Twenty Years of Load Theory – Where Are We Now and Where Should We Go Next?

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Abstract

Selective attention allows us to ignore what is task-irrelevant and focus on what is task-relevant. The cognitive and neural mechanisms which underlie this process is a key topic of investigation in cognitive psychology. One of the more prominent theories of attention is Perceptual Load Theory which suggests that the efficiency of selective attention is dependent on both perceptual and cognitive load. It is now more than 20 years since the proposal of Load Theory and it is timely to evaluate the evidence in support of this influential model. The present article supplements and extends upon previous reviews (Lavie, 2005; 2010) by examining more recent research in what appears to be a rapidly expanding area of research. The article comprises five parts, examining (1) the evidence for the effects of perceptual load on attention, (2) cognitive load, (3) individual differences under load, (4) alternative theories & criticisms and (5) the future of Load Theory. We argue that the key next step for Load Theory is the application of the model to real world tasks. The potential benefits of applied attention research are numerous and there is tentative evidence that applied research would provide strong support for the theory itself as well as real world benefits in activities where attention is crucial, such as driving and education.

Keywords

Selective Attention : Perception : Perceptual Load : Load Theory : Distraction : Visual Attention

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Selective attention is the ability to focus on that which is important to the task at hand while ignoring or suppressing task-irrelevant information. A key question that has fuelled much debate and research in psychology is how, and crucially when this irrelevant information is filtered out. For example, while reading this article the reader may be surrounded by many potential distractors such as the noise of a fly buzzing around the room. Given the top-down goal of reading this paper, how much information is available to you about the fly? Can the processing of irrelevant stimuli be reduced or even prevented by internal or external factors? Inability to ignore distractors is a common experience in daily life and while it may at times have minor consequences such as extending the length of time it takes to read an article, there are other situations where lapses of attention have far more serious consequences (e.g. in healthcare situations, or while operating heavy machinery). Perceptual Load Theory (Lavie & Tsal, 1994; Lavie, 1995; 2005; 2010) suggests that the success or failure of selective attention is dependent on the processing demands of the current task. That is, the level of perceptual load as well as any cognitive load will determine the efficiency of distractor rejection. This theory has been hugely influential over the last twenty years, with Lavie's 1995 paper 'Perceptual Load as a Necessary Condition for Selective Attention' cited 1385 times at the time of writing this article (source: Google Scholar). What made Load Theory attractive was that it proposed a solution to the long-standing 'early vs. late selection' debate, which had been the focus of attention researchers for decades (Driver, 2001). Despite taking this important step in attention research, there are still outstanding issues and valid criticisms surrounding Load Theory. This review will examine the state of the research to date - it is timely that we do so now, having passed the 20th anniversary of the load hypothesis (first proposed in Lavie & Tsal, 1994).

The major reviews in this area are becoming out-dated (Lavie, 2005; Lavie, 2010), such is the speed with which new research is being published in the field, along with the shift in thinking that has occurred in the last number of years. Recently, the focus of Load Theory research has moved away from simply establishing the basic consequences of load and focused more on generalising the theory beyond the original paradigms. Where Load Theory traditionally created a black and white distinction between perceptual and cognitive load and their opposing effects on attentional selection, recent research has contributed many more shades of grey. For example, research has focussed on different forms of cognitive load, on different populations, and on the effects of different stimulus sets. Thus both the limits and potential of Load Theory are at once becoming clearer, allowing more concrete applied predictions to be made. The more recent, independent reviews available are critical reviews, focusing on particular theoretical or methodological flaws in Load Theory, rather than the broader state of the research and potential future directions (e.g. Khethrapal, 2010; Benoni & Tsal, 2013). The purpose of the current review then is to supplement and expand upon previous reviews with one eye on the applied future of the theory, as that is, we feel, the crucial next step for Load Theory. This paper will have 5 major sections – evidence for the effect of (i) perceptual and (ii) cognitive load to date; (iii) individual differences research; (iv) alternative theories, and finally, (v) the future of Load Theory. First we will present the theory itself and the circumstances that led to the model becoming so influential.

Perceptual Load Theory

A widely debated question in attention research has been whether selective attention operates at an early or late stage of processing. The 'early selection' view, first proposed in the 1950s, holds that due to a limited perceptual processing capacity (a 'bottleneck' in the attentional process), individuals necessarily perceive only what they attend to; thus, focused attention can prevent distractor processing at an early stage (e.g. Broadbent, 1958; Treisman, 1969). Broadbent's filter theory is the classic example of 'early selection', stating that incoming information is selected based on physical features. This was typically demonstrated using dichotic listening experiments in which subjects must attend to one of two audio streams presented to the left and right ears. Participants are instructed to select one stream based on features such as the gender of the speaker or the ear to which it is presented. Studies that supported the early selection model typically used direct measures of awareness such as recall for the unattended stream (e.g. Cherry, 1953). However, more indirect measures suggested that the bottleneck might not be absolute, with subjects displaying increased galvanic skin response (GSR) when words, which had previously been paired with an electric shock, were presented in the unattended stream (Moray, 1969). This evidence that selection could occur later, beyond the supposed 'bottleneck' led some to favour a theory of late selection.

The 'late selection' view states that perception is of unlimited capacity and that it is proceeds automatically, processing relevant and irrelevant stimuli indiscriminately. Late selection theorists suggest that it is later processes such as memory or behavioural response which are affected by selective attention (Deutsch & Deutsch, 1963; Duncan, 1980). They reconciled this theory with early-selection evidence by hypothesising that the poor recall of unattended information in dichotic listening tasks was not due to early filtering of irrelevant information, but due to late selection which prevented entry of that information to memory or deliberate behaviour based on the information (e.g. Duncan, 1980). While early-selection initially gained the most empirical support (Cherry, 1953; Moray, 1959; Neisser, 1969; Sperling, 1960),in the late 70's the pendulum shifted and the majority of evidence seemed to be in favour of late selection (e.g. Eriksen & Eriksen, 1974; LaBerge, 1975; Miller, 1987; Posner, 1980).

Kahneman and Treisman (1984) argued that this new support for late selection was the result of a paradigmatic shift in attention research. The studies which supported early selection often used the 'filtering paradigm' – a strategy wherein participants are bombarded with information, both relevant and irrelevant, and asked to attend to a particular stimulus and provide a complex response (e.g. Cherry, 1953). Later studies that supported late selection were more inclined to use the 'selective set paradigm', in which participants are presented with a small number of stimuli and asked to perform a simple task (e.g. Posner, 1980). Kahneman and Treisman highlighted the differences between these paradigms and cautioned against any meaningful generalization across these studies. Yantis and Johnson (1990) then proposed a hybrid model of selective attention with a flexible locus of selective attention. While early and late selection theorists had argued as to where in the perceptual process the attentional filter was located, Yantis & Johnson suggested that the filter could move, depending on the task demands. When the task involved processing multiple objects, they found that attention could be perfectly selective. They argued that there was an early locus of attention when the task involved filtering out irrelevant objects but that the locus could move to a late stage, post identification, under certain conditions.

Lavie and Tsal (1994) built on this idea by detailing what exactly determines the movement of the filter; perceptual load. Perceptual Load Theory states that perception is a limited capacity process (similar to early selection views) and proceeds automatically until that capacity is filled (in line with late selection views). When a task imposes high perceptual load, capacity is reached and distractors cannot be processed, resulting in performance that is consistent with early selection. However, when a task involves low perceptual load, all available stimuli are processed, distractors and targets alike, necessitating late selection. Cognitive load, such as a high working memory requirement, can cause late selection to fail (Lavie, 2005).

To use the previous real life example, how does one read this paper while ignoring a fly buzzing around the room? How is it that this sentence is selected and the fly is rejected? Early selection theory dictates that as the fly is irrelevant, it would not be processed. This page would be selected for further attention at an early stage and nothing about the fly would be processed beyond that point. Late selection theory would suggest that the fly (and other surrounding stimuli) would be processed along with the page. Selective attention would take place at a later stage in processing, preventing the distractors from affecting behaviour. Load theory incorporates aspects of both early and late selection to explain this scenario. If the visual properties of this article incurred high perceptual load (e.g. if the paper was transparent and the words written on the reverse of this page were visible here, demanding increased attention to distinguish these relevant words from the irrelevant distractor words) it is likely that the fly would be filtered out of the reader's awareness at the perceptual stage and not processed further; early selection occurs in this case because perceptual capacity is exhausted. If, however, the article incurred lower perceptual load (e.g. written on thick, white paper with no translucent properties), the fly would be processed along with the page to a later stage of processing where the reader must select the page and prevent the fly from interfering with the primary task. The allocation of attention at this late stage is dependent on available cognitive resources and may fail if cognitive load is high. The process of selective attention is, according to Load Theory, dependent on external properties (perceptual load) and internal properties (cognitive load).

Now we will break down the state of the research on Load Theory into 5 distinct branches – evidence for perceptual load effects, cognitive load, individual differences under load, criticisms and alternatives and finally, the future of Load Theory.

1. Perceptual Load Studies

1.1 Behavioural Evidence

Perceptual load is commonly manipulated in the visual domain in one of three ways. Firstly, load can be altered by varying the number of items in the display. For example, in the frequently used flanker task (Eriksen & Eriksen, 1974), participants are asked to identify which of the target letters X or N are present in a display. In a low-load trial the target may appear alone while in a high-load trial the target may be surrounded by 6 neutral letters (e.g. Lavie & De Fockert, 2003). The second manipulation of perceptual load in the visual domain is a manipulation of the similarity of target and non-target items, as shown in Figure 1 (e.g. Beck & Lavie, 2005; Lavie & Cox, 1997). For example, in the X or N search task, the extra letters can be visually dissimilar to the target in some way such as their angularity. In a low-load trial the extra letters may be all O's, while in a high-load trial they may be angular letters that are more similar to the target (K, V, W, K, Z). Finally, it is possible to keep the display constant between conditions and instead manipulate perceptual load by altering the task to be performed. This form of manipulation is often seen in experiments that require participants to make a judgement about an object, for example viewing a briefly presented cross and reporting which arm, horizontal or vertical, is green (low load) or which arm is slightly longer (high load) (Cartwright-Finch and Lavie, 2006), see Figure 2a. Note that this paradigm has the benefit of using identical stimuli for both conditions.

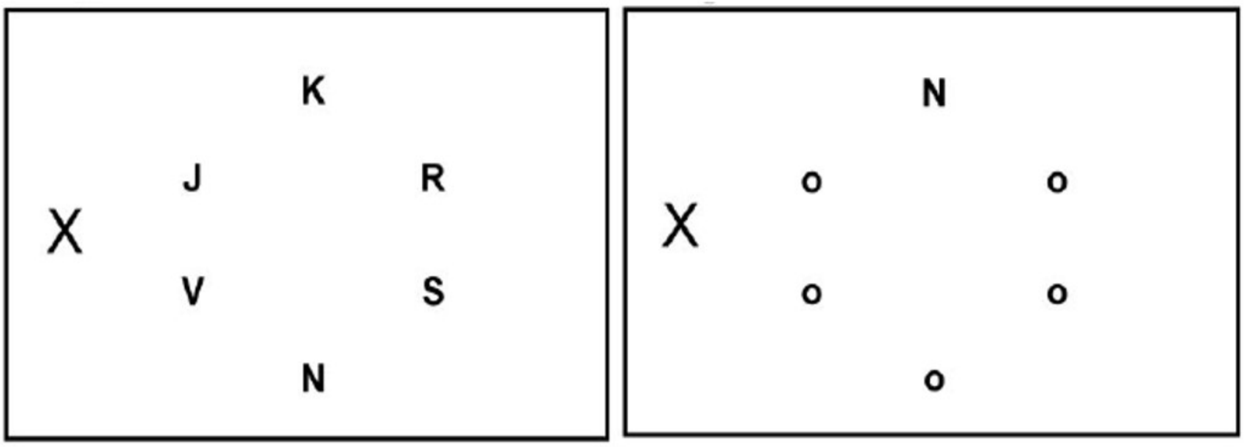

Figure 1: Example of a classic Load Theory search task from Beck & Lavie, (2005, pp 594). Participants must indicate if there is an X or N present in the circle of letters, while ignoring the peripheral, distractor letter which may be congruent or incongruent with the target (in this case both are incongruent). In the low load task (right) the target is surrounded by a number of identical round shapes, while in the high load task (left) the target is surrounded by a number of different, angular, shapes. Load Theory predicts that as the distractor letter will be processed under low load, there will be a large distractor interference effect for response times (incongruent RT – congruent RT = distractor interference effect). Under high load, as the distractor is not processed, the distractor interference effect will be significantly attenuated.

The efficiency of selective attention in most visual studies is measured by the difference in target response time for trials containing congruent and incongruent distractors. If early selection takes place then the distractor will not be processed and so there will be no effect of congruency, however if late selection occurs then incongruent distractors will result in delayed reactions and more errors. This congruency effect arises because the required response for the target is in direct conflict with the required response for the distractor.

Many behavioural studies have consistently shown that perceptual load affects the level of distractor interference (Lavie & Tsal, 1994; Lavie & Cox, 1997; Rees, Frith & Lavie, 1997; Forster & Lavie, 2008; Wei, Kang & Zhou, 2013). High perceptual load results in longer reaction times and higher error rates (due to the increased task difficulty), but eliminates distractor interference (unlike general task difficulty). To investigate whether the observed effects of high perceptual load are simply a by-product of the increased task difficulty associated with high load and the simultaneous slowing of performance, Lavie & DeFockert (2003) conducted an experiment wherein the task display was subjected to extreme sensory degradation, so much that the target could barely be seen. This was done to increase task difficulty in a manner that could not be compensated for by simply applying more attention. If the effects of perceptual load were simply due to task difficulty then they would also be evident with degraded stimuli. They found that this was not the case, the altered stimuli reduced speed and accuracy compared to a clearly visible target, but crucially did not decrease distractor interference. However, Yeshurun & Marciano, (2013) recently manipulated stimulus degradation more systematically and found more complex patterns of results. While Lavie & DeFockert (2003) only varied the degradation of the target (inadvertently making the distractor more salient), Yeshurun & Marciano varied a) only the target, b) only the distractor and c) both the target and distractor. They found distractor interference evident at both low and high perceptual load, contrary to the predictions of Load Theory. The authors suggested that the relative conspicuity of the target is an important factor in determining the efficiency of selective attention but agreed that task difficulty does not explain load effects. The issue of conspicuity will be discussed in section 4 – Criticisms and Alternative Theories.

Proponents of the perceptual load model claim that the reduction in distractor interference under high load is indicative of more focused attention (decreased distractor perception), though one could argue that it may be due to better rejection, or inhibition, of distractors. To resolve this uncertainty, Lavie and Fox (2000) investigated the effect of perceptual load on negative priming. Negative priming is the slowing of responses to previous distractor stimuli when those stimuli are presented as a target on a later trial

(Tipper, 1985). Negative priming has been viewed as evidence for late selection (Driver, 2001) as it reflects active distractor inhibition, whereby distractors *are* perceived but then inhibited at a later stage. Lavie and Fox found negative priming effects from distractors presented under low perceptual load however these effects were eliminated when perceptual load was increased. The authors concluded that the reduced distractor interference under high load that has been demonstrated in the literature is unlikely to be caused by increased distractor inhibition but instead is most likely a result of decreased distractor perception. This supports the key prediction of the perceptual load model - increased perceptual demand prevents the processing of unattended information, resulting in reduced distractor interference, rather than improved distractor inhibition.

1.2 Distractors

The perceptual load model focuses on ability to ignore irrelevant distractors, making the definition of an irrelevant distractor crucial. Forster & Lavie (2008) conducted an experiment using a letter search task comparing interference from response-competing distractors (letters) with interference from distractors deemed truly irrelevant (cartoon characters). The researchers chose cartoon characters as distractors as previous research had suggested that they are a particularly distracting type of stimuli as they possess characteristics such as visual salience and meaningfulness. They found that irrelevant distractors were just as likely to interfere with task performance as relevant distractors and importantly, that their interference effects could also be reduced to the same degree via high perceptual load. This study has important implications for the practical application of Load Theory, as it suggests that the response competing qualities of a distractor do not interfere with the predictions of load theory.

However, there is evidence that there are special distractors that continue to cause interference under high perceptual load. Faces have an obvious biological and social significance and it has long been suggested that faces might be a special case in attention (see Farah, Wilson, Drain & Tanaka, 1998 for a review). Neuroimaging research suggests that faces may be processed by a specialized module (De Renzi, 2000; Kanwisher, McDermott & Chun, 1997). Lavie, Ro & Russell (2003) investigated this possibility in relation to perceptual load. They found that while distraction from meaningful, non-face objects (e.g. fruits, musical instruments) was eliminated under high perceptual load, distraction by celebrity faces remained. This effect was replicated by Sato & Kawahara (2014) who found that the attentional capture by distractor faces persisted even when they had a different onset time to the search array. This result was not apparent when this experiment was replicated using animal faces as distractors (Hains & Baillargeon, 2011), which might suggest that this finding is reflective of the special significance of human faces and/or our expertise with them. Evidence from event-related potentials also suggests that human faces are a special case. In an ERP study, Neumann, Mohamed & Schweinberger (2011) compared repetition effects in the processing of unfamiliar distractor faces, houses and hands. Participants were presented with a perceptual load letter search task (as in Figure 1), superimposed on a background image of an unfamiliar (i.e. non-celebrity) face, house or hand. Later, images of faces, houses and hands were presented without the letter task. Some of these were repeats from the earlier trials, and some were new stimuli. Brain activity is thought to be modulated in response to stimuli which are repeated (e.g. Henson et al., 2000; Grill-Spector et al., 2006) and thus this paradigm allows for an estimation of background distractor processing in the letter search task. Neumann & colleagues found evidence of repetition modulation for faces, while there was no such effect for houses or hands. Importantly, the repetition modulation for faces was not extinguished under high perceptual load, suggesting that faces are a special case in the Load Theory model, continuing to be processed even when a central task imposes high perceptual load. Recently, it has been suggested that attention capacities may even be divided between 'face capacity' and 'non-face capacity' (Thoma & Lavie, 2013). Thoma & Lavie's behavioural study found that face and non-face load had different effects on face distractor interference – face load eliminated face distraction easily, however non-face load had no effect on face distraction. This study suggests that faces are special because they are processed separately, but by exhausting the capacity of the facial processing module, the predictions of Load Theory can be upheld.

However, there is an opposing body of evidence that the observed ability to process distractor faces under high load may not be due to a face-selective attention module, but instead a result of expertise. There is evidence that visual expertise for other objects can induce the same effect. Neuroimaging studies of experts in birds and cars have found that the same area of the brain that is used for face processing is recruited in the processing of the object of the participant's expertise (Gauthier, Skudlarski, Gore & Anderson, 2000). This expertise hypothesis was tested by Ro, Friggel and Lavie (2009) in a follow up to the study on famous faces. They found that expert musicians suffered distractor interference from musical instruments under high perceptual load. For non-musicians, there was a significant effect of set size, with the distractor interference effect decreasing as set sized increased. However, for musicians there was no effect of set size. Thus it could be argued that the previously discussed evidence in favour of the 'special case' of faces may simply be reflective of a specialized processing mechanism for objects of high familiarity, one that is either more efficient or has a greater capacity. He and Chen (2010) also found that interference from familiar natural distractors persisted under high perceptual load while Lin & Yeh (2014) found that when one's own name or another person's name was presented as a distractor in a search task, participants were more likely to recall seeing their name than the other name, even under high load.

The proposed existence of a specialized face-processing module is an on-going debate that has yet to result in a consensus, but from a Load Theory perspective, what is important to note is that not all distractors are equal. Whether due to the special case of faces or expertise, what you are trying to ignore is almost as important as what you are trying to attend to. This is quite an important point to note when applying the load model to real life tasks.

1.3 Awareness Under Load

The behavioural evidence discussed thus far has focused on the degree to which distractors can be ignored – a rather indirect measure of processing. There is also evidence that load influences conscious, in the moment awareness of distractors in the form of inattentional blindness research (see Lavie, Beck & Konstantinou, (2014) for a review). Inattentional blindness is the failure to notice a visible stimulus because one's attention was consumed with another task. Cartwright-Finch and Lavie (2006) instructed participants to make a discrimination about a cross which incurred low load (which arm is green?) or high load (which arm is longer?), see Figure 2a. Participants' awareness of a small black square that appeared on the critical final trial was assessed immediately via direct questioning. Reported awareness of the shape was 40-50% lower in high perceptual load conditions. Recent research suggests that this inattentional blindness caused by high load occurs at an early stage of processing (Calvillo & Jackson, 2014). While performing a low or high load categorization task, Calvillo & Jackon presented participants with an unexpected additional object that was either animate or inanimate. Awareness for the unexpected object was assessed immediately after the critical trial. Previous studies have established that animate objects are detected more quickly and easily than inanimate objects with animate and inanimate objects activating different visual brain regions (ventrolateral and ventromedial regions) (Wiggett, Pritchard & Downing, 2009). Calvillo & Jackson found that under low load, animate objects were significantly more likely to be detected than inanimate objects, however this effect was eliminated under high load. This suggests that even basic categorisation of distractor stimuli is prevented under high perceptual load, which in turn affects predicted levels of awareness.

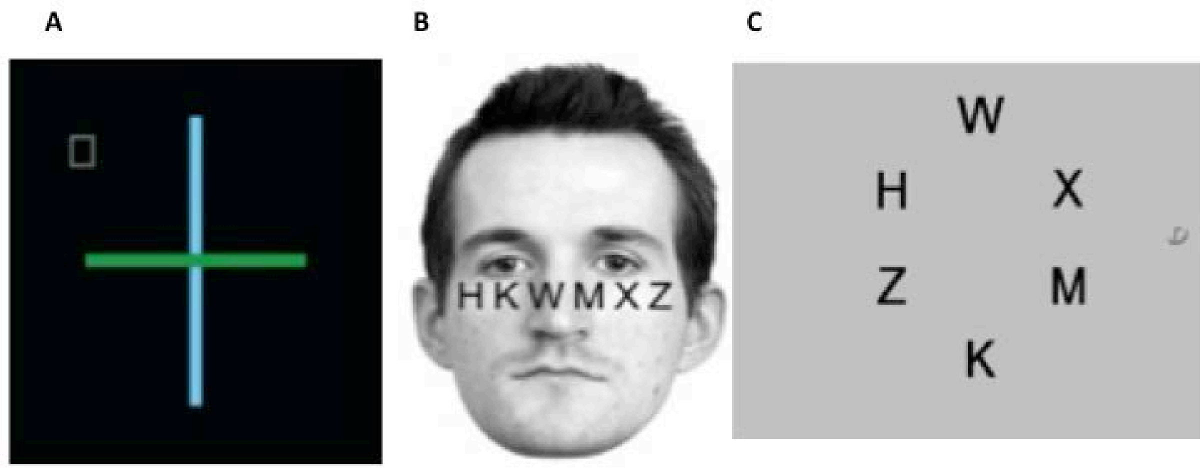

Figure 2: Example stimuli from paradigms investigating perceptual load effects on awareness. Panel (a) shows the final, critical trial from Cartwright-Finch & Lavie (2006). The stimulus was identical for both low and high load trials but under low load the task was simpler (identify which arm is blue) than high load (identify which arm is longer). On the final trial, an unexepected shape was presented along with the cross and awareness for the shape was assessed. Awareness was significantly worse under high load. Panel (b) is a high load trial from Jenkins, Lavie & Driver (2005). Participants were presented with a letter search task which was superimposed onto a human face which they were instructed to ignore.

Following the task, participants were given a surprise recognition memory test for the irrelevant faces, with recognition significantly worse under high load. Panel (c) presents an example of a high load trial from Macdonald & Lavie (2008). During a perceptual load letter-search tasks, participants' awareness for a small, unexpected shape was assessed. Detection sensitivity was significantly worse under high load.

As with traditional inattentional blindness research, one interpretation of these results is inattentional amnesia (Wolfe, 1999) – that participants did process the unexpected object but forgot they had seen it. Indeed there is evidence that perceptual load affects memory for distractors. Jenkins, Lavie & Driver (2005) presented participants with a letter search task superimposed on a human face (see Figure 2b). Participants were told to ignore the distractor face throughout the experiment but were then presented with a surprise test. Recognition for the distractor face was dependent on perceptual load at exposure, with faces displayed in low load tasks recognized more often than those presented in high load tasks. This suggests that load in a non-face task can reduce facial recognition, that, in line with the predictions of Load Theory, perceptual capacity is limited and beyond a certain threshold, information can no longer be processed. Failing to recognise task-irrelevant information does not necessarily mean that participants were unaware of the faces; it is possible that the stimuli were simply not processed sufficiently to allow later recognition. Addressing this, Macdonald & Lavie conducted a follow up study (2008), which measured in-the-moment awareness of a target shape, rather than relying on questioning at the end of the experiment. While undertaking a traditional perceptual-load search task where a target letter (X or N) was sought amongst non-target letters, participants were asked to report the presence of a small grey shape that could appear on some trials (see Figure 2c). The results showed that the shape was detected 90% of the time under low perceptual load but only 37% of the time under high perceptual load. This suggests that the level of load in a task truly modulates conscious awareness of additional information, rather than just affecting post-event recall.

This strand of research is important for the real-world applications of Load Theory because failing to detect objects can be just as troublesome as being distracted, since many activities and occupations are dependent on noticing unexpected objects. While the traditional Load Theory paradigms rely on distractor interference as a measure of the efficiency of selective attention, it is of course important to note that in the real world, being immune to the 'distraction' of non-targets may not be beneficial. For example when driving, a pedestrian on the footpath may be a distractor, but should that pedestrian turn to cross the road, they become a potential hazard that ought to be attended to. A complete understanding of load-induced blindness could be applied to numerous domains, as will be discussed later in this article.

1.4 Neuroimaging Evidence

Though the Load Theory model does not describe the mechanisms at work, there is a body of neural evidence in support of the effect of perceptual load. Torralbo and Beck (2008) have theorised that perceptual load affects distractor interference via a top-down biasing signal which arises as a consequence of neural competition. Previous fMRI studies have established that when stimuli are presented simultaneously in the visual field, their cortical representations in the object recognition pathway interact in a mutually suppressing manner (Kastner, De Weerd, Desimone & Ungerleider, 1998; Beck & Kastner, 2005). Single-cell recordings in extrastriate cortex in monkeys have found that the response to a target presented within a neuron's receptive field is reduced when a second stimulus is presented simultaneously within the same field (Miller, Gochin & Gross, 1993; Moran & Desimone, 1985; Connor, Preddie, Gallant & Van Essen, 1997). Stimuli are thus not processed independently, but rather interact competitively, at least when they are 'close' to each other in a particular modality (temporally, spatially, etc.). Macaque studies have however shown that when attention is directed to the target stimuli, the neural response is as large as when the stimulus is presented alone (Reynolds, Chelazzi & Desimone, 1999). This suggests that directing attention to a target overcomes the suppressive influence of distractor stimuli in a top-down manner. These studies support the biased competition model of selective attention (Desimone & Duncan, 1995), where neural competition for representation is said to be controlled by bottom-up factors (e.g. when one stimulus is more novel) and top-down factors (e.g. when one stimulus is more situationally relevant).

Torralbo and Beck (2008) argue that this top-down bias is at the heart of the neural mechanisms underlying perceptual load. The degree of competition between stimuli dictates the strength of the required top-down biasing mechanism, which in turn determines the degree to which the unattended stimulus is processed. Displays which induce a high degree of competition will require a strong bias to overcome the competition and select the target for further processing. This amounts to high perceptual load, and ensures that the competing stimulus is ignored. Conversely, if there is minimal competition between task relevant stimuli, very little top down bias is necessary to overcome the conflict, amounting to low perceptual load. This theory is in line with much of the current body of evidence for Load Theory (Scalf, Torralbo, Tapia & Beck, 2013).

In a behavioural study, Torralbo and Beck (2008) found that stimuli that should produce greater competition in the visual cortex resulted in reduced distractor interference effects, akin to high perceptual load. In a search task, a display of four closely-spaced letters resulted in less distractor interference than a similar display with the same letters spaced further apart. Distractor interference was also reduced when the targets and non-targets appeared in the same hemi-field rather than different hemi-fields, as local interactions occur within rather than between hemi-fields (Torralbo and Beck, 2008). This finding was replicated in a recent behavioural study (Wei, Kang & Zhou, 2013). Similarly, Parks, Beck and Kramer (2013) found that steady-state visual evoked potentials (SSVEPs) for distractors were reduced under high perceptual load when the distractor was positioned close to the target location but this effect was not evident at more eccentric locations. These results suggest that increased perceptual load induces a relatively narrow area of improved distractor resistance. Distractor filtering does not appear to occur across the visual field, but rather as a direct result of the resolution of competitive interactions in the visual cortex. This contradicts classic Load Theory in that it suggests that there is no single visual 'perceptual capacity' that can be exhausted by load. Clearly more research is needed to define the mechanisms that underlie visual perceptual load at a neural level.

While there is still debate as to the exact mechanisms at work, studies have shown that the level of perceptual load in a given task modulates neural activity related to distractors. This has been illustrated using fMRI (Yi et al., 2004; O'Connor et al., 2002; Xu et al., 2011; Fu et al., 2010; Sy & Giesbrecht, 2010; Wei et al., 2013), EEG (Handy et al., 2001; Parks, Hilmire & Corballis, 2009; 2011; Parks et al., 2011; Schwartz et al., 2005; Rees Frith & Lavie, 1997; Rorden et al., 2008; Rauss et al., 2009; Parks, Beck & Kramer, 2013; Fu et al., 2009; Wang et al., 2012) and both simultaneously (Sabri et al., 2013). There is neuroimaging evidence that identifies a push-pull relationship between targets and distractors in V4 (Pinsk et al., 2004) (i.e. enhanced attention to a target occurs at the expense of other stimuli in the display). This is in line with the principle of competitive interactions, which suggests "if one stimulus is "pushed up" by attention then, by virtue of their competitive/inhibitory connections, other competing stimuli will necessarily be "pulled down" (Scalf et al., 2014, p6). Crucially for Load Theory, there is evidence that the extent of this push-pull dynamic is moderated by the level of perceptual load of the central task. For example, event-related potential studies suggest that increased perceptual load in the relevant task results in stronger N1 responses to relevant information and weaker N1 signals to irrelevant information (Rorden et al., 2008). The visual N1 is a component which reflects processing of any visual stimulus, but the amplitude is larger for attended-location stimuli compared to unattended-location stimuli (Luck, Hillyard, Mouloua, Woldorff, Clark & Hawkins, 1994). Research suggests that the N1 component is reflective of the discrimination process in selective attention (Vogel & Luck, 2000). Fu et al., (2010) also found that under high load, the N1 amplitude was greater in the attended than the unattended hemi-field, while there was no significant difference under low load.

Moving distractors are often used to assess the related activity in the visual cortex. In a study investigating early evoked potentials, participants were asked to indicate if a word was presented in upper case or lower case (low load) or to count the number of syllables in the word (high load) while ignoring an irrelevant motion background (Rees, Frith & Lavie, 1997). Under low load, the distractor background evoked responses in areas of the brain responsive to movement (e.g. MT, V1/V2, V5), but such responses were markedly reduced under high load.

In a similar fMRI study, Yi, Woodman, Widders, Marois & Chun, (2004) instructed participants to ignore pictures of houses (both internal and external) presented in the background while monitoring for face repetitions at the fixation point. The perceptual load of the faces being monitored was varied by adding noise (random salt and pepper distortions) to each face. Yi and colleagues found that parahippocampal activity related to the background scenes was substantially reduced under conditions of high load. They also found evidence of repetition suppression under low load, i.e. upon repetition of a background scene, the stimulus signal weakened considerably. Such an effect was eliminated under high perceptual load, suggesting that the brain was less sensitive to repetition under high load.

Schwartz et al. (2005) and O'Connor, Fukui, Pinsk & Kastner (2002) used peripheral checkerboards as distractors while subjects performed a centrally presented task. Both studies found that activity across the visual cortex related to the checkerboards (from V1 to V4) was significantly reduced with a high load central task compared to a low load task. Using retinotopic mapping, O'Connor and colleagues found that activity in the lateral geniculate nucleus (LGN) related to the irrelevant checkerboards was also modulated by load. The LGN is the relay centre for messages sent by the retina and is said to be the first point of access for sensory information into the visual cortex (Jones, 1985; Sherman & Guillery, 2001). As this is the first point at which top-down signals could affect visual processing, perceptual load can thus be said to affect the earliest processing site in the visual pathway. As this was an fMRI study where the BOLD (Blood Oxygen Level Dependent) signal is integrated over seconds, it is possible that the altered activity in the LGN is a product of feedback from other areas (Briggs and Usrey, 2011; Ichida, Mavity-Hudson and

Casagrande, 2014). However, this study suggests that, in line with the predictions of Load Theory, there is a qualitative difference in processing under conditions of low and high perceptual load.

Though most of the evidence discussed here relates to visuo-spatial attention, the effect of perceptual load has also been observed with auditory stimuli (e.g. Sabri et al., 2013). Both fMRI and EEG were used to analyse neural responses during a dichotic listening experiment. Subjects performed a signal detection task with one ear (discriminating between short and long duration tones) and ignored the sounds in the other ear. The short tone was always 50msec. In the low-load condition the long tone was 100msec while in the high-load condition the long tone was 60msec, forcing a more difficult discrimination. Participants' ability to detect an irrelevant deviant tone amongst the standard irrelevant tones was assessed. EEG results showed that the mismatch negativity response (MMN), which is associated with the passive detection of deviant stimuli, was larger in the low-load task.

1.5 Cross-Modal Perceptual Load Studies

Visual and auditory studies of perceptual load have been discussed thus far, however the real world is rarely unimodal and attention often functions across multiple senses simultaneously. What is the effect of perceptual load in one modality on distractor inhibition in another? This question must be addressed before Load Theory can move forward with applied research. The literature remains divided on this issue, though it has been a focus of much research in recent years. There is considerable theoretical and empirical support for the view that attentional resources are modality specific (Allport et al., 1972; Treisman and Davies, 1973; Wickens, 1980; Parks et al., 2011) with load in one mode having no effect on distractor inhibition in another. For example, in a PET study, Rees, Frith & Lavie, (2001) found that there was no difference in the distraction caused by an irrelevant motion distractor under high and low audio load. Subjects were asked to identify loudly spoken words amongst quietly spoken words (low-load) or to identify bisyllabic words amongst monosyllabic and trisyllabic words (high-load), while ignoring irrelevant visual motion stimuli. Rees and colleagues found that motion-related visual areas were activated by the irrelevant stimuli in both low and high perceptual load conditions, suggesting that perceptual load effects are evident within but not between modalities.

However there is also evidence that capacity limits are supramodal, with load in one mode increasing distractor inhibition across all senses (Broadbent, 1958; Houghton et al., 2003; Klemen et al,. 2009; Parks et al., 2009, Berman and Colby, 2002). For example, one fMRI study found that angry distractor voices produced altered responses in the amygdala and auditory cortex compared to neutral voices under low visual load, while this difference was eliminated under high visual load (Mothes-Lasch, Miltner & Straube, 2012). Further evidence for supramodal capacities has emerged from studies investigating awareness of distractors. Macdonald and Lavie (2011) established the phenomenon of 'inattentional deafness' in visual perceptual load studies. Using a similar paradigm to the inattentional blindness experiments described above, participants were asked to perform discrimination about a cross and to report when they heard a brief tone played in the room. Under high perceptual load, participants were significantly less likely to report hearing the sound, suggesting that the amount of visual load affected the degree to which audio distractors were processed.

Methodological differences across these studies make it difficult to draw conclusions but a recent study by Jacoby, Hall & Mattingley (2012) can perhaps offer a resolution to this conflicting evidence. Neural responses (steady-state evoked potentials) to an irrelevant checkerboard were measured under levels of visual and audio perceptual load. In line with Load Theory, high perceptual visual load led to decreased responses to the irrelevant, visual distractor. However, when the target was auditory, high audio load actually increased responses to the distractor checkerboard. A previous behavioural study found similar results when the distractor was auditory – increasing visual perceptual load eliminated distraction by irrelevant visual distractors but increased distraction by audio distractors (Tellinghuisen and Nowak, 2003). Tellinghuisen and Nowak (2003) suggested that the same resources that direct attention to task relevant stimuli are also critical in inhibiting distraction arising from non-attended modalities. Therefore, an increase in perceptual load in the attended modality will have two distinct effects; it will improve distractor rejection within the attended modality by exhausting the available capacity, while simultaneously weakening the suppression of stimuli from other senses (Jacoby et al., 2012). In the language of Load Theory, cross-modal tasks require more executive control, amounting to cognitive load (Brand-D'Abrescia & Lavie, 2008). As predicted by the load model, this cognitive load disrupts late selection processes, leading to greater distraction. Some resources, such as perceptual capacity, may be modality specific, accounting for previous findings where load in one modality has no effect on processing in another (Rees et al., 2001). However, when the task requires recruitment of executive control processes, increases in distraction become apparent as top down control is modality independent.

2. Cognitive Load

The literature reviewed so far indicates clearly that distractors are more difficult to ignore under conditions of low perceptual load. However, individuals do not completely fail to reject distractors under low perceptual load; instead we would expect to see both within and between subject variations in ability to focus on the primary task. Under low perceptual load then, what determines the effectiveness of selective attention? How do individuals achieve late selection, preventing perceived distractors from affecting behaviour? Lavie's (2010) model theorises that executive functions are responsible for late selection as they are known to be involved in top-down, goal-directed behaviour, actively maintaining current priorities. This is evidenced by neuropsychological studies in which those with damage to the frontal lobe can suffer from 'dysexecutive syndrome'. This disorder is characterised by an inability to suppress response to irrelevant distractors and difficulty maintaining behaviour in line with current goals (Baddeley & Wilson, 1988). Interestingly, the frontal lobe is also known to be the last to develop in young people and the first to deteriorate in old age. This may explain the increased distractor interference that has been shown in children (Couperus, 2011) and the elderly (Maylor & Lavie, 1998). Indeed, research has shown that individual differences in distractibility are highly associated with individual differences in cognitive control capacities (Engle, 2002).

Research has shown that loading executive functions (cognitive load) has the opposite effect to perceptual load. When cognitive load is high, it is more likely that distractor inhibition will fail and distractor interference effects will be observed. Using the earlier example of reading a paper while ignoring the buzzing of a fly in the room, imagine that the reader is also trying to actively remember a phone number as they read (placing a high load on working memory). This would make them much more vulnerable to the distracting effects of the fly, as they do not have sufficient remaining cognitive resources to maintain top-down, goal directed behaviour. The literature has traditionally loaded cognitive function through working memory tasks and numerous studies have found that high working memory load disrupts selective attention (Burnham, 2010; Lavie & deFockert 2005; Lavie, Hirst, deFockert & Viding, 2004). Participants complete a 'sandwich task' (see Figure 3), i.e. they are first presented with something to remember, then while maintaining it in memory they must complete a response-competition visual search task, before answering a question about the to-be-remembered item (e.g. de Fockert, Rees, Frith, & Lavie, 2001). In this manner, the effect of working memory load on distractor interference can be examined. While most studies in this area manipulate visual and auditory attention, a novel study investigated the effect of cognitive load on tactile selective attention. Dalton, Lavie and Spence (2009) instructed participants to focus on target vibrations while ignoring distractor vibrations. They found that high working memory load resulted in greater distractor interference. There is also evidence that neural responses to irrelevant distractors increase under high cognitive load (DeFockert et al., 2001; Rissman, Gazzaley & D'Esposito, 2009; Kelley & Lavie, 2010).

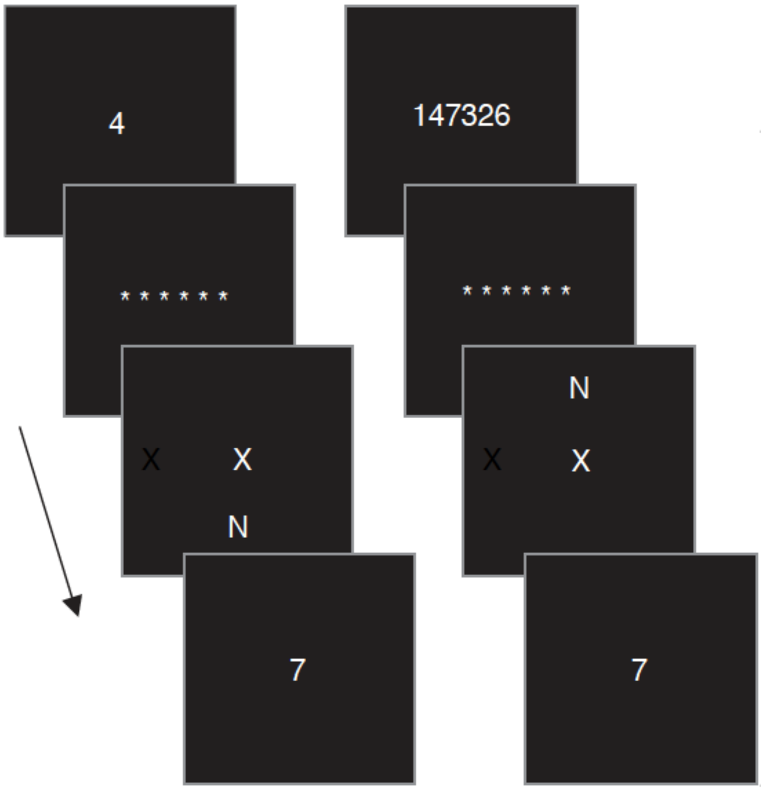

Figure 3: Typical procedure for assessing the effect of low (left) and high (right) working memory load on attention (Lavie, 2005, pp 76). Participants are first presented with a number of digits to remember and instructed to hold them in memory throughout the trial. They are then presented with a search task (in this case a response-competition task) which they must complete as quickly and accurately as they can. Participants are then presented with a probe digit and they must indicate if the probe appeared in the initial memory set. The reaction times and accuracy for the search tasks are assessed, excluding any trials where the response to the memory probe was incorrect. In general, working memory load has the opposite effect of perceptual load, increasing distraction by irrelevant stimuli.

The predictions of Load Theory in regards to cognitive load are rather simplistic – ‘cognitive load increases distractor interference’. There are many different forms of cognitive load, however Load Theory research has almost exclusively used a simple working memory task (remembering a list of numbers). Recent research has taken a closer look at the term ‘cognitive load’ and found that not all working memory tasks are equal, with different types of tasks having different effects.

Baddeley’s working memory model has several components: the ‘slave systems’ which process and maintain information (the phonological loop and visuo-spatial sketchpad), a system responsible for binding information together (the episodic buffer) and the supervisory system which governs the activity of the rest (the central executive) (Baddeley & Hitch, 1974; Baddeley, 2000). While most studies of cognitive load used verbal working memory tasks (e.g. remembering a series of numbers or letters), a recent study attempted to assess the effect of loading other working memory components (Burnham, Sabia & Langan, 2014). For subjects performing a visual search task (identifying a green diamond amongst 5 or 9 green circles), loading the central executive (subjects were given a starting number and had to complete a backwards counting task for the duration of the trial), visual working memory (remembering four coloured squares and indicating if a probe colour was present in the original set) and spatial working memory (remembering the location of two squares and indicating if two probe squares were in the same location as the original set) increased distraction. However, loading phonological working memory (remembering two monosyllabic three-letter words and indicating if a probe word was in the original set) had no effect on attentional capture in the search task. This suggests that it is not just any working memory load that influences distractor rejection, rather it is only working memory tasks that require the same resources as the search task. In line with Load Theory's general principles, it is a question of limited resources and processing limitations. This has interesting implications for real-life attention, where resources are commonly tapped by two tasks simultaneously (e.g. holding a picture of a map in memory while walking).

However, there is some conflicting evidence in this area. Rose, Schmid, Winzen, Sommer & Buchel (2005) found that, contrary to the predictions of Load Theory, increasing the load in a working memory task (n-back) decreased processing of task-irrelevant visual stimuli (background images). They assessed irrelevant object processing in a series of behavioural, fMRI and EEG studies, finding that increasing working memory load reduced processing of the irrelevant objects, in the same manner as increasing perceptual load. These apparently contradictory findings may simply be a result of imprecise definition of cognitive load. Within Baddeley's working memory model there is a clear distinction between tasks that require maintenance and tasks which require cognitive control, with neuroimaging research indicating that these tasks require differential recruitment of prefrontal cortex regions (Baddeley, 1992; Smith, Jonides, Koeppe & Marshuetz, 1998). Konstantinou & Lavie (2013) hypothesised that this distinction would manifest in perceptual load studies, with visual working memory load (maintenance) reducing visual representation capacity, and recall of randomly ordered digits in proper order (cognitive control) reducing top-down control of priorities. The effect of maintenance was assessed with a simple spatial memory task where participants memorised a set of coloured squares, while cognitive control was manipulated via the 'successor naming task' where participants remembered a number of digits in order. They were then prompted with a single probe digit and had to indicate which digit came after the probe. During the retention interval of the working memory task, participants performed a visual search task while also monitoring the periphery for a masked shape. In line with their predictions, they found that visual working memory load reduced the ability to detect a peripheral shape in a visual search task, presumably due to reduced visual processing capacity (similar to the effects of high perceptual load) (see Figure 4). Loading cognitive control however, had the opposite effect, with increased sensitivity to the peripheral shape. This reflects a lack of priority-based control of attention, in accordance with classic Load Theory predictions relating to cognitive load effects.

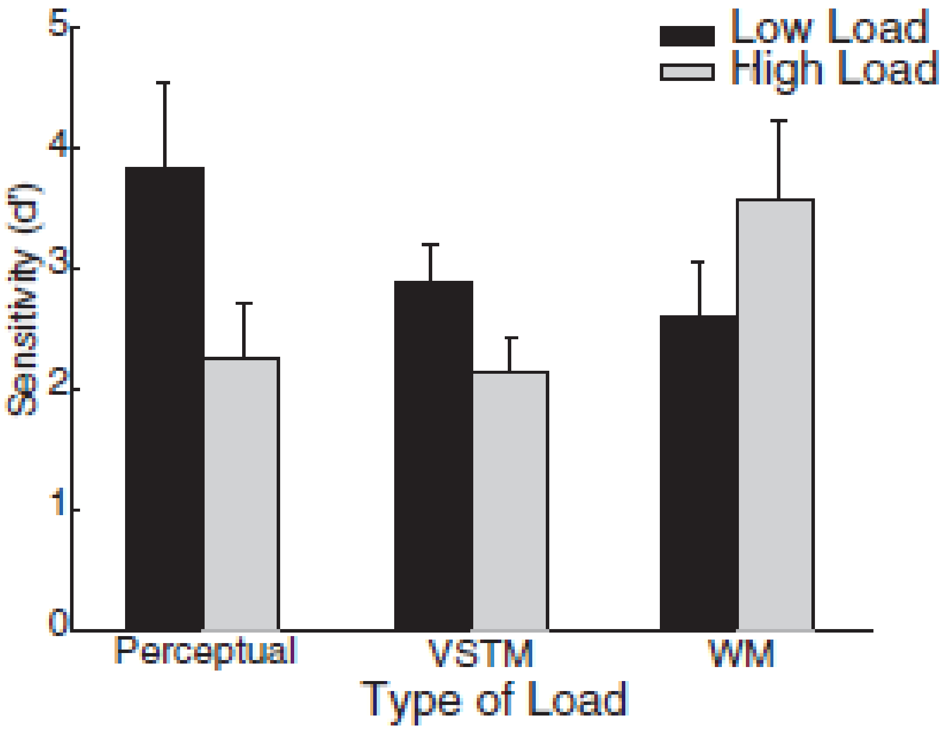

Figure 4: Results from Konstantinou & Lavie (2013). The effect of perceptual load, visual short term memory load (requiring simple maintenance) and working memory load (requiring cognitive control) on awareness for a shape presented adjacent to a central search task. Loading cognitive control (WM) had the opposite effect to a maintenance memory task (VSTM), increasing awareness for the shape.

These results conflict with a previous study which compared a maintenance-based working memory task (remembering a string of digits) and a working memory task that involved executive control (rearranging the order of the numbers) (Fougnie & Marois, 2007). The executive control task was significantly more likely to induce inattentional blindness for an unexpected shape, though Konstantinou & Lavie (2013) argue that this result was likely due to a confounding increase in general task difficulty. Konstantinou & Lavie (2013) suggest that accurately distinguishing between different types of working memory explains the discrepancy in previous findings, with methodological differences between studies where cognitive load increased distractor interference (Lavie & deFockert, 2005; Lavie et al., 2004, Carmel, Fairnie & Lavie, 2012) and those where cognitive load reduced distractor interference (Rose, Schmid, Winzen, Sommer & Buchel, 2005; Bollinger, Masangkay, Zanto & Gazzaley, 2009; Screenivasan & Jha, 2007). This distinction has since been replicated (Konstantinou, Beal, King & Lavie, 2014; Roper & Vecera, 2014), strengthening the cognitive-load related claims of Load Theory.

The distinction between the effects of different kinds of memory load is important for future studies which manipulate load to note. This research also sparks an interesting question as to the possible effects of other types of cognitive load and their potential interactions with perceptual load (for example, the processes of judgement, decision making and prospective memory are ripe for examination). A review of the Load Theory literature suggests that far more research has been conducted on the topic of perceptual load rather than cognitive load over the past twenty years. However they both play an important role in determining selective attention performance. Further research into other forms of cognitive load (and their interactions with perceptual load) would be beneficial for both theoretical and applied purposes as the concept of cognitive load in Load Theory has been somewhat neglected.

3. Individual Differences under Load

Load Theory, depending as it does on capacity limitations, predicts individual differences in response to distractors. Processing capacity is known to develop during childhood and to deteriorate later in life. Research conducted with children and the elderly has shown that the effects of visual selective attention are the same as for younger adults, however there are differences in what constitutes low and high load. Maylor and Lavie (1998) found that older adults needed a smaller increase in perceptual load in order to decrease distractor interference. Similar studies involving children have found that young children require less perceptual load than older children or adults to induce early selection (Huang-Pollock et al., 2002; Couperus, 2011). All three studies found that performance matched that of young adults in high load but not low load tasks. This suggests that early selection may engage processes that mature earlier and regress later than late selection processes. Younger children have also been found to be more susceptible to inattentional blindness under low and moderate levels load compared to slightly older children (Remington, Cartwright-Finch & Lavie, 2014).

Similarly, cognitively impaired individuals have less perceptual capacity and so require a smaller increase in load in order to induce early selection. Research has shown that individuals with a brain lesion in areas associated with attention respond to perceptual load similarly to children and older adults (Lavie & Robertson, 2001). Patients with a right parietal lesion demonstrating left neglect are extremely vulnerable to distracting stimuli in their right visual field but Lavie and Robertson found that a small increase in the perceptual load of the central task resulted in reduced interference by right distractors. This effect was observed by increasing the set size of a letter search task from one to two, a change which had no effect on healthy controls. This suggests that the lesions have a direct effect on attentional capacity, reducing the amount of perceptual load necessary to induce early selection. Similar results have been observed in people with schizophrenia and schizotypal personality (Ducato et al., 2008). There has been disagreement as to whether schizophrenia results in reduced or increased attentional capacity, with many studies finding different results using different paradigms. Ducato et al. suggested that perceptual load could be responsible for these discrepancies and indeed they found that under low load, all subjects showed distractor interference. As load increased from low to medium, only participants with schizophrenia or schizotypal personality disorder demonstrated reduced distractor interference. Medium load had no effect on the controls. This suggests that schizophrenia may be associated with a reduced perceptual capacity, not an improved ability to filter out distractors. This is just one example of how Load Theory, with its simple predictions founded on perceptual capacity, can be used to better understand clinical disorders.

There are also a number of disorders where increased perceptual load is necessary to observe the effects of the Load Theory model. Remington, Swettenham & Lavie (2012) hypothesised that the Load Theory model, with its focus on perceptual capacity, may be a means of resolving discrepancies in previous studies where individuals with Autism Spectrum Disorder (ASD) have displayed improved attentional abilities (e.g. improved performance in visual search tasks) and yet greater distractibility. Indeed they found that high perceptual load reduced distractor interference in normal adults but not in people with ASD. Further studies have shown under extremely high perceptual load, there is no difference between ASD participants and controls (Hessels, Hooge, Snijders & Kemner, 2014). Children with autism have been found to be less susceptible to inattentional blindness than controls and while increases in perceptual load are associated with increased inattentional blindness in controls, children with autism were unaffected by load increases (Swettenham et al., 2014). Interestingly, in a study of neurotypical individuals, those who scored above average on the Autism Spectrum Quotient (AQ) suffered from greater distractor interference at high load than those who scored below average (Bayliss & Kritikos, 2011). This suggests that even in non-clinical populations, autistic symptoms are associated with individual differences in selective attention under load. Deaf individuals also appear to provide a caveat for perceptual Load Theory due to their apparently enhanced visual capacity limits. High perceptual load, sufficient to eliminate distractor interference in hearing participants, had no effect on deaf participants (Hauthal, Neumann & Schweinberger, 2012). On the contrary, adults with Attention Deficit Hyperactivity Disorder (ADHD) experience increased distraction compared to controls but increasing perceptual load has been found to be equally effective at reducing distractor interference for both groups (Forster et al., 2014). As Perceptual Load Theory is rooted in the notion of a limited perceptual capacity, studies with groups known (or suspected) to have altered capacities are useful in examining the model and how it functions. The results of these studies support the most central tenet of Load Theory; that attention is constrained by perceptual capacity and, as predicted, deviations from average capacity can alter the predictions of the model. In turn, Load Theory, with its clear predictions and large body of evidence, may allow better insight into how the process of attention is affected by such disorders.

In daily life too, perceptual load can be affected by individual differences. Forster and Lavie (2007) investigated the relationship between load and everyday distractibility. Distractibility was measured by the Cognitive Failures Questionnaire (Broadbent, Cooper, Fitzgerald & Parkes, 1982). The CFQ features questions such as 'Do you find you forget why you went from one part of the house to the other?' and 'Do you read something and find you haven't been thinking about it and must read it again?' They found that individuals who reported high levels of absent-mindedness in their everyday lives suffered from greater distraction by irrelevant stimuli under low load. However, under high load, distractor interference was reduced for all individuals, regardless of their general distractibility. The authors concluded that 'high perceptual load makes everybody equal' – that individual differences could be eliminated once a high enough level of load is reached. Interestingly, this relationship between everyday distractibility and distractibility in perceptual load tasks has been discovered in relation to audio distractors also, with those scoring high on the CFQ displaying greater distractor interference effects in response to irrelevant auditory distractors (Murphy & Dalton, 2014). A related study also found evidence that perceptual load can eliminate the effect of internal sources of distraction (i.e. mind wandering) (Forster & Lavie, 2009).

Attentional Control Theory (Eysenck, Derakshan, Santos & Calvo, 2007) posits that trait anxiety reduces the influence of goal-directed attention and increases the extent to which attention allocation is stimulus-driven (Corbetta & Shulman, 2002). Thus in situations where attentional resources are strained, highly anxious individuals are expected to exhibit greater distractor interference. This could be considered in opposition to the predictions of Load Theory, where increased perceptual load is claimed to exhaust perceptual capacity and result in decreased distractor interference. Recent research has examined how attention is modulated by load in individuals high in trait anxiety. An fMRI study found a negative correlation between trait anxiety and activity in the dorsolateral prefrontal cortex under low perceptual load, despite no significant effect on performance (Bishop, 2009). Highly anxious individuals appear to be able to compensate for this deficit by exerting more effort, and so at low load there is no observable behavioural difference between those with high and low anxiety. This is in line with the predictions of Attentional Control Theory (Eysenck et al., 2007). However at high load, where attentional resources are exhausted, increased distractor interference is evident in highly anxious individuals (Sadeh & Bredemeier, 2011). This is what would be predicted by Attentional Control Theory but not by Load Theory. It appears that increased distractor processing in individuals high in anxiety is not overcome by typical load effects, as it is in those who are high in distractibility (Forster & Lavie, 2007) and individuals diagnosed with ADHD (Forster et al., 2014). The attentional dysregulation caused by trait anxiety appears to be resistant to the effects of high load, though it is difficult to definitively conclude that interference persists under high load in an anxious population. In the studies discussed, a task was designed that was presumed to impose high perceptual load; for the control population this was apparently achieved and distractor interference was significantly reduced. It is possible that the task did not constitute high enough load for the anxious group, i.e. that they have increased perceptual capacity and that with a more demanding task, load effects would be restored. This is a common methodological flaw in individual differences perceptual load research that makes concrete conclusions difficult.

These studies do illustrate that the individuals high in trait anxiety perform differently under the same amount of perceptual load. Research on personality traits such as anxiety can benefit our understanding of attention under load, highlighting situations where the load model is not upheld and prompting interesting questions as to why that would be the case. This line of research also provides valuable insight as to how attention is affected by the trait in question (e.g. that perceptual load is a factor which can engender increased distraction in highly anxious individuals). What seems clear is that Load Theory is not a one-size-fits-all approach, and that individual differences in cognitive and emotional factors can moderate the effects of load. At present there is little evidence that other personality traits interact with perceptual load but it is a question worthy of future investigation.

The effect of state anxiety on load effects has also been examined, though there are surprisingly few studies published on this topic, given the importance of stress in understanding load in applied contexts, and evidence suggesting that state and trait anxiety have different effects on attentional processes (Pacheco-Unguetti, Acosta, Callejas and Lupianez, 2010). Acute stress has been shown to influence the effects of perceptual load (Sato, Takenada & Kawahara, 2012). Subjects underwent the Trier Social Stress Test before completing a flanker task, with self-report and salivary cortisol measures confirming the increase in stress levels. Control (non-stressed) participants experienced distractor interference under low load but not under high load, as predicted by Load Theory. Interestingly, stressed participants displayed the opposite pattern of effects. Under low load, stressed participants experienced no distractor interference, suggesting that stress may recruit the same resources as attention. Under high load, however, stressed participants experienced significant distractor interference. While the combination of low load and stress mimics the effects of high load and eliminates the interference effect, it may be that high load and stress amounts to excessive load. The authors surmise that such a burden disrupts top-down maintenance, affecting the dorsal fronto-parietal network

(Corbetta, Patel & Shulman, 2008). The concept of excessive load requires validation in further studies and we would also suggest that more work should be conducted assessing the effect of transient, everyday stress on perceptual load, for example driver distraction in low and high load driving scenes, when completing a stressful time-limited task.

As top-down control is so central to the predictions of Load Theory, it is logical that mental fatigue would also have an impact on performance. In a recent study, the effect of time-on-task at different levels of perceptual load was examined (Csatho et al., 2012). Participants performed a flanker task for 2.5 hours without breaks, at low, medium and high perceptual load. Under low perceptual load, fatigue led to greater interference effects, indicative of difficulty maintaining top down control of priorities. However, at medium and high load, fatigue had no such effect. The effect of both fatigue and acute stress is extremely relevant for the application of Load Theory to our understanding of real world distraction, in particular because high-load everyday tasks (such as driving in difficult conditions) are likely to also induce fatigue and stress.

3.1 Attentional plasticity in video game players

A fascinating strand of research in the area of individual differences under load is looking at attention in video game players (see Hubert-Wallander, Green & Bavelier, 2010 for a review). Experienced video-game players have provided evidence for the plasticity of perceptual capacity limits. In particular, action video games seem to have an effect on performance under load, with individuals who regularly play these games seemingly less affected by increases in load in a central task (Cohen, Green & Bavelier, 2007). These are first or third person games such as *Halo*, *Medal of Honour* and *Call of Duty, which* require the player to monitor the simulated environment and respond quickly to the presence of targets amongst distractors (Achtman, Green & Bavelier, 2008). Critically, the attentional benefits of such games are evident across a number of tasks outside of gaming situations, including traditional Load Theory paradigms (Dye, Green & Bavelier, 2009). This suggests that something about regularly playing action video games actually increases an individual's perceptual capacity. For a model like Load Theory, which is founded on the principle of perceptual capacity, this line of research is of extreme interest. Studies have found that both children and adult action video game players experience a much higher degree of interference from distractors under high perceptual load (Green & Bavelier, 2003; Green & Bavelier, 2006; Dye, Green & Bavelier, 2009). As load increases, distractor interference is eliminated in non-gamers but not in gamers, which may indicate that gamers have an increased perceptual capacity. Overall, gamers are also much faster at search tasks across all levels of load and congruency. Gamers are more accurate than non-gamers under all conditions and this effect holds even when performing a concurrent centre task, ruling out the possibility that this effect is from improved direction of attention (Green & Bavelier, 2006). Benefits of gaming in other tasks such as the attentional blink paradigm (Green & Bavelier, 2003) suggest that these studies reflect real improvement in visual attention rather than greater distractibility (Lavie, 2005). One problem with this area of research is that to date, studies have simply designed conditions of low and high load and presented them to gamers and non-gamers. Distractor interference effects are preserved in gamers under high load and thus it could be concluded that they have a larger perceptual capacity, i.e. what constitutes high perceptual load to a non-gamer may be low or moderate load to an experienced gamer. It is impossible to be certain in this conclusion though until a study is conducted which finds the threshold for high load in gamers. If these gaming effects are due to an increased perceptual capacity then load effects should be restored once the task imposes a sufficiently high level of load.

Importantly, studies have shown the causal relationship between gaming and improved perceptual capacity. In such studies, subjects are required to play either fast-paced action games or control games. Those in the action video game group show significantly greater pre to post-test improvement in many selective attention tasks (Feng, Spence & Pratt, 2007; Green & Bavelier, 2003, 2006, 2007; Cohen, Green & Bavelier, 2007). Furthermore, two such studies followed up on participants and tested them a third time, from several months to several years after the experiment (Feng et al.,2007; Li, Polat, Makous & Bavelier, 2009), with both studies finding that the majority of participants retained their training-related improvements over time.

In an fMRI study investigating attentional network recruitment, moving distractors were found to result in less activation of the brain area associated with motion sensitivity (middle temporal complex) in gamers compared to non-gamers (Bavelier, Achtman, Mani & Focker, 2012). This is indicative of better early filtering of irrelevant stimuli in gamers. As perceptual load increased, non-gamers showed greater recruitment of the fronto-parietal network areas known to be involved with the control of attention (see Figure 5). This reduced neural activity in video game players is in line with the hypothesis that video game players develop more efficient attentional processes and therefore respond to increasing perceptual load in a different manner to non-gamers. These results provide further confirmation of the tenets of Load Theory, demonstrating that the locus of the attentional filter is dependent on the point at which perceptual capacity is exhausted.

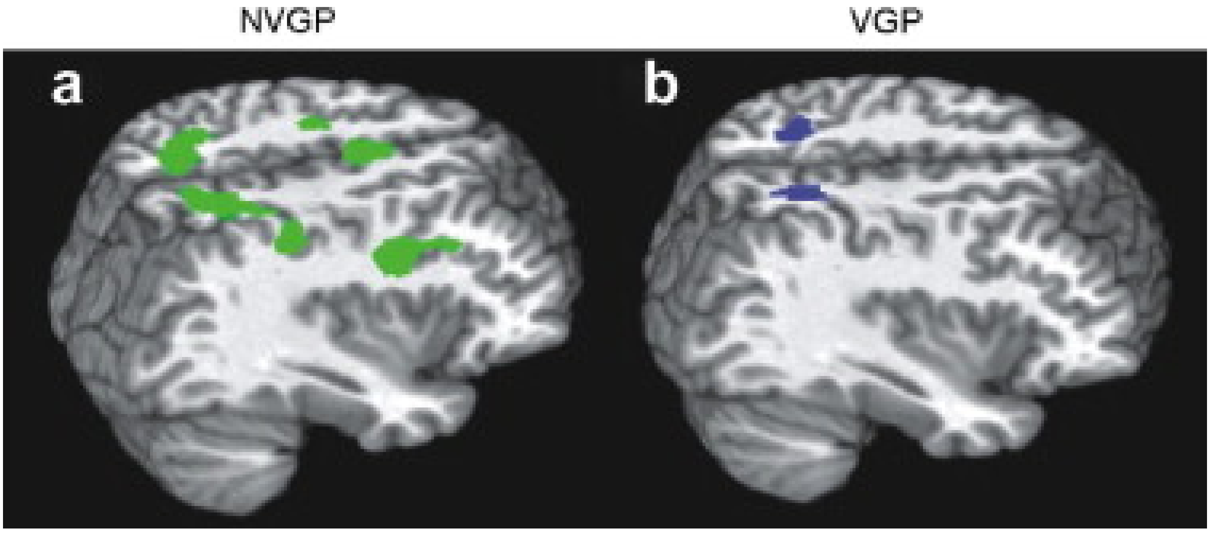

Figure 5: Activation as perceptual load is increased for non-video game players (left, in green) and experienced video game players (right, in blue) (Bavellier, Achtman, Mani & Focker, 2012). Video game players demonstrated markedly less recruitment of the fronto-parietal network compared to non-gamers.

This area of research is important for the future of Load Theory because it remains the most convincing evidence that Load Theory might scale up to dynamic, continuous, complex tasks outside the laboratory. It is also significant as it suggests that it is possible to improve selective attention performance. Perhaps the type of training that video game players undergo is also evident in other populations. The most obvious example here is experienced drivers; particularly professional drivers (i.e. ambulance drivers or police officers) who may become accustomed to high speed, high stakes target searches, similar to action video game players.

4. Criticisms & Alternatives to Load Theory

4.1 Defining load

Perhaps the most urgent criticism of perceptual load research is the nebulous nature of the term 'perceptual load' itself. Though emerging neural explanations are promising and useful, in behavioural terms perceptual load is more clearly defined by paradigms (e.g. set size manipulations, target/distractor similarity) than by explicit, process-based definitions (Benoni & Tsal, 2013). What *is* high perceptual load? Load that is sufficient to prevent the processing of distractors. What does high perceptual load *do*? It prevents the processing of distractors. There is a circularity here that makes unambiguous refutation rather difficult (Roper, Vecera & Cosman, 2013). If the expected results are not observed under 'high load' then is this a true result or a reflection of unsuccessful load manipulation? One can imagine that this uncertainty can lead to many well-intentioned scientists interfering with experiments at the piloting stage – continuing to manipulate load until the expected results appear. When variable X is selected because of its observed relationship with variable Y, it can no longer be considered truly independent (Kriegeskorte, Simmons, Bellgowan & Baker, 2009). This can lead to inflated effect sizes and 'voodoo correlations' (Kingstone et al., 2003). A recent attempt by Roper, Vercera & Cosman (2013) to delineate the factors that influence perceptual load is an important next step for Load Theory. In order to move forward, a clear operational definition of perceptual load needs to be established and agreed upon. Until then, cross-paradigm comparison remains difficult.

There are also criticisms of cognitive load and its role in the load model. As discussed in section 2.0, there is some ambiguity as to what constitutes cognitive load, with different effects observed when tasks used maintenance-based memory tasks vs. tasks requiring cognitive control. Another issue faced by researchers in this field is disentangling perceptual and cognitive load. With both concepts lacking a clear operational definition, achieving a clean manipulation of either or both is incredibly difficult. This difficulty is only magnified when load theory is applied to more complex real world tasks. For example, in Marciano & Yeshurun's 2012 & 2015 studies, perceptual load was manipulated in a driving context. Central perceptual load was manipulated via the number and congestion of vehicles on the road surrounding the participant's vehicle, while peripheral perceptual load was manipulated via the number of roadside objects such as pedestrians, buildings, etc. One could argue that as the number of vehicles on the road increases, it is not just perceptual load which is affected, but cognitive load also. Drivers attend to the other vehicles on the road, increasing the amount of information to be processed (perceptual load) but likely also have to make more judgements about their own speed, distance to the car in front, intended actions of the drivers around them, etc. Does this constitute a confound with cognitive load? With the current lack of clarity around cognitive load manipulations and their effects it remains difficult to say. In the interests of applied future research it is crucial that a more precise definition of cognitive load (and how exactly it differs from perceptual load in practice) is agreed upon.

4.2. Dilution

Some researchers have offered alternative explanations for the pattern of results observed under load. Yehoshua Tsal, the co-author of the paper which first proposed the load hypothesis (Lavie & Tsal, 1994) has been one of the most vocal critics of the theory. Tsal and colleagues have proposed an alternative explanation for much of the existing Load Theory evidence; dilution. Many experiments manipulate load by varying the number of items in the display (e.g. Lavie, 1995). Under low load, the potentially interfering distractor is presented alone, while under high load this distractor may be surrounded by other distractor letters. Tsal has argued that the distractor is processed to the same degree in both instances, but in the high-load condition, the interference caused by the distractor is diluted by the presence of the neutral stimuli (Tsal & Benoni, 2010). Tsal & Benoni (2010) conducted a series of experiments which separated load and dilution effects (see Figure 6). In one study, they compared displays which were low load, low dilution (Figure 6A), high load, high dilution (Figure 6B) and low load, high dilution (Figure 6C). The two high dilution displays contained the same number of items, but the low-load condition featured a target which was clearly distinguishable from the neutral items (due to a different colour font). Thus while perceptual load differed between the two conditions, the degree of dilution was controlled for. They found that distractor interference effects were evident in both the low load low dilution condition and the high load high dilution condition, but this was eliminated in the low load, high dilution display. Furthermore, when dilution was controlled for, Tsal & Benoni found that high perceptual load resulted in greater distractor interference than low load. The authors concluded from these studies that the display size effects predicted by Load Theory have been "misattributed to perceptual load [and are] fully accounted for by dilution". This interpretation has received support from a number of studies (Dittrich and Stahl, 2011; Marciano & Yeshurun, 2011; Benoni & Tsal, 2012; Biggs & Gibson, 2013; Chen & Cave, 2013).

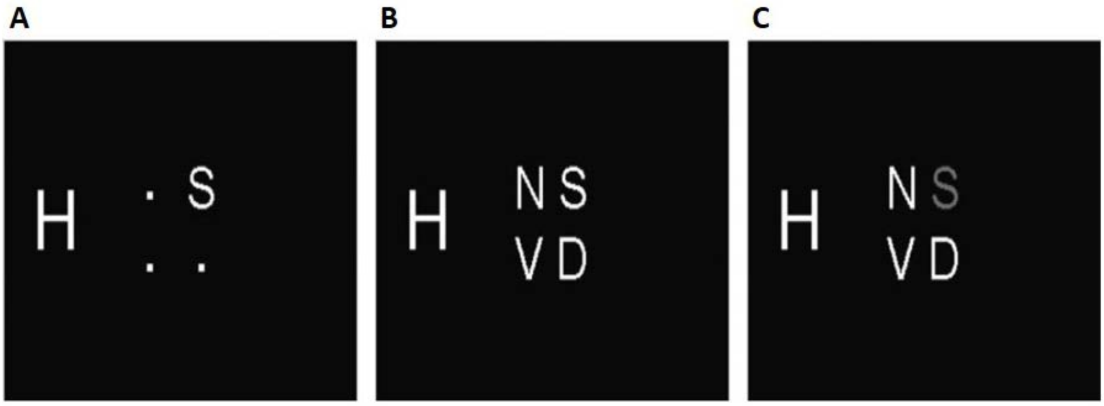

Figure 6: Example stimuli from Benoni & Tsal (2010). Distractor interference was assessed under conditions of (A) low load, low dilution, (B) high load, high dilution and (C) low load, high dilution. Participants indicated if the target was H or K, or C or S while ignoring the distractor letter (to the left) which could be congruent or incongruent with the target. The two high dilution displays were identical except the target letter was red in the low load, high dilution condition, creating a pop-out effect.

However, Tsal & Benoni's conclusions were criticised in a response by Lavie and Torralbo (2010) who maintained that the dilution argument is built on a misunderstanding of the load hypothesis, namely the involuntary nature of attention spillover. They argued that just because the pop-out search in the low load, high dilution condition renders the processing of the additional stimuli in the array unnecessary, does not mean that they will not be processed. In other words, the additional letters *are* being processed, they are simply not affecting the chosen dependent measure – response times to the target letter. This hypothesis suggests that if the additional, neutral items in the array were replaced with response-competing distractors, then distractor interference effects would again be evident. Lavie & Torralbo conducted such an experiment and found evidence in support of the capacity spillover hypothesis, suggesting that irrelevant items are processed under conditions of low perceptual load, even with high dilution, in line with the Load Theory model.

Lavie also drew attention to research which manipulated load with no change in set size - where the display is identical across conditions but the complexity of the task changes between high and low load conditions (i.e. search for any red shape in low load, search for a red square in high load (Lavie, 1997). Benoni & Tsal (2013) however have also argued that such tasks fail to control the load on working memory and as such, perceptual and cognitive load become confounded (Fournier et al., 2004). It should be noted that this problem does not apply to the discrimination task described earlier (Cartwright-Finch & Lavie, 2006) where participants view a briefly presented cross and are asked to make a low-load discrimination (which arm is blue?) or a high-load discrimination (which arm is longer?). Recent publications have suggested that there may be a middle ground between dilution and Load Theory, and that evidence for dilution indicates that the effect of neutral stimuli may be more complex than previously assumed (Chen & Cave, 2013; Scalf et al., 2013). A hybrid theory, which would fit well with theories of neural representation competition, may be the way to reconcile these opposing bodies of evidence. Scalf and colleagues (2013) have proposed such a hybrid theory, rooted in the theory of biased competition discussed earlier. They suggest that competition for neural representation among stimuli hinders their representation in the brain, and so both dilution and perceptual load have an effect on attention. Dilution does occur and affects distractor processing, however perceptual load, through top-down biasing signals, also determines the efficiency of selective attention.

4.3. Other criticisms

There are a number of other variables that may need to be taken into account in revisions of classic Load Theory such as the effect of distractor salience (Eltiti, Wallace & Fox, 2005;

Koivisto & Revonsuo, 2009) and spatial proximity (Paquet & Craig, 1997). There is also evidence that high perceptual load only decreases processing of the distractor if there is clear spatial separation between the target and the distractor. Research on object-based attention suggests that if the distractor is part of the target (e.g. in a Stroop task) then high perceptual load can actually increase distractor interference (Chen, 2003; Cosman & Vecera, 2012). It is theorised that when the distractor and target are part of the same object, paying more attention to the target means paying more attention to the distractor. Expectancy, as manipulated through pre-cueing targets and running blocks of all high load or all low load trials, has also been shown to reduce or eliminate distractor interference in low load conditions (Johnson, McGrath & McNeil, 2002; Sy, Guerin, Stegaman & Giesbrecht, 2014; Theeuwes et al., 2004). Yet there are many other studies that have presented blocks of either high or low load trials, where load could be accurately predicted, and still found evidence in support of Load Theory (Beck & Lavie, 2005; Forster & Lavie, 2007; 2008; Konstantinou & Lavie, 2013)

Experiments which manipulate perceptual and cognitive load simultaneously (so called 'sandwich tasks' as shown in Figure 3), have found that high perceptual load only reduces distractor interference when cognitive load is low (Linnell & Caparos, 2011). One interpretation of this finding is that perceptual load induces early selection not because it exhausts perceptual capacity, but because it engages cognitive resources in a manner that focuses spatial attention (Linnell and Caparos, 2013). The increased loads necessary for video game players and individuals with autism (see section 3) may be because lower loads are not sufficient to induce cognitive engagement. Linnell and colleagues propose a default attentional state of engagement that can differ across cultures, citing evidence from the

Himba, a remote population living in northern Namibia who appear to have more focused spatial attention that both British individuals living in London and Himba who now live in more urban areas (Linnell et al., 2013). Though the Himba displayed sensitivity to increases in perceptual load, they were capable of focused spatial attention at the very lowest level of load. Linnell and Caparos hypothesise that individuals living in fast-paced, dense urban environments favour late over early selection, i.e. it is better to inefficiently take in all of the surrounding information, because distractors can so suddenly become targets. Remote communities like the Himba however, have a default attentional state that fully engages cognitive resources with the task at hand. This, combined with evidence that increasing the social relevance of a display while keeping perceptual load constant induced early selection in the same manner as load (Linnell et al., 2013), suggests that further research is needed to delineate perceptual load and attentional engagement. However the effect of high cognitive load on distractor processing can perhaps be more simply explained in relation to the implementation of a top-down biasing signal to resolve stimulus competition. This signal draws on the same frontoparietal resources as traditional cognitive load tasks (e.g. working memory tasks) (deFockert et al., 2001; Lavie et al., 2005; 2010). Thus, when cognitive load is high, the resolution between target and distractor cannot be easily achieved, resulting in increased distractor interference effects relative to low cognitive load trials (Scalf et al., 2013).

Clearly the evidence indicates that perceptual and cognitive load are not the only determinants of selective attention. Yet there is a wealth of evidence that suggests that under some circumstances at least, load is a major factor. Future research ought to examine other factors which contribute to selective attention under load and how they alter Load

Theory predictions. It is unlikely that Load Theory can explain attention in every instance, but instead attention is determined by many factors. Remaining tied to any particular paradigm makes it difficult to ascertain how these factors work together to affect attention. Real world research will be important for examining how load functions in complex, dynamic scenarios in which load is not the only contributing factor. Applied research is therefore a promising means of comparing the explanatory power of Load Theory to other approaches such as dilution or attentional engagement.

5. The Future of Load Theory

5.1 Defining & Operationalizing Load

As discussed throughout this paper, a key criticism of Load Theory is the poor definition of perceptual load itself. In order for Load Theory to be advanced, a clear, operational definition of load must be agreed upon. Until a clear consensus on load is reached, it remains impossible to endorse or refute experimental results with certainty. Closely related to this is the question of how to operationalize load. Much of the evidence discussed in this paper has arisen from variations on a single paradigm, a flanker search task involving letters. Experiments using faces and objects have also been conducted but the vast majority of evidence for Load Theory is divorced from real world applications of attention (Furley, Memmert & Schmid, 2012). Load Theory does not stand alone in this regard; it has been suggested that many attentional research paradigms have failed to remain grounded in real life behaviour (Kingstone et al., 2003). Friesen & Kingstone (1998) demonstrated the fallacy of deriving theories of attention from artificial paradigms. By replacing the arrows in the Posner cuing paradigm (Posner, 1978) with eye gazes, they found results which contrasted with the traditional findings of the paradigm. Remaining tied to one experimental paradigm can generate results that fail to generalise to real life behaviour, but of much more concern is that they can cloud and mislead understanding of the cognitive process under investigation. As Meiser (2011, p. 185) excellently puts it, the paradigm 'turns from the tool of research to the target of research'. The early vs. late selection debate discussed at the beginning of this article is an apt example of this. Both camps employed different paradigms and so quite understandably came to different conclusions about the nature of selective attention. What appeared to be contrasting evidence was in fact little more than a change in paradigm. As Load Theory emerges as a solution to this debate, researchers would do well not to go down the same path and become overly reliant on any one paradigm.

Reflecting on the issue of inflated effect sizes in neuroscience, Fiedler (2011) discusses the many methodological and theoretical issues which can arise from paradigmatic research. Among the many suggested solutions for this problem, and relevant to the furthering of Load Theory, is the introduction of a range of truly representative designs, amounting to convergent validation of effects (Garner, Hake & Eriksen, 1956). Instead of focusing on quantitative evaluation of the effect of perceptual load, we should perhaps look for qualitative confirmation of its existence across conditions with some relevance to real world behaviour. Kingstone and colleagues remarked that 'it is time for cognitive psychology to reaffirm the difficult task of studying attention in a manner that has relevance to real-life situations' (2003, p. 176). Though they made this assertion in 2003, not much has changed in the decade since. Studying naturally occurring selective attention is indeed a challenge, however as we have discussed, it is certainly a goal worth pursuing.

This issue of artificial research has become a somewhat tired criticism in cognitive psychology, one that could be levelled at almost any model. However, Load Theory appears to have the means to overcome this for a number of reasons. Perhaps most importantly, perceptual load manipulations are naturally occurring. The demand that is placed on attention when walking down a cluttered street filled with billboards, pedestrians, vehicles, cyclists and all manner of sounds is very different to the demand placed by a quiet, rural street. The difference is clear and intuitively noticed. What we don't know intuitively is the effect these different load environments have on our attention and awareness. Load Theory can provide a framework to understand attention in these everyday contexts as it makes clear, easily testable predictions about the interaction of perceptual and cognitive load. Though there is some work to be done to more clearly define the constructs involved, there are obvious applications of Load Theory in many domains.

Aside from having perhaps greater potential to overcome this issue, we also feel that Load Theory arguably has a greater responsibility to do so. Attention and distraction are key issues in many applied settings; for example, driver inattention has been found to be the main cause of road accidents in many naturalistic studies (e.g. Klauer et al., 2009). Predicting when and how and why we get distracted remains an important (if lofty) goal for applied cognitive psychology, with implications for dozens of applied settings. The ability to predict and perhaps eventually design environments that assist efficient attention in drivers, pilots, healthcare practitioners and educators would represent one of the greatest contributions of cognitive psychology to society. Load Theory has the potential to achieve this as it has strong predictions as to when additional information is processed and when distraction is more likely. Unlike some other cognitive theories, Load Theory seems almost designed to be applied in real-world settings, and can therefore be used to better understand and improve everyday attention.

The applications of Load Theory are numerous and exciting and we will now discuss the existing applied studies and highlight some potential future directions.

5.2 Real World Research

Given that it is a theory that seeks to explain when distraction is likely to occur, Load Theory obviously has many real world applications. Attention is crucial to many occupations (students, healthcare professionals) and activities (driving, sports) as well as general daily functioning (reading this article from start to finish without repeatedly being distracted by the sights, sounds and smells of the environment). The real world applications of Load Theory have been alluded to in the literature; they are promising but often nebulous. However, in a study on perceptual load and distractibility, Forster and Lavie found that under high perceptual load, individual differences in distractibility were eliminated (2007). The authors recommended that this result should be applied to teaching; if a lecturer were to increase the perceptual load of their presentation (through hand gestures, content-heavy slides, etc.) this may benefit students who would otherwise be susceptible to distraction. This is a clear, verifiable application of Load Theory to real life, one of many which should be empirically tested. Given the current state of the model, it is somewhat difficult to estimate the effect of such an intervention – would increasing the content of the slides increase cognitive load as well as (or instead of) perceptual load? This is however an empirical question and can be directly assessed, provided the expected effects of increased perceptual or cognitive load are explicitly described. These kinds of studies are necessary to progress the theory in future and may result in many useful applications.

Preliminary steps have been taken in the transfer of Load Theory to the domain of sport (Furley, Memmert & Schmid, 2012). In an experiment examining expertise effects, Furley and colleagues assessed the performance of soccer players and non-soccer players on a classic letter search task and a novel soccer-specific task (see Figure 7). Participants were presented with a tactics board with two teams (X's and O's) and had to determine which team had the ball, denoted by a small circle attached to the letter. The game constellations were meaningful and load was manipulated by varying the number of 'players' on the field. The goalkeeper served as an irrelevant distractor as he never had the ball, and could be congruent (belonging to the same team as the player who had the ball) or incongruent. The predictions of Load Theory were upheld in this new, more meaningful paradigm; however there was no effect of expertise. This is perhaps due to the fact that tactics boards are not equivalent to playing soccer and so soccer players may not have sufficient experience with tactics boards to affect their attentional capacities. Though this experiment involved a search task for black and white letters, it represents a step towards confirming the applicability of Load Theory to real life tasks. Future research examining expertise effects on high load sports-related tasks could help to elucidate the nature of novice/expert differences in attention in sports, though the nature of the load task and its similarity to the sport is likely crucial. Applying Load Theory to the vibrant area of sports psychology may ultimately allow enhanced sports performance. Load Theory is rooted in perceptual capacity limits and there is evidence from video-game players that perceptual capacity can be increased through targeted training. Could the same be achieved with high level sports players? Using the Load Theory framework, perhaps better training could be designed to help athletes cope with high perceptual and cognitive load and/or the interaction of load with the stress, fatigue and anxiety of competition. Furley and colleagues have begun to transfer Load Theory to the domain of sports but there is still a long way to go before achieving an ecologically valid assessment of load in a sporting context. The potential benefits however, are intriguing.

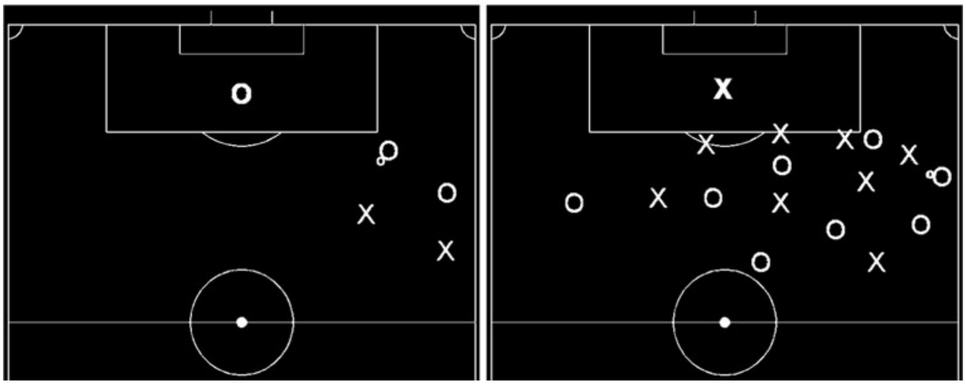

Figure 7: Furley, Memmert & Schmid, (2012) translated a traditional Load Theory search task to a sports-related task. The task was to find which team (X's or O's) were in possession of the ball (denoted by the small circle). Low load trials (left) had fewer players than high load trials (right) and the goalkeeper could be either congruent (left) or incongruent (right) with the team in possession.

Other experimental studies have paved the way for further Load Theory applications. In a study investigating the effect of working memory load on distractor processing, Carmel, Fairnie & Lavie (2012) presented participants with a high or low load memory task (manipulated through set size), while ignoring irrelevant images. The results of a surprise quiz suggested that under high working memory load, participants were better at identifying faces that had been presented amongst the irrelevant images during the trial. This effect was only true for faces, not for irrelevant images of buildings. The authors pointed out the potential application of this result to our understanding of eye-witness testimony, a situation where irrelevant information suddenly becomes important. Future studies could elucidate the relationship between perceptual and cognitive load present in everyday life (e.g. using a mobile phone, having a conversation, etc.) and ability to give reliable eye-witness reports. This research, along with many other studies discussed in this paper, represents just the first step toward applying Load Theory to real world issues. As there is evidence that load impacts memory for seemingly irrelevant information, the next logical step would be to assess the effect of load using traditional eyewitness paradigms (e.g. viewing an event or a video of an event that imposes high or low perceptual load and then answering questions, as in a real eyewitness situation). There is still some uncertainty with applying these principles in a real world forensic context. Even if we can illustrate that high perceptual load results in less accurate memories for everyday events, how would one establish that a crime had taken place under conditions of high perceptual load? Once again we return to the idea of naturally occurring load and how exactly we can quantify it. Clearly further research is needed in this area but there is great potential to make real world contributions using Load Theory.

The research on load-induced inattentional blindness is also promising in terms of real life applications. Along with the many mildly irritating incidents of inattentional blindness/deafness that happen in everyday life, such as not seeing a friend waving at you from a crowd or not hearing someone calling your name when you're busy doing something else (Simons & Chabris, 1999), it is thought that inattentional blindness may have a role to play in more serious performance failures. Drew, Vo & Wolfe (2013) conducted a study where 24 radiologists inspected a lung scan for nodules. An image of a gorilla, which was 48 times larger than the average nodule, was clearly visible on the scan and yet 83% of the radiologists failed to detect it. Inattentional blindness may also be the cause of certain types of road accidents, such as when individuals report that another road user 'just came out of nowhere'. Common examples include drivers taking a right turn and cutting off an oncoming cyclist or motorcyclist (Simons, 2000). Understanding the role of load in such real-world instances of inattentional blindness is a clear avenue for future research. Experiments using a driving simulator, for example, would allow assessment of inattentional blindness while engaging in a complex task in a dynamically changing environment. Furthermore, given that perceptual and cognitive load have been shown to affect levels of inattentional blindness, future inattentional blindness studies ought to control for the level of load imposed by the central task, to allow for more meaningful comparison between studies (Memmert & Furley, 2010). Finding that inattentional blindness for one stimulus is greater than another stimulus (e.g. a cyclist with and without a high-visibility neon jacket) is meaningless if the central tasks are imposing different levels of perceptual load (e.g. a rural road vs. a city centre intersection). Again, precise quantification of naturally occurring perceptual load is key.

A number of studies have already applied Load Theory to driving (Redenbo & Lee, 2009; Marciano & Yeshurun, 2012; 2015). During a series of experiments in a driving simulator, Marciano & Yeshurun systematically manipulated perceptual load both on the road and on the sides of the road, while assessing measures of driving performance such as speed, reaction times to events, accident rates and reaction to hazards presented centrally or peripherally. They found that, broadly in line with perceptual Load Theory, driving performance was moderated by the level of perceptual load in the environment. High load on the road mainly caused drivers to drive slower, while high load at the sides of the road negatively impacted their ability to detect safety critical events originating from the roadside. These studies represent just a fraction of the potential applications of Load Theory to driving. As discussed above, inattentional blindness may be responsible for many road accidents and perceptual load is known to have a striking effect on levels of inattentional blindness (and deafness). Manipulating perceptual load in a naturally occurring manner (such as via roadside clutter) and examining the resultant levels of inattentional blindness for driving-relevant stimuli (such as pedestrians) would generate useful applied recommendations. Load Theory could help to identify roads that may be beneficial or detrimental to driver attention via simple studies like this.

Conclusion

In this article, we have reviewed a broad range of studies on Load Theory. In recent years, researchers have moved beyond the early efforts to establish the effect of perceptual and cognitive load and began adding colour to the model, with research on cross-modal effects, individual differences and more ecologically valid tasks advancing our understanding of how load influences distraction. We strongly feel that the crucial next step for Load Theory is to investigate a wide range of real world applications. Distraction is an issue in almost every occupation and activity and so the potential benefits of Load Theory applications are numerous. In order to progress to elegant experimental applications, it is first necessary to form a clearer definition of perceptual and cognitive load. Process-based definitions, which clearly define perceptual load at a cognitive and/or neural level, will allow for more creative use of novel paradigms, which will in turn confirm the existence of Load Theory outside traditional paradigms. There are still unanswered questions with regard to individual differences under load such as the potential interaction of perceptual and cognitive load with personality and intelligence. Question marks also remain over dilution, cross-modal attention, the effect of spatial separation between targets and distractors and the role of object based attention. While valid criticisms remain, Load Theory is certainly a fruitful area of research. This is an exciting and fast moving area and we hope that this review will generate further interest and stimulate new ideas as Load Theory makes its way out of the lab and into the world.

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