The perils of automaticity

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Abstract

Classical theories of skill acquisition propose that automatization (i.e., performance requires progressively less attention as experience is acquired) is a defining characteristic of expertise in a variety of domains (e.g., Fitts & Posner, 1967). Automaticity is believed to enhance smooth and efficient skill execution by allowing performers to focus on strategic elements of performance rather than on the mechanical details that govern task implementation (see Williams & Ford, 2008). By contrast, conscious processing (i.e., paying conscious attention to one's action during motor execution) has been found to disrupt skilled movement and performance proficiency (e.g., Beilock & Carr, 2001). On the basis of this evidence, researchers have tended to extol the virtues of automaticity. However, few researchers have considered the wide range of empirical evidence which indicates that highly automated behaviours can, on occasion, lead to a series of *errors* that may prove deleterious to skilled performance. Therefore, the purpose of the current paper is to highlight the perils, rather than the virtues, of automaticity. We draw on Reason's (1990) classification scheme of everyday errors to show how an over-reliance on automated procedures may lead to three specific performance errors (i.e., mistakes, slips and lapses) in a variety of skill domains (e.g., sport, dance, music). We conclude by arguing that skilled performance requires the dynamic interplay of automatic processing and conscious processing in order to avoid performance errors and to meet the contextually-contingent demands that characterise competitive environments in a range of skill domains.

Keywords: Automaticity, expertise, performance error, cognitive control

The perils of automaticity

A key tenet of classical theories of skill acquisition (e.g., Fitts & Posner, 1967) is that performance becomes automatized (i.e., requires progressively fewer attentional resources) as a function of practice. Automatic processes are believed to be 'fast, stimulus-driven and characterised by a lack of intention, attention and awareness' (Saling & Phillips, 2007, p. 2). By contrast, controlled processes (which are typically portrayed as conscious and effortful in nature, Schneider & Shiffrin, 1977) are believed to be too slow to allow skilled performers to initiate action sequences when environmental or internal conditions demand immediate responses. Nevertheless, it is thought that this mode of processing may prove beneficial to novice performers (as they need to attend to skill execution in a step-by-step manner) and to experts when they are faced with unique situational demands or attenuated movement patterns (see Beilock, Carr, MacMahon, & Starkes, 2002; Beilock & Gray, 2007).

However, when performing routine and familiar tasks (such as dribbling a soccer ball through a series of cones), conscious control has been found to be highly disruptive to expert movement and performance proficiency (e.g., Beilock & Carr, 2001; Jackson, Ashford, & Norsworthy, 2006). In these latter situations, instead of consciously deliberating over the course of action to be taken, experts are believed to possess a repertoire of "situational discriminations" (i.e., well-worn neural pathways built from extensive experience with a wide variety of responses to each of the situations he/she has encountered) which allows them to intuitively see how to achieve their goal. Accordingly, the expert no longer needs to rely on rules or "verbally articulable propositions" as the skill is thought to have become "so much a part of him that he need be no more aware of it than he is of his own body" (Dreyfus & Dreyfus, 1986, p. 30).

In complex cognitive tasks such as chess, automaticity allows skilled players to benefit from *parallel processing* which enables them to process the relational position of all pieces on a board simultaneously. By contrast, less-skilled players process the relational position of each piece one at a time (i.e., serially; see Reingold, Charness, Schultetus, & Stamp, 2001). In sport, automated processing of the mechanical details of a skill (e.g. the backhand drive in tennis) enables the expert player to focus on strategic features of performance (e.g., the precise target for a cross-court backhand drive). Additionally, skilled athletes' response speed and efficiency is enhanced by processes such as advance cue utilisation (i.e., athlete's ability to make accurate predictions based on contextual information early in an action sequence; Williams, Davids, & Williams, 1999) and visuospatial pattern recognition (the ability to detect patterns of play early in their development) allowing them to respond intuitively in dynamic environments where time constraints provide little opportunity to deliberate and plan one's course of action (for a review, see Williams & Ford, 2008).

On the basis of the preceding evidence it is perhaps understandable that psychologists, skill acquisition specialists, and cognitive neuroscientists have focused on extolling the virtues of automaticity in facilitating expert performance. However, as we shall argue below, these perspectives ignore a wide range of evidence which indicates that highly routinized behaviours can, on occasion, lead to *errors* that are likely to prove deleterious to performance proficiency in a variety of skill domains. Therefore, the purpose of the present paper is to highlight the perils, rather than the virtues, of automaticity.

What exactly constitutes a performance error? Reason (1990) conducted extensive research on the psychology of human error and argued that the latter term "encompasses all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when those failures cannot be attributed to the intervention of some chance agency" (p. 9). He further suggested that correct performance and systematic errors are 'two sides of the same cognitive balance sheet' and that an analysis of 'recurrent error forms is essential to achieving a proper understanding of the largely hidden processes that govern thought and action' (p. 2). Unfortunately, researchers have yet to conduct a systematic analysis of the error forms that might occur during the performance of skilled motor action. In seeking to address this issue the current paper draws on a wide range of empirical evidence in order to argue that there are a number of different motor and cognitive tasks where a reliance on automaticity is 'not desired for fear that it might lead to error' (Norman & Shallice, 1986, p. 3). In doing so, we draw on Reason's (1990) classification scheme of everyday errors to show how automaticity may lead to errors in performance in a variety of skill domains (e.g., sport, dance, music).

At the outset, Reason (1990) distinguished between performance errors based on *mistakes in planning* and those based on *lapses or slips* in the *course of execution*. In the former case, *errors* might arise from a lack of knowledge, inadequate or incorrect information, or from the misapplication of rules. Reason (1990) defined *mistakes* as 'deficiencies or failures in the judgemental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision-scheme run according to plan' (p. 9). Reason (1990) believed that mistakes can be subdivided into (a) failures of expertise, where some preestablished plan or problem solving is applied inappropriately and (b) a lack of expertise, where the individual, not having an appropriate 'off-the-shelf' routine, is forced to 'work out a plan of action from first principles, relying upon whatever relevant knowledge he or she currently possesses' (p. 12).

By contrast, *slips* and *lapses* in the course of execution are most likely to occur during heavily practiced or routine actions. According to Reason (1990) slips and lapses are 'errors which result from some failure in the execution and/or storage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective' (p. 9). Finally, Reason argued that *slips* (e.g., slips of the tongue) are more likely to be observable than *lapses* (although, as we will proceed to argue later, this may not always be true in the case of skilled performance) – as the latter form of error characterises more covert forms of action that may only be apparent to the person who experiences them. Reason (1990) argued that slips generally occur as a result of *inattention* (when somebody fails to make a necessary check during action) but that they can also be caused by *overattention* – which occurs when we attend to performance at an inappropriate point in an automated action sequence. *Lapses* typically involve failures of memory so a musician may, for example, miss or forget a crucial turning point in a piece (i.e., where they are supposed to alter the expressivity of their play; see Chaffin & Logan, 2006). The performer is likely to instantaneously recognise this lapse but the error may not be apparent to the audience.

Empirical evidence and phenomenological description suggests that an overreliance on automated responses might lead to planning and execution errors/failures in a variety of complex and demanding tasks across various skill domains (e.g., Memmert, Unkelbach, & Ganns, 2010). We draw on this evidence to argue that automaticity is not an all-or-nothing phenomenon and that there may be 'excessive' amounts of it (i.e., the mindlessness that appears to characterise classical conceptualizations of automaticity; see Kahneman & Henik, 1981; MacLeod & Dunbar, 1988) that can lead to *mistakes*, *slips*, and *lapses* in skilled performance. *First*, we show how excessive automaticity might cause errors by interfering with effective planning/decision making not only in skill domains where time is available (such as chess) but also in fast-paced/open-skilled sports (where intuitive responses are generally considered to be most effective) that occur in environments characterised by severe time constraints. *Second*, we show how automaticity might cause *slips* in performance by invoking *ironic processes* or *habit lag* during on-line skill execution and demonstrate how slips might arise when the performer is overly-reliant on automated processes during the performance of dangerous or technically demanding motor tasks.

Third, we argue that excessive automaticity can cause *lapses* in performance by (1) hindering performers' ability to react flexibly in dynamically unfolding performance environments and (2) by reducing a performer's capacity for expressivity. The paper concludes by drawing on Christensen, Sutton, and McIlwain's (in press) 'mesh theory' to argue that skilled performance requires the dynamic interplay of automatic processing and cognitive control in order to avoid performance errors and to meet the contextually-contingent demands that characterise competitive environments in a range of skill domains.

Errors resulting from mistakes in planning

Let us start by considering how automaticity might lead to *errors* during the decision making process. Researchers have coined the phrase the *einstellung effect* to describe the phenomena whereby skilled chess players make mistakes in positions where familiar solutions are present (see Bilalić, McLeod, & Gobet, 2008). These mistakes occur when prior knowledge/experience or domain specific knowledge interferes with how we solve a current problem. Here, prior exposure to similar problems may actually have a negative influence on performance as this experience triggers a familiar but inappropriate solution and prevents alternative solutions being considered (Kaplan & Simon, 1990; MacGregor, Ormerod, & Chronicle, 2001). At first glance, this idea might seem somewhat counterintuitive given the wide range of empirical evidence which indicates that 'stimulus familiarity and domain-specific knowledge acquired through extensive and deliberate practice underlie the superior performance of experts relative to their less-skilled counterparts' (Ellis & Reingold, 2014, p. 1). Nevertheless, evidence from studies on chess (e.g., Bilalić et al. 2008, 2010; Reingold, Charness, Pomplun, & Stampe, 2001) and medicine (Croskerry, 2003; Gordon & Franklin,

2003) reveals that expert performers may succumb to the negative impact of prior experience and stimulus familiarity. To illustrate, Biliać et al. (2008) used eye-tracking technology to study the einstellung effect in chess experts. In this study, participants were required to find a checkmate with as few moves as possible. The researchers manipulated board positions so that there were two possible solutions: a familiar five-move sequence and a less well known three move sequence. Having identified the familiar pattern the chess players reported that they were still looking for a better solution. However, their eye patterns showed that they continued to focus on features of the problem related to the solution they had already generated. Biliać et al. (2008) speculated that the familiar pattern activated a schema in memory which ensures that attentional focus is directed to information relevant to the activated schema. As a result, the chess player focuses on information consistent with the activated schema and ignores contradictory information. This merely strengthens their conviction that they have chosen the correct schema and means that they are less likely to consider alternative options.

Having considered how automaticity might result in tactical decision making *errors* in chess we now consider this issue in a sporting context. Furley, Memmert and Heller (2010) examined how *inattentional blindness* influences decision making in a real-world basketball task based on the premise that there are both *costs* and *benefits* associated with the automated processing of task-relevant stimuli. *Inattentional blindness* refers to a phenomenon whereby participants who are engaged in attentionally demanding tasks "often fail to perceive an unexpected object, even if it appears at fixation" (Mack & Rock, 1998, p. 14). In sport this phenomenon might cause the performer to miss an unexpected event or fail to detect important cues. To test skilled athletes' susceptibility to this experience, Furley et al. examined whether basketball players would fail to pass to an unmarked player in a computer based sport task if they already held a representation of an alternative player in working memory. Specifically, the task required participants to decide who to pass to in a basketball situation photographed from their own perspective. Here, participants (acting as an attacker) were confronted by either one defender (who could occupy two potential positions) or two defenders (who could occupy three potential positions) in the stimulus display while one of their teammates was always left unguarded. Results showed that participants' attention was indeed biased towards certain teammates that resemble internal templates that are being held in working memory**.** Furley et al. suggested that the attention-demanding task may have automatically triggered an internalized production rule ("if-then" statements that describe what action should be executed if a designated condition is met). As a result, performers formed an intention to pass to a certain player, and subsequently completed that pass, even though it may not have been the best option available (as determined by expert ratings). This problem might be exacerbated when there are more objects in the visual display (e.g., more teammates available to pass to) as this results in greater competition between visual stimuli which are competing for limited attentional resources.

Furley et al sought to explain these findings by suggesting that certain coaching practices lead players to automatically trigger "if-then" rules. For example, if the defence responds by doing A, then you should do B; if they respond in manner C, then you should do D. Coaches are likely to utilise this mode of instruction in order to circumvent performers' limited processing capacities by directing their focus of attention to what they consider to be information-rich areas in a visual field. While such attention-guiding instructions often help, they may also lead to error. Specifically, they may hamper performance by inducing an *attentional set* (i.e., the prioritisation of certain stimuli; see Furley et al. 2010) and, as such, may help explain the preceding results (also see Memmert, Simons, & Grimme, 2009) indicating that offensive players fail to detect and subsequently pass to an unguarded teammate (i.e., one who is free and unchallenged by a defensive player) because that individual is not part of a specific offensive play and so is not factored into the decision making process. This effect resembles a form of confirmation bias (i.e., the seeking or interpreting of evidence in ways that are partial to existing beliefs or expectations) which will mean that the expert takes notice of, and focuses on, information that validates and confirms their expectations.

Of course, we need to recognise the important role that attentional sets play in guiding skilled performance. Without a repertoire of automatic responses, it would be extremely difficult for a performer (particularly one who is engaged in a dynamic environment where decisions must be made rapidly) to consider all or even a great number of the possibilities/options available to them. To circumvent these attentional demands performers are likely to consider options that have been intuitively generated or those that they have been directed to by a coach's instructions (perhaps in a pre-game scenario or even as the game unfolds). However, we need to consider why such automatic processing may hinder attentional flexibility (i.e., the ability to engage, disengage attention on various locations in space) causing the performer to miss important cues/game-related information. Answering this question might help coaches devise training regimes that prevent some of these errors (even if it is unreasonable to think that all could be eliminated).

Furley et al (2010) argued that attentional sets might also prevent performers from adopting an 'expecting-the-unexpected' strategy (Pesce, Tessitore, Casella, Pirritano, & Capranica, 2007) which helps performers zoom out their visuospatial attention and process a wider array of stimuli. In fact, evidence suggests that skilled performers can exert endogenous control on automatic attentional processes (see Jacoby, Ste-Marie, & Toth, 1993; Pesce-Anzeneder & Bösel, 1998) and are required to do so because open skilled sports are characterised by ever-changing conditions which require the flexible allocation of attention. In these situations performers must be able to utilise *selective attention* (i.e., the ability to limit incoming information in order to focus processing on specific stimuli) – a cognitive process which allows them to disengage quickly from an incorrectly cued spatial location and reorient attention to a correct location (Hodgins & Adair, 2010). Here, higher order control might allow performers to focus on attentional sets in order to meet specific task requirements (e.g., following a coach's instructions to exploit an opponent's defensive weaknesses) whilst retaining an overall awareness so that one can eschew these instructions in order to react appropriately in a dynamically unfolding environment. Unfortunately, excessive automaticity appears to render performers incapable of utilising such attentional flexibility.

Errors that result from slips in the course of execution

We now consider how automatic processes might lead to errors during on-line skill execution. Evidence from a range of studies demonstrates that under conditions of mental load or stress *automatic processes* that monitor the failure of our conscious intentions can, ironically, create that failure during skilled performance (Wheatley & Wegner, 2001). Wheatley and Wegner refer to such processes as "ironic processes". Ironic processes represent errors in performance because although the performer may have the correct plan or intention (e.g., a penalty taker in soccer may intend to place a spot kick beyond the reach of a goalkeeper by aiming for the upper corner of the net), automatic processes may lead to errors in task execution (i.e., by causing him/her to focus on what should be avoided, that is, hitting the ball close to the goalkeeper). Wegner's (1994) theory of ironic processes of *mental control* (i.e., people's ability to implement their intentions successfully) postulates that self-instructions *not* to carry out certain acts – under various forms of mental load (e.g., anxiety) - can lead to the individual behaving or thinking (through the prioritisation of automated processes) in the very manner that he or she had sought to avoid. In explaining this latter phenomenon Wegner (1994) referred to two hypothesised processes that work together to maintain mental control: the *operating* process and the *monitoring* process. The "operating process" searches for items that are in line with the desired goal or state. In contrast, the "monitoring process" is less cognitively demanding and identifies signals that one has failed to achieve the desired state. Wegner (1994) argued that an increase in mental load (e.g., as a result of anxiety) will reduce the attentional resources available to the operating process, resulting in the contents of the monitoring process (now unchecked by the operating process) becoming prioritised. As a result, the monitoring process activates the very thoughts or actions the performer had sought to avoid.

Empirical support for the theory of ironic processes has been found in a number of studies (e.g., Bakker, Oudejans, Binsch, & Van Der Kamp, 2006; Binsch, Oudejans, Bakker, & Savelsbergh, 2009; Woodman & Davis, 2008). For example, Dugdale and Eklund (2003) found that skilled dancers demonstrated more unwanted movements on a static balance task when instructed to try not to wobble than when they were simply asked to hold the wobble board steady. One might be inclined to explain this outcome in terms of Wulf's research on the benefits of adopting an external versus internal focus; however, another explanation is that via ironic processes led the dancers to do the very thing that they had sought to avoid. In another study, Binsch, Oudejans, Bakker, Hoozemans & Savelsbergh (2010), found that experienced footballers showed lapses in mental control (i.e., ironic performance) during a penalty kick task when instructed to shoot as accurately as possible whilst remaining careful not to shoot within reach of the goalkeeper. Ironic effects were accompanied by shorter final fixations on the target area (i.e., the open goal space). Research has shown that a longer fixation on the target prior to and during aiming is a characteristic of high levels of skill and accuracy (see Vine, Moore & Wilson, 2014, for a review).

Binsch et al. put forward two explanations as to why these ironic effects may have occurred. First, for some participants, their initial fixation on the keeper may have lasted too long for them to dedicate a sufficiently lengthy fixation on the open goal space. Second, the remaining participants may have dedicated an insufficiently long final fixation on the open goal space as they subsequently returned their gaze to the keeper. With the former group, the negative instruction not to aim within reach of the keeper may have caused the word ‘keeper’ to remain within conscious awareness meaning that it was difficult for the performers to disengage their visual fixation from this stimuli. In the latter group the word also lingered in their cognitive system and left insufficient time for a proper final fixation on the target. Together, these results demonstrate that automatic processes can lead to the very performance errors that the athlete had sought to avoid. It is, however, important to note that, in contrast to ironic behaviour, a number of studies have found that instructions can result in overcompensating, for example, missing a golf putt to the right of the target when one has been instructed not to miss to the left (see Beilock, Afremow, Rabe & Carr, 2001; Toner, Moran, & Jackson, 2013). Further research is therefore required to establish the prevalence of ironic processes as examples of automaticity-induced errors amongst skilled performers. Nevertheless, there is a growing body of evidence which suggests that rather than alerting the performer to a failure of conscious intentions, automatic processes may actually activate thoughts that prove deleterious to performance proficiency.

“Habit lag” appears to represent another intrusive-like error which occurs when the automatization process proves to be dysfunctional. According to Mannell and Duthie (1975) “habit lag” may occur ‘when an automatized response, no longer appropriate in a given situation, is nonetheless emitted counter to the intentions of the performer, thus disrupting a complex motor performance’ (p. 74). In this case, “habit” involves an automatized response while “lag” refers to the persistence of an old, outmoded response. Under certain conditions, habit lag may actually result in the accidental performance of the undesirable response. For example, a performer may inhibit the undesirable response by deliberately and consciously substituting it with a more desirable one but habit lag may arise when conditions are demanding or require attentional resources to be simultaneously divided between tasks. Fitts and Posner (1967) were amongst the first authors to describe this phenomenon when they reported anecdotal evidence which indicated that pilots who have learnt how to operate the controls in one cockpit, and subsequently moved on to operating in another have, under emergency conditions, reverted to old habits with catastrophic consequences. In this situation, the pilots may have stopped thinking about the new operational procedures and reverted back to the outmoded or 'ingrained' response pattern. Mannell and Duthie (1975) tested the habit lag construct by examining whether outmoded automatized responses would persist in a task requiring participants to perform two motor responses simultaneously in response to a televised display. Following a visual discrimination task, participants performed a task involving a repetitive lever response. Results revealed that 'automatized participants' (who performed the discrimination and the original lever response) committed substantially more errors than the nonautomatized group (who performed only the discrimination response). The authors argued that the attentional demand required from the discrimination task may have reduced attention to the automatized response for a substantial period of time thus facilitating habit lag. These responses occurred in spite of the performers' best efforts to inhibit the old behaviour – a finding which emphasises the persistence of automatized action.

Although few studies have examined how habit lag might influence skilled motor action this phenomenon does appear to resemble the errors that arise due to perseverance in the Wisconsin card sorting task (Kaplan, Şengör, Gürvit, Genç, & Güzeliş, 2006) or the A-not-B error in studies of infant and toddler search behaviour (Ahmed & Ruffman, 1998). But how might habit lag manifest itself in the sporting context? Skilled performers going through a period of technical change may be particularly susceptible to this undesirable outcome (Carson & Collins, 2011). Here, performers seeking to replace an old, inefficient movement pattern (identified by a coach or on the basis of self-regulation of one's actions) with a more proficient one, may find that the old habit can be difficult to exorcise and can remain present as 'a ghost...of a stable solution in the attractor outlet' (Huys, Daffertshofer, & Beek, 2009, p 359). These performers might find that, despite their best efforts, the old movement pattern remains stubbornly difficult to inhibit during on-line skill execution. This might occur when a coach or instructor fails to create sufficient 'noise' in the motor system by neglecting to create competition between the pre-existing stable state and the task to be learned (i.e., the current technique vs. the desired technique; see Carson & Collins, 2011).

Next we consider the *errors* that might occur when the skilled performer relies on automaticity during the on-line performance of tasks that are considered to be dangerous or technically demanding. One might argue that errors/action slips that arise whilst performing relatively simple tasks, such as reading or typing, are unlikely to be particularly harmful to one's health or wellbeing. By contrast, errors that occur during trapeeze acts, gymnastics or race car driving can be lethal. We argue that performers in these skill domains carry out activities which are so inherently complex, and potentially dangerous if movements are performed incorrectly, that actions cannot become wholly automatic. It is important to consider the latter possibility in light of recent perspectives in the sport psychology and skill acquisition literature that have encouraged skilled performers to promote *automatic* functioning by adopting an external focus of attention (i.e., focusing on the effects of one's movements on the environment; see Wulf, 2013). To explain, Wulf and her colleagues have produced a huge volume of evidence (for a review see Wulf, 2013) demonstrating that an external focus of attention (e.g., attending to the trajectory of a baseball as it leaves one's bat), will lead to a more *automatic* mode of control (across skill domains and skill levels) than an internal focus of attention (i.e., focusing on the movement of one's limbs). Wulf (2013) has argued that an internal focus constrains the automatic control processes that would normally regulate the movement while an external focus allows the motor system to more naturally self-organize. For example, Wulf, McNevin and Shea (2001) found that a group of participants instructed to adopt an internal focus produced higher balance errors on a dynamic balance task (stabilometer) when compared to the performance of an external focus of attention group. The results revealed that the external group demonstrated lower probe reaction times (a measure of attentional demands, and hence, the extent to which a movement is automatized) than the internal focus group. Although these findings point to the efficacy of an external focus (especially with relatively simple motor tasks) Wulf (2008) has acknowledged that there might be a ‘limit to the performance-enhancing effects of external focus instructions for top-level performers’ (p. 323).

Wulf (2008) reached this conclusion after discovering that an external focus did not enhance movement efficiency (relative to a normal focus condition and to an internal focus condition) when Cirque Du Soleil performers were required to balance on an inflated rubber disk. It is important to note that these performers carry out extraordinarily dangerous and daring feats of acrobatic brilliance which have, on occasions, led to severe injury and even fatalities (see Zuckerman, 2013). In seeking to explain her findings Wulf (2008) argued that performance in the “normal condition” (which required participants to stand still) would be governed by the highest control level. That is, as an action becomes automated it starts to be monitored at progressively higher levels of control. So, for a skilled golfer, hitting a towering draw (i.e., right-to-left trajectory) would represent a high-level goal while the mechanical steps required to achieve it (e.g., creating an in-to-out swing plane) would be represented at a lower level. In Wulf’s (2008) study, requiring elite acrobats to focus on minimizing the movement of the disk (external focus) or their feet (internal focus) may have directed them to a lower level goal and disrupted the ‘finely tuned, reflexive control mechanisms that normally control their balance’ (p. 323). Performance in the normal condition was characterised by more rapid adjustments than performance in the external and internal conditions. By adopting their typical focus under normal conditions (no manipulation check was employed so we don't know precisely what this focus may have involved) performers could compensate for perturbations of the disk's center of pressure by relying on reflex-type control. In the normal condition, instead of performers relying on some reflex-like response (which is likely to be mindless or intuitive) they may have drawn on a highly developed kinaesthetic awareness of their movement efficiency which allows them to rapidly identify (even in the midst of on-line skill execution) features of movement which require alteration. In fact, it would seem that attending to performance in these situations is important if one wishes to avoid performance errors.

Evidence to support this proposal can be found in a range of studies. For example, an elite acrobatic athlete in Hauw's (2009) study recalled the following situation when performance went awry: 'there was a second there where I told myself I was doing well and I was almost done…and so I relaxed and on the eight, I made the error' (p. 349). Hauw and Durand (2007) argued that performers experienced this state when they 'fell into a constant rhythm in their actions that sometimes led to a loss of attention' (p. 178). Similarly, Wiersma (2014) completed phenomenological interviews with elite big-wave surfers and found that they navigated their focus of attention to ensure that they were simultaneously aware of what was happening in front of (e.g., the contours and bumps of the water), and behind (e.g., the sound of what the wave was doing), their board so that they react accordingly. The type of awareness required in such situations would not involve the computationally demanding process of analysing each step-by-step component of the desired action but instead requires the performer to attend to certain cues, or kinesthetic sensations (see Ilundáin-Agurruza, 2015, for a similar argument relating to the role of 'kinesthetic attunement') during on-line movement control. Indeed, an elite trampolinist in Hauw & Durand's (2007) study sought to avoid injury (as a result of poor execution) by using kinaesthetic feedback to survey body position and the tautness and flexibility of the trampoline bed. According to Jackson & Csikszenthihalyi (1999) performers appear to process ‘information about the fine nuances of our involvement in the activity’ in order to make ‘adjustments to what you are doing when something is not quite right’ (p. 105). The preceding evidence indicates that in tasks that require the execution of technically complex movements, which might have fatal consequences if performed incorrectly (as in the case of Cirque Du Soleil), performers must avoid the mindlessness that can accompany automatic processing by ensuring that they continue to monitor movement proficiency.

Lapses during on-line skill execution

Let us now turn our attention from *action slips* and consider how automaticity might promote *lapses* in on-line skill execution. These performance errors may be harder to detect than action slips as they characterize more covert forms of action that may only be recognized by the performer. For example, a musician may experience a lapse when their performance lacks the desired expressivity (such as missing a turning point in a piece where musical feeling is supposed to change) but this subtle error may only be apparent to the performer and not to the audience. A range of empirical and phenomenological evidence suggests that skilled performers tend to experience these lapses in the midst of task execution.

In this section we consider how automaticity might lead to two specific lapses. *First* we consider how this form of information processing might reduce one’s ability to respond flexibly to performance demands in challenging conditions. *Second*, we discuss how the expressivity of skilled movement might be negatively influenced by a reliance on automaticity.

Performers are regularly presented with challenging conditions (not necessarily dangerous as in the previous section) – but ‘situations whose fine grained structure hasn’t been previously experienced’ (Christensen et al. in press, p. 24). Even Dreyfus and Dreyfus (1986; leading proponents of intuition in high-level skill) admit that few if any situations ‘are seen as being of exactly the kind for which prior experience intuitively dictates what move or decision must be made’ (p. 37). If this is the case then few situations encountered by the expert can be so similar to past experience that intuition or automaticity can be relied upon (Christensen et al. in press). These new situations will inevitably possess a degree of complexity and unpredictability that requires some form of evaluation (i.e., deliberation), heightened awareness, or subtle adjustments to movement or action in order to meet contextually-contingent demands. Bicknell (2012) discusses this issue in relation to expert mountain-biking and argues that an embodied understanding of skills must include access to tactical knowledge that allows riders to safely navigate challenging terrain. For instance, the rider might use imagery (based on previous experience of racing a route) to anticipate and prepare for the demands that they face on an impending section of the track. Bicknell reports how one performer neglected to pay attention to their speed as they came into a drop (i.e., a step-shaped section of a track where the lower part can be up to five meters lower than the higher part) and was dismounted from their bike in a very dangerous manner. Bicknell argues that reflection and decision making are possible, and necessary, during embodied states in order to allow the performer to monitor trail conditions and bodily performance (e.g., fatigue) during skill execution.

Similarly, Eccles and Arsal (2015) argue that expertise in orienteering (a sport requiring navigational skills using a map and compass to travel from point to point in what is usually unfamiliar terrain) is characterized by the use of cognitive strategies which allows participants to overcome the natural limitations of attentional resources by distributing the planning of map information over time. For example, one performer revealed that when he is on an easy part of the course (e.g., running on even surfaces such as roads) he makes effective use of that time to ‘plan the rest of the course so we’d be…be looking at the map…at another part of the course [to be covered] later on’ (Eccles, Walsh, & Ingledew, 2002, p. 78). As a result, this form of cognitive control allows the performer to focus on their running form or to ensure that they avoid potential hazards rather than having to attend to the map when they reach these demanding sections of the course. Orienteers reported that a lapse might arise if they lost their position on the map. To avoid this outcome they ensured that they kept in contact with the map throughout the race.

Almost all researchers who maintain that high level performance, at its best, occurs automatically also hold that in challenging situations the mind comes in to guide action. However, there are many forms of expert actions that are perpetually challenging. Indeed, even the most skilled performers are presented with unfamiliar situations which requires one to relinquish a reliance on automated procedures. For example, Macquet, Eccles and Barraux (2012) interviewed a world champion orienteer who revealed that in planning a route he had to consider a zone that ‘he didn’t yet know how difficult it will be to cross, we haven’t experienced this type of vegetation before: it’s half open and dense and low vegetation….I’ll see what it’s like when I get there; if needed, I’ll change routes’ (p. 95). Here, the performer recognizes that challenges lie in wait and that he must remain deeply attentive to performance in order to respond effectively.

Similary, performers may need to alternate between reflective and more automated actions in order to deal with challenging events that occur in the midst of fast-moving performances. To illustrate, Nyberg (2015) found that elite freeskiers monitored their rotational activity during the in-flight phase of a jump so as to ascertain “whether they will be able to perform the trick the way it was intended without adjustments or whether they will need to make adjustments during the flight phase" (p. 115). Nyberg suggests that these performers can use their focal awareness (which is conscious and might include knowledge of their velocity and how they need to alter it) and their subsidiary awareness which is 'less conscious' and includes knowledge of the 'particulars' such as the friction of the snow and their feelings of previous jumps. These elite performers were found to navigate their focal awareness by rapidly shifting its target even in the midst of the activity itself. Accordingly performers could monitor their rotational velocity while in the air but could quickly change their awareness to take into account environmental conditions such as their position in relation to the targeted landing area.

What mechanisms might allow performers to successfully shift between different modes of awareness during on-line skill execution? Rucinka's (2014) notion of "enactive creativity" might help us answer this question. Carr (2015) has drawn on Rucinka's work to suggest that this kind of creativity may enable the performer to 'diversify his or her experiences and to attempt to master the opportunities provided by changing performance environments' (p. 231). Interestingly, Carr (2015) proposes that learning to deal with unusual circumstances in an 'appropriate and effective way – which involves creation – is a trainable skill in and of itself' (p. 232). Future research may wish to explore this intriguing possibility.

We must also consider the possibility that mindlessness/excessive automaticity might cause lapses in performance by hampering the *artistic expression* of skilled movement in a number of domains. Relying on habit to take over and spontaneously do what has normally worked is fine when performing routine and simple everyday tasks (buttering a piece of toast in the morning) but is unlikely to prove sufficient when performing complex movements that require expressivity. Montero (2010) considered this issue in to relation to dance and suggested that 'performing the same piece in the same way day in and day out can result in a performance without any spark' (p. 117). On these occasions a lapse occurs: one goes through the motions, but the artistry is missing, and as such, the performance of such actions appears flat, insipid and uninspiring. It is like when the musician forgets a crucial turning point in a piece and so neglects to alter the expressivity of their play. To ensure that their actions possess the requisite levels of expressivity Montero (in preparation) argues that dancers evaluate the aesthetic qualities of their movements by retaining a proprioceptive awareness of their action. As Dewey (1922) notes, such conscious reflection on our movement 'keeps that act from sinking below consciousness into *routine habit* or whimsical brutality. It preserves the meaning of that act alive, and keeps it growing in depth and refinement of meaning' (p. 208). Thus reflection appears necessary if performers are to avoid lapsing into doing what they have always done, a mode of performing which precludes creative inspiration. Interestingly, Chaffin and Logan (2006) argue that performers may face a paradox in these situations. That is, performance must be largely automatic or it might be forgotten in the adrenaline rush that accompanies performing in front of a big audience and yet the performance itself is an inherently creative endeavour – not mindless repetition of overlearned movements.

How might performers resolve this dilemma? Chaffin and Logan (2006) found that concert soloists attend to *expressive* performance cues (e.g., such as musical feelings like excitement that can be conveyed to the audience). These authors suggested that the integration of automatic motor performance and cognitive control was required to provide flexibility (i.e., to communicate emotionally with the audience and permit recovery from performance errors) and that this was achieved through the practice of performance cues. Chaffin et al describe these cues as landmarks in the mental map of a piece that the musician monitors during performance to ensure that important aspects of performance go according to plan. These cues appear to be placed at key points in the routine to act as a safeguard if performance proficiency is disrupted by *memory failure* or *lapses in attention* (that is, if performance deviates from a plan of action). In other words, these cues may be used to guide embodied action and ensure that performance continues to evolve and result in something new. These cues may be *structural* (such as section boundaries in a musical piece), *expressive* (representative of turning points in a piece where musical feeling changes), *interpretive* (where interpretation requires attention such as a possible change in tempo) or *basic* (fundamental details of technique such as changes in the direction of bowing). Importantly, the cues allow performers to adjust their performance in order to meet the 'unique opportunities and demands of the occasion to achieve the maximum possible impact on the audience' (Chaffin & Logan, 2006, p. 127). Of course, we recognise that these cues are merely one aspect of what guides performers creative choices.

In the current paper, we sought to draw attention to a range of empirical evidence and phenomenological description which questions the common assumption that skilled performers in normal situations rely exclusively on automated procedures. It appears that contemporary accounts of skilled performance equate automaticity with mindlessness and we echo Saling and Phillips (2007) concern that such a conceptualization 'relegates human beings to the realm of the inflexible, unthinking robot' (p. 17). It is important to note, however, that although we have pointed to some of the problems associated with automaticity we recognise the obvious benefits that it confers upon the performer. That is, for the most part, automatic processing allows skilled performers to execute complex skills with breathtaking efficiency. Nevertheless, we believe it is important for researchers, practitioners and athletes to recognise that there are drawbacks associated with this facet of human cognition since this may pave the way towards training regimes that ultimately produce athletes that can both reap the benefits and avoid the pitfalls of automaticity. As Reason (1990) put it, there are 'penalties that must be paid for our remarkable ability to model the regularities of the world and then to use these stored representations to simplify complex information-handling tasks' (p. 17). In the preceding sections we have shown how these 'penalties' may occur in the form of mistakes or action slips or lapses during skilled performance. Given the propensity for skilled performers to experience these errors it is worth asking whether any can be avoided and if so, how. Here we have taken a first step towards addressing this question by examining empirical evidence and phenomenological descriptions that put pressure on the common assumption that skilled performance is almost exclusively automatic. Let us now aim to further understand some of the cognitive mechanisms responsible for the undesirable outcomes of automaticity.

Reason (1990) warns us that it is very tempting to argue that mistakes and slips originate from different cognitive mechanisms. Indeed, he indicated that *mistakes* arise from failures of 'the higher-order cognitive processes involved in judging the available information, setting objectives and deciding upon the means to achieve them' while *slips* stem from 'the unintended activation of largely automatic procedural routines' (associated primarily with inappropriate attentional monitoring; 1990, p. 54). However, if mistakes and slips did originate from different cognitive mechanisms then we would expect them to take different forms yet Reason argues that they do not always do so. For example, some errors may contain elements of mistakes in that they involve inappropriate evaluations of the current problem yet they may also demonstrate sliplike features in that 'strong-but-wrong' (i.e., where the inefficient behaviour is more in keeping with past practice than the current situation demands) choices are made. Reason (1990) acknowledged that the mistakes/slips dichotomy was a useful starting point for understanding human error but he also recognised that certain errors 'fall between the simple slip and mistakes categories' (p. 54) - that is, they possess categories common to both. For example, a highly skilled chess player might face a truly elite performer and find that prior experience triggers a familiar but inappropriate solution (i.e., mistake). However this solution may have helped them gain an advantage in prior encounters with less-skilled players (i.e., a strong-but-wrong action slip).

In seeking to resolve this problem Reason (1990) proposed that we differentiate between slips (i.e. actions-not-as-planned", p. 9) and lapses (i.e., "more covert error forms … that do not necessarily manifest themselves in actual behaviour and may only be apparent to the person who experiences them", p. 9) and two kinds of errors: rule-based (RB) errors and knowledge-based (KB) errors. Reason (1990) used a host of dimensions (e.g., type of activity, focus of attention) to summarise the distinctions between these three error types but it may be particularly useful to focus on the dimension 'relationship to change' - given the evidence outlined in the current paper which indicates that the dynamically unfolding nature of performance environments may render athletes particularly susceptible to the perils of automaticity. According to Reason's account, 'skill-based' (SB) slips might be occasioned by attentional failures such as intrusions (e.g., ironic processes) while lapses might be due to memory failures (e.g., forgetting to maintain the requisite expressivity or to remember the next step in a planned sequence). These latter errors might arise because in performance environments, knowledge relating to changes (e.g., adoption of task-irrelevant thoughts) are not accessed at the correct time – perhaps owing to attentional 'capture'. By contrast, rule-based mistakes involve the misapplication of a normally good rule, the application of a 'bad' rule or the failure to apply a 'good' rule (Reason, 2008). These mistakes can be anticipated to some extent (e.g., knowledge that an unmarked teammate may suddenly be picked up by an opponent) but the individual is unsure when the change in the environment will occur or the precise form it will take. Knowledge-based mistakes, on the other hand, are occasioned by changes that have neither been prepared for nor anticipated. Reason (1990) argued that the three error types can be discriminated according to the 'degree of preparedness' that exists prior to the change in the environment. He also proposed that SB and RB errors differ from

KB errors in their underlying cognitive structures. Specifically, whereas SB and RB errors occur while behaviour is "under the control of largely automatic units within the knowledge base" (Reason, 1990, p. 57), KB errors typically arise when the performer "is forced to resort to attentional processing within the conscious workspace" (p. 57).

Applying this line of thinking to the evidence outlined in the current paper we suggest that at the SB level the performer is aware of the potential for moment-by-moment changes in task constraints and possesses routines for dealing with them. Unfortunately, on certain occasions, the performer fails to use an attentional check to ensure that alternative strategies are utilised. At the RB level, the performer is aware that changes in the task environment are likely but makes a mistake through the application of a 'bad' rule or the misapplication of a 'good' rule. Finally, KB mistakes might arise when the performer encounters a change which falls outside the scope of their prior experience and leads them to engage in error-prone 'on-line' reasoning.

Accordingly, we suggest that Reason's category of dimensions might serve as a useful theoretical lens for researchers seeking to better understand how various cognitive mechanisms may interact to produce errors amongst skilled performers. One important caveat to note, however, is that much of Reason's work explored the prevalence of error without using experimental control over factors such as degrees of expertise or levels of automaticity. In one of the few studies to do so, Brown and Carr (1989) required participants to perform a sequential keypressing task, in conjunction with a short-term digit-span secondary task, and found no evidence for the kinds of slips at transition points evident in the various tasks reported by Reason. As a result, we acknowledge the challenges (i.e., combining ecological validity with experimental control) that are likely to face researchers who wish to explore the prevalence of error amongst skilled performers. Nevertheless, we believe this is an important endeavour if we are to better understand the mechanisms that govern thought and action in skilled movement control.

Considering the interplay between automatic processes and cognitive control

In discussing some of the performance errors that might arise when one is overly-reliant on automated processes we have hinted at the important role that cognitive control (i.e., the functions of the cognitive system that allow people to regulate their behaviour according to higher order goals or plans; Vebruggen, McLaren, & Chambers, 2014) might play in protecting the performer against these undesirable outcomes. In seeking to further advance this argument we echo Christensen et al.’s (in press) suggestion that athletes may be more susceptible to performance errors if they fail to shift from a more automatic mode of processing to a more attention-based mode of control at the right time during performance. Christensen et al.’s (in press) ‘mesh’ theory proposes that cognitive and automatic processes can operate together in a meshed arrangement with cognitive control focused on strategic elements of performance and automatic control responsible for implementation. According to this perspective, performers can enhance strategic focus (e.g., awareness of teammates who are best placed to receive a pass) providing they reduce attention to details of task implementation (e.g., the mechanical details involved in executing the pass). Significantly, however, this theory sees a very important role for cognitive control in skilled performance. That is, experts are often faced with complex and difficult performance conditions and may use cognitive control to evaluate situational demands and adjust lower order sensorimotor processes appropriately.

We agree with Christensen et al.’s proposal that cognitive control may be required for interpretation, decision making (e.g., in practice contexts or during pre-performance routines) and responding flexibly in dynamically unfolding competitive environments (which might include the use of cue words to enhance expressivity). In fact, many experts appear to actively avoid the excessive automaticity that has been privileged by a number of influential skill acquisition theorists because it limits their ability to respond to contextually-contingent demands and renders them vulnerable to performance errors (such as mistakes in planning or attentional lapses; see for example, Breivik, 2013; Nyberg, 2015). On occasions, deliberate control is necessary to suppress undesirable actions (e.g., passing to a poorly positioned teammate) and to enhance desirable actions (increase the expressivity of movement). Unfortunately, excessive proceduralization may prevent the expert from strategically re-routing semi-automated routines (Sutton, 2007). Indeed, Sutton (2007) warns us that some conceptualizations of automaticity might be equated with inflexible or rigid processing. By contrast, he asks us to conceive of sophisticated skill memory as regulated improvisation rather than reflexive conditioning. Such a perspective acknowledges that embodied skills are intrinsically active and flexible and might help us begin to explain how performers can avoid certain performance errors. So, what higher order cognitive processes might allow performers to use attentional processes in a flexible and adaptable manner?

In conclusion we would like to suggest that mindfulness approaches (involving bare awareness and attention to the present moment) might be particularly useful in achieving this latter aim. Interestingly, recent evidence suggests that attentional performance and cognitive flexibility are positively related to meditation practice and levels of mindfulness (Moore & Malinowski, 2009). For example, Moore and Malinowski (2009) found that self-reported mindfulness (that is, reports as to the level of attention and awareness one has in the present moment) was higher in meditators than non-meditators and the former group performed significantly better on all measures of attention (e.g., stroop interference test). By increasing mindfulness, and hence one's cognitive flexibility, performers become better equipped at sustaining and guiding their focus of attention, at suppressing interfering information, and deautomatising automated responses (see Chong, Kee, & Chaturvedi, in press).

Such an approach may allow the individual ‘to inhibit initial, automatic responses to sensory data in order to retain flexibility necessary to react effectively to changing circumstances’ (Rossano, 2003, p. 219). Additionally, performers can be encouraged to become aware of their psychophysical states (thoughts, emotions, bodily reactions) and mindfully accept any unpleasant feelings that may arise. Instead of attempting to suppress these states the performer might use self-regulatory processes in order to recognize that an alternative plan of action is required (e.g., by starting to focus on core action components, that is, features of action previously identified as functional to task achievement; see Bortoli, Bertollo, Hanin, & Robazza, 2012). As such, mindfulness acts as a form of attentional checking allowing the performer to establish whether actions are still running according to plan and whether the plan is still adequate to achieve the desired outcome. In addition, performers might combat excessive automaticity by retaining a somaesthetic awareness (i.e., a proprioceptive feel) of their bodily movement which will enable them to identify the emergence of inefficient movement patterns. It is important to acknowledge that this mindful bodily awareness does not necessarily involve a conscious analysis of the individual components of action but would, instead, typically require athletes to pay heed to their movement and recognise when it is causing them pain, discomfort, or consistently undesirable outcomes (see Toner & Moran, 2014; 2015, for a detailed discussion). This form of mindful awareness will allow performers to identify factors that are compromising the efficient execution of desired movements and help them determine how they might execute movements with greater precision (Shusterman, 2008). Of course, it is important that psychologists seeking to enhance a performer’s attentional flexibility ensure that they avoid disrupting finely tuned attentional patterns that facilitate performance proficiency. Instead, approaches such as mindfulness should be employed to help performers enhance attentional flexibility and avoid the mindlessness that appears to lead to a variety of performance errors.

The situations faced by experts appear to have too much variability for them to be able to rely exclusively on automatic processes (Christensen, Sutton & McIlwain, in press). We have argued that performance cannot be wholly 'autonomous' or 'spontaneous' in nature as certain facets of skilled performance must be attended to in order to avoid the 'perils of automaticity'. To support this argument, we drew on a range of evidence which demonstrates some of the errors that might arise when performers rely entirely on an automated mode of processing. Thankfully, phenomenological and empirical evidence indicates that skilled performers are quite capable of using a number of different forms of conscious processing in seeking to alter or guide movement execution (see Carson, Collins, & Jones, 2014; Nyberg, 2015). Nevertheless, further research is required to examine the various ways in which performers improvise their embodied skills in the midst of skill execution. For example, researchers may wish to examine how performers use metacognitive processes (see MacIntyre, Igou, Campbell, Moran, & Matthews, 2014) in seeking to alternate between automatic and conscious processing. In addition, experts may need to be taught how to avoid excessive automaticity/proceduralisation and develop techniques (e.g., somaesthetic awareness, mindfulness) that allow them to monitor and control semi-automated routines. Of course, too much conscious attention is not a good thing, but so is too much automaticity. Rather, our recommendation is for performers to find the right balance. We recognize that this is a challenging process but it appears necessary if performers are to retain the attentional flexibility that is required to avoid errors during the performance of complex actions in dynamically unfolding environments.

Finally, a potentially fruitful new direction for research in this field concerns the possible influence of emotion on "habit memory" in skilled performers. To explain, Packard

& Goodman (2012) distinguished between stimulus-response or “habit” memory (sub-served by the dorsal striatum) and “cognitive” memory (sub-served by the hippocampus). Interestingly, research (e.g., see Goodman, Leong, & Packard (2012) shows that in certain forms of psychopathology (e.g. obsessive compulsive disorder, post-traumatic stress disorder), excessive anxiety tends to activate dorsal striatal-dependent (‘habit memory’) processes at the expense of their hippocampal-dependent (‘cognitive memory’) counterparts. What is not clear, however, is whether or not this shift to habitual behaviour (or “stress-mediated habit bias”; Packard & Goodman, 2012) also occurs in the case of motor skill experts who are exposed to stressful situations in competitive settings.

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