Social Cognition*, *24*(5), 657–701. https://doi.org/10.1521/soco.2006.24.5.657

Zeeland, A. A. S., Dapretto, M., Ghahremani, D. G., Poldrack, R. A., & Bookheimer, S. Y. (2011). Reward Processing in Autism. *Autism*, *3*(2), 53–67. https://doi.org/10.1002/aur.122.Reward

Zentner, M. R., & Kagan, J. (1996). Perception of music by infants. *Nature*, *383*(6595), 29.

Zürcher, N. R., Donnelly, N., Rogier, O., Russo, B., Hippolyte, L., Hadwin, J., … Hadjikhani, N. (2013). It's All in the Eyes: Subcortical and Cortical Activation during Grotesqueness Perception in Autism. *PLoS ONE*, *8*(1), 1–14. https://doi.org/10.1371/journal.pone.0054313

Zwaigenbaum, L., Bryson, S. E., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience*, *23*(2–3), 143–152.