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Crossmodal Load and Selective Attention

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The University of Sheffield

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Declaration

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Tom Bullock

Abstract

This thesis explores a current dominant theory of attention - the load theory of selective attention and cognitive control (Lavie et al., 2004b). Load theory has been posited as a potential resolution to the long-running debate over the locus of selection in attention. Numerous studies confirm that high visual perceptual load in a relevant task leads to reduced interference from task-relevant distractors; whereas high working memory load leads to increased interference from task-irrelevant distractors in a relevant task. However, very few studies have directly tested perceptual and working memory load effects on the processing of task-relevant stimuli, and even fewer studies have tested the impact of load on processing both within and between different sensory modalities.

This thesis details several novel experiments that test both visual and auditory perceptual and working memory load effects on task-relevant change detection in a change-blindness "flicker" task. Results indicate that both high visual and auditory perceptual load can impact on change detection, which implies that the perceptual load model can account for load effects on change detection, both within and between different sensory modalities. Results also indicate that high visual working memory load can impact on change detection. By contrast, high auditory working memory load did not appear to impact change detection. These findings do not directly challenge load theory per-se, but instead highlight how working memory load can have markedly different effects in different experimental paradigms.

The final part of this thesis explores whether high perceptual load can attenuate distraction from highly emotionally salient stimuli. The findings suggest that potent emotional stimuli can "breakthrough" and override the effects of high perceptual load - a result that presents a challenge to load theory.

All findings are discussed with reference to new challenges to load theory, particularly the "dilution" argument.

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Chapter 1

Early/Late Selection and Load Theory

This introductory chapter provides an overview of early and late models of selection in attention and introduces perceptual load theory as a resolution to early/late selection debate.

1.1 Models of Early and Late Selection

> "It [attention] is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a

> real opposite in the confused, dazed, scatterbrained state." (William James, 1890, p. 403-404)

Our ability to attend to important, relevant information while ignoring unimportant and irrelevant information is a fundamental component of human information processing. We are constantly bombarded by input from all of our senses and our ability to focus on one thing at the expense of other things is the key to us making sense of the world around us. Selective attention is the generic term used to describe the cognitive mechanisms whereby we focus on one aspect of our environment at the expense of others. Without this ability our experience of the world would be terribly chaotic.

This thesis explores selective attention. It is important to establish from the outset that my usage of the term "attention" throughout this thesis always refers to *selective* attention, instead of the more general processes involved in maintaining concentration, arousal and alertness. A distinction can be drawn between selection that is determined by bottom-up (exogenous) factors, or by top-down (endogenous) factors. In the visual sensory domain, exogenous selection occurs when image-relevant features capture attention independently of the relevant task. For example, if a feature of a object (e.g. colour, texture or orientation) is markedly different from neighbouring objects, then the object will stand out and thus capture attention. Conversely, endogenous selection occurs when, under volitional control, attention is focused on a particular object, feature or region in space. A further distinction can be drawn between "overt" and "covert" attentional selection. In terms of the visual sensory domain, overt attention refers to directing eye gaze towards a specific object or location, whereas covert attention refers to a mental shift of attention to an object or location in the periphery.

Selective attention has been a topic of much research and debate for over a century. Back in the 1890s introspection was the order of the day, and in the early 1900s the topic was discussed within the British Psychological Society (Hicks, cited in Edgell, 2001). Serious advances in our understanding of selective attention started to be made in the 1950s, where research was focused on audition and the "Cocktail Party" problem. This example was used to illustrate the problems faced when trying to explain how when faced with a room full of people, we are able pick out the sounds that are relevant to the conversation that we are involved in, despite sound from multiple different sources entering our ears at the same time. How is it that we are able to tune into the person that we're speaking to while tuning out everyone else? This effect was studied in the lab by Cherry (1953) in his early dichotic listening experiments. In one version of the task participants were presented with two different spoken messages, one in each ear, and were required to repeat one of the messages back to him out loud. Cherry manipulated the stimuli presented in the unattended stream and discovered that while participants were able to detect changes in physical properties (e.g. when the stream changed from speech to a tone, or from a male to female voice), they were unable to report detailed aspects, such as individual words, semantic content and even what language was being used.

The first theory of selective attention was put forward by Donald Broadbent (1958) in his highly influential book "Perception and Communication". Broadbent became interested in the question of how air traffic controllers are able to cope with messages coming in from multiple aircraft at one time. He proposed "Filter Theory" - a two stage model of processing. In the first stage the "physical" properties of the stimuli, such as pitch, volume and location, were extracted in "parallel" manner. In the second stage more detailed properties were extracted, such as the semantic properties of words. Broadbent argued that capacity at the semantic identification stage was far more limited than at the first stage, and stimuli had to pass through a selective filter in order to undergo processing at the second stage. The selective filter only allowed stimuli with certain physical properties to pass through to the second stage - other stimuli received no further processing. This was referred to as an early selection model, as the bottleneck filtered stimuli on the basis of physical attributes and it was determined at a relatively early stage whether or not stimuli were to receive further processing. The model was able to account for the findings demonstrated in the dichotic listening studies, as it suggested that the unattended stream was not processed past the first "parallel" stage, hence why subjects could report sudden changes in the physical characteristics of the stream, but were unable to report any of the semantic content.

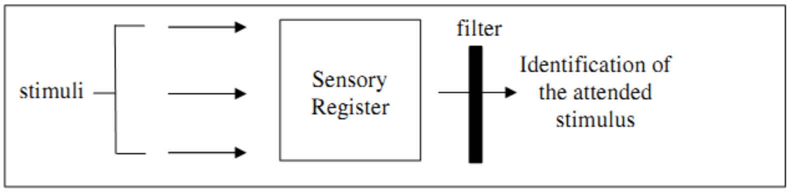

Figure 1.1: Filter theory of selective attention Broadbent (1958)

The model was tested extensively by various other researchers using variations of the dichotic listening paradigm, and was fairly rapidly called into question after other studies began to demonstrate processing of unattended stimuli at the semantic level. For example, Moray (1959) inserted the participant's name into the unattended stream and found they were able to recognise it. Driver (2001) highlights some important methodological issues with these early dichotic listening studies. The fact that participants were being given surprise/retrospective questions about the information in the unattended stream was problematic, because information recall would be dependent on memory, so one could argue that the information may have been processed and then forgotten, rather than never processed at all. But it would make no sense to question people about the unattended information during the task itself, as this might influence them to start paying more attention to the unattended stream. Some years later Corteen and Dunn (1974) addressed this issue by relying on a covert measure of unattended stimuli processing. They first fear-conditioned subjects by pairing certain words with an electric shock, so that when subjects subsequently heard these words they elicited an increased Galvanic Skin Response (GSR). Participants were then played two streams of information in a dichotic listening task, with the fear conditioned words inserted into the unattended stream, and asked to shadow the attended stream. The words still evoked an increased GSR, suggesting that they were processed at the semantic level, despite participants not becoming consciously aware of them. Both the Moray and Corteen and Dunn studies suggested that unattended salient stimuli are processed at the semantic level despite attention being directed to the other stream, and this could not be accounted for with the Filter Theory.

An alternative theory proposed by Deutsch and Deutsch (1963) suggested that stimuli are not filtered out at an early sensory stage - instead all stimuli undergo full perceptual processing and semantic analysis, but then only the most relevant stimuli are selected to form explicit memories or for deliberate responses. The model suggests that in the previously mentioned studies, stimuli in the unattended stream were processed to the semantic level despite their supposed irrelevance, and if the stimuli in the unattended stream were salient enough then they could reach conscious awareness. This model also proposed two stages of processing - first perceptual and then semantic - but selective attention was thought to operate at the later semantic stage, hence “late selection”.

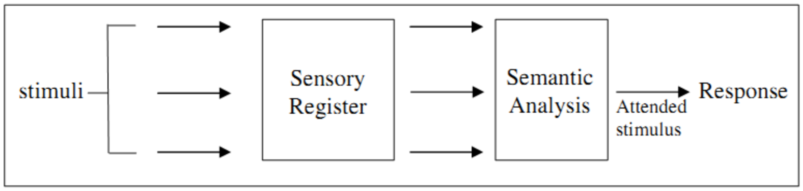

Figure 1.2: Late selection model of selective attention (Deutsch and Deutsch, 1963)

Filter theory was also adapted by Treisman (1960; 1964) to accommodate the evidence that certain unattended stimuli can be processed at the semantic level. Treisman retained the concept of an early, perceptual filter that processes stimuli on the basis of their physical features only, but suggested that filter acts to *attenuate* the input from the irrelevant messages, rather than completely blocking it. The concept of attenuation is akin to turning down the volume of the unattended signal(s) - the strength of the unattended signal is thought to be reduced, but not completely lost, meaning that if stimuli of sufficient salience appear in the unattended stream, such as a personal name in Moray’s study (1959) or the fear-conditioned words in Corteen and Dunn (1974), then they may be processed to the extent that they can be identified. This model improves on Broadbent’s model as it goes some way towards explaining how unattended stimuli can reach awareness, but has received criticism for not sufficiently explaining how the attenuation process works. The concept of the “attenuator” was not very well explained and perhaps just added an unnecessary extra stage of processing which could just happen at later stages of processing, as suggested by the late selection model . Furthermore, Driver (2001) points out that during the early/late selection debate that ensued over the forthcoming decades, the filter attenuation model of attention seemed to receive less attention than the more polarised early and late selection models, probably because many researchers were polarised in their opinions that the correct view of selection was either early *or* late.

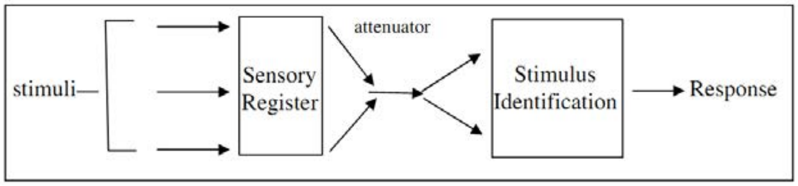

Figure 1.3: Attenuation Model of Selective Attention (Treisman, 1964)

Treisman went on to put forward a further model to account for how attention operates during visual search. Based upon early selection ideals that physical features are processed in parallel at an early, perceptual stage (Broadbent, 1958), Feature Integration Theory (FIT) (Treisman and Gelade, 1980; Treisman and Schmidt, 1982; Treisman and Paterson, 1984) proposed that visual stimuli are initially processed at a “pre-attentive” perceptual stage, where separate primitive features such as colour, orientation and shape are analysed in parallel by different parts of the brain and coded as different spatiotopically organised “maps” (e.g. one map might code where the colour green occurs, another might code where a vertical line occurs, and so on). FIT proposes that attention is the process whereby features that are represented in the different feature maps are integrated to enable a visual stimulus to be identified. If a stimulus can be identified on the basis of a single feature then visual search for the stimulus is rapid and happens in parallel (referred to as “feature” search). However, if a stimulus can only be identified from a combination of two or more features that are bound together, then the features must be processed one after another, and hence visual search proceeds in a serial manner (referred to as “conjunction” search).

FIT was supported by data from visual search tasks (e.g. Treisman and Gelade, 1980; Treisman, 1986) which demonstrated that feature search (e.g. a target red X among green O’s) is more rapid than conjunction search (e.g. a target red X among green X’s and red O’s). Another primary source of support comes from studies on illusory conjectors (e.g. Prinzmetal et al., 1986; Briand and Klein, 1987), which demonstrate that if participants are presented with several items in a search display but then attention is diverted away from the items, then some of the item’s features, such as shape and colour, can be incorrectly combined to form illusory conjunctions. However, FIT has also received its fair share of criticism e.g. Tsal (1989) questions whether the illusory conjunctions phenomenon really does provide support for FIT, and also criticises the theory for being too vague for failing to explicate the process whereby separate primitive features are “glued” into objects. The original version of FIT was quickly falsified and replaced with modified versions of the theory, such as the Guided Search theory proposed by Wolfe et al. (1989), and different accounts of visual attention, such as Duncan and Humphreys (1989) model which was more aligned with Duncan’s (1980) late selection theory of attention. FIT was a very influential model which sparked a considerable amount of research on the topic of visual search - however, a satisfactory resolution to the early/late selection debate in attention had yet to be reached.

1.2 Evidence for Early Vs Late Selection

From around the 1960s onwards the focus of selective attention research shifted over from audition to vision. Sperling (1960) carried out a series of experiments that involved presenting a set of 12 digits to participants very briefly (50ms) and testing their recall ability. He discovered that when participants were required to recall the whole set, recall was typically quite poor (no more than 4.5 digits per presentation on average) which suggests limited capacity in the visual system. However, in a further experiment where the visual presentation of the letters was immediately followed by a tone which cued participants towards attending to just one part of the set (e.g. a low tone cued the bottom row), recall rates improved dramatically. These findings can be framed within the early selection model, as success in the partial report task suggests that only those letters that are relevant are able to pass through the selective filter to be processed at the semantic level.

Numerous studies since the 1970s have demonstrated the importance of attention in visual perception (see Neisser, 1979, for an overview). Neisser and colleagues (e.g. Neisser and Becklen, 1975) developed visual tasks that were analogous to the dichotic listening experiments discussed earlier. The dichotic listening tasks demonstrated that when participants attended to one stream of spoken information in one ear they often failed to process the semantic content of another stream. In one example of a visual analogue, Neisser and Becklen showed participants a pair of distinct videos superimposed onto a single screen: one video depicting a group passing a basketball around, the other depicting a group playing a hand slapping game. They found that participants who were required to monitor the events in one video and perform a task (e.g. count the number of basketball passes, or the number of hand slaps) failed to notice an unexpected event in the other video, such as the hand slappers abruptly stopping their game and shaking hands. The term "Inattentional Blindness" (IB) was first used by Mack and Rock (1998) to refer to findings from numerous studies where participants fail to detect unattended objects. In one of their tasks participants were are required to view a cross briefly presented on a monitor screen and determine which of the arms, vertical or horizontal, is longer. In the "critical trial" an unexpected shape (small cube) was presented along with the cross. After the final display subjects were asked if they had seen anything else along with the cross; results indicated that often the unexpected stimulus remained undetected. One aspect of IB studies that has been criticised (Wolfe, 1999) is that the measure of IB relies on surprise retrospective questioning about the presence of the stimuli, which of course is necessary as you cannot inform subjects that there will be an unexpected stimulus presented, as this would prime them to look for it. Wolfe suggests that the critical stimulus may have been perceived, but perhaps just not encoded sufficiently into memory. However, (Simons, 2007) points out that this argument seems less applicable when the unexpected event is highly salient, such as in a famous study by Simons and Chabris (1999) where participants who are required to monitor two teams of players passing a basketball around often completely fail to spot a man in a Gorilla costume who strides across the screen and beats his chest!

IB appears to support early selection in visual attention, whereby an early filter stage blocks the processing of unattended stimuli. Indeed, based on this evidence one could perhaps argue that evidence for early visual selection is even more compelling, given that highly salient unattended stimuli such as chest-beating Gorilla men remain unattended, whereas unattended salient auditory stimuli, such as personal names, are more frequently detected by participants. However, these paradigms do not provide a measure of the extent to which the unexpected, unattended stimuli have been processed. In the same way that Corteen and Dunn (1974) discovered that fear-conditioned words in the unattended stream were being processed to the semantic level, despite not being processed to the stage of conscious awareness, the unattended visual stimuli in these IB paradigms could still receive some degree of processing that went unmeasured. In a study on the negative priming effect, Tipper (1985) presented a prime display with two superimposed objects, and then immediately afterwards a probe display with an object to be named. If the ignored object in the prime display matched the probe object, then participants typically took longer to name the object. This indicates that an internal representation of the ignored prime object must be formed in order to inhibit selection of the correct response, thus suggesting that unattended visual stimuli are processed to a relatively high (semantic) level, which is in line with a late selection model..

Tipper's findings concur with previous evidence that demonstrates how unattended stimuli (distractors) which share characteristics of the attended (target) stimuli can impact on the processing of the target. For example, Stroop (1935) demonstrated that naming the colour of a printed word is more difficult if the written word is incongruent with the text colour (e.g. RED printed in yellow ink) compared to when the written text is congruent with the colour (e.g. GREEN printed in green ink). Eriksen and Eriksen (1974) found that reaction times to a target were increased if the target was flanked by distractor letters that compete with the target for response. In their study the target was a two alternative forced choice (2AFC) task (targets H or K required a level response movement in one direction, targets S and C required a response in the other direction) and the flanking distractors were either compatible (the same response assignment as the target), incompatible (different response assignment to the target) or neutral (non-target letters). Target reaction times (RTs) were greater on incompatible trials. These findings were interpreted by early and late selectionists in different ways: proponents of late selection argued that these findings must suggest that unattended stimuli are processed to the semantic level, whereas early selectionists argued instead that the distractors must have been momentarily attended due to some form of attentional failure.

Kahneman and Treisman (1984) suggest that the reason that the early selection model gained support in the late 1950s and 1960s, whereas the late selection model became more popular in the 1970s and 1980s was due to a shift in the types of selective attention paradigms being utilised by researchers. Paradigms concerned with early selection were typically based around "filtering" tasks, in which participants were presented with an overwhelming amount of relevant and irrelevant information, such as in dichotic listening studies (e.g. Cherry, 1953) where participants had to cope with two concurrent streams of auditory information, and the Sperling (1960) partial report task. Paradigms that show support for late selection tended to based on "selective set" tasks, which typically involved detection of a single target stimulus from one or more discretely presented irrelevant stimuli, such as the response competition paradigm (Eriksen and Eriksen, 1974) and visual search experiments (e.g. Shiffrin and Schneider, 1977; Schneider and Shiffrin, 1977). Lavie and Tsal (1994) suggest that this paradigm shift happened because theories of attention became more focused on the role of automatic processes in attention. Kahneman and Treisman suggested that the differences in the two sets of paradigms were such that they might actually test different attentional mechanisms, hence it was not possible to make any meaningful generalisations regarding definitive support for either early or late selection.

1.3 Perceptual Load Theory

1.3.1 Evidence for a flexible locus of selection in visual attention

In a 1994 review paper, Lavie & Tsal proposed a resolution. They expanded on Kahneman and Treisman (1984) by suggesting that the early/late debate in selective attention can be resolved by determining under which task conditions early selection operates. The authors point out that although there is plenty of evidence that early selection can occur under certain conditions but not others, there has been very little discussion regarding why this is the case. The limited processing capacity of the brain means that selection is necessary for efficient information processing, and Lavie and Tsal (1994) argue that the level of perceptual load in the task plays a key role in determining the locus of this selection. Although early selection does appear to take place, as evidenced by early dichotic listening research, this is not always sufficient to prevent the processing of irrelevant material, as evidenced by numerous tasks which clearly demonstrate that physically distinct targets and irrelevant distractors are processed to the semantic level. Lavie and Tsal (1994) proposed that early selection mechanisms can only operate when the perceptual load of a relevant task is high enough to exhaust all available capacity and thus prevent the processing of task-irrelevant stimuli.

The concept of a flexible locus of selection in attention was not an entirely new idea. Johnston and Heinz (1979) proposed that there are a number of different stages for the processing of incoming stimuli. The brain has limited processing capacity and each stage requires a certain amount of capacity; therefore unattended stimuli are only processed the level that they need to be. In another dichotic listening study participants were required to verbally shadow one stream of words while ignoring another stream in two separate conditions. In the easy condition one stream was a female voice and the other a male voice; in the difficult condition both streams were male voices. The authors found that when given a surprise recall test participants were able to recall more words in the difficult condition, suggesting that selection can be both early and late under different conditions of task difficulty. In the easy condition the relevant information could be filtered from the irrelevant information on the basis of physical properties, as suggested by early selection models; whereas in the difficult condition information cannot be separated at the physical stage, hence all information has to receive more processing in order to determine what is relevant and what is not.

Lavie and Tsal (1994) acknowledge that the concept of perceptual load is hard to operationally define, as it necessarily involves defining how many units are in a display, and the nature of processing required for each of the units (this has been an ongoing bone of contention). Despite this, Lavie (1995) manipulated perceptual difficulty in a series of experiments that were thought to create a load on perceptual processes, rather than post-perceptual processes, such as working memory (WM). All experiments were based around the Erickson response competition paradigm (Eriksen and Eriksen, 1974) and involved identifying a target presented concurrently with a critical distractor. A go/no-go task was used; the target was always one of two letters (e.g. X or N) and the distractor was either compatible, incompatible, or neutral to the target. Critically, Lavie manipulated perceptual load in each of the experiments by increasing the amount of perceptual processing needed to successfully identify the target. In Experiment 1 set size was manipulated by increasing the number of non-target items presented along with the target[1]. In Experiment 2 the load manipulation was based on the premise of feature integration theory (Treisman and Gelade, 1980). The task required a shape to be identified in order to determine how to respond to the target - under low load a single feature of the shape had to be identified (GO if shape is blue) whereas under high load a conjunction of features had to be identified (GO if shape is red circle or blue square). In Experiment 3 the load manipulation was based on the premise that detection is more rapid than identification (e.g. Bonnel et al., 1987, 1992). The task required detection of either a circle or bar shape under low load (GO if either shape present) or identification that the shape was the right size and position (GO if right size and in right position). Importantly, the outcome of all three studies was that distractor interference was *only* found under low load.

Lavie and Cox (1997) also demonstrated how load theory can be applied to visual search. They did this by combining a visual search task similar to that

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[1] In this version of the response competition paradigm, non-targets are considered as items presented alongside the target that never compete for response selection, whereas the distractor can either corroborate the response selection (compatible), compete with it (incompatible) or not compete (neutral).

used by Duncan and Humphreys (1989) with the Eriksen and Eriksen (1974) response competition paradigm to demonstrate that efficient search for a target among non-targets leads to inefficient distractor rejection. This time a two alternative forced choice task (2AFC) task was used. In the low load task search was for a target X or N among non-target O's (efficient "feature" search, due to dissimilarity between target and non-targets), whereas in the high load task search was for a target X among a variety of angular letters, such as K, M, V (inefficient search, due to the visual similarity between the target and non-targets). An irrelevant distractor flanked the display - this was either compatible (target X, distractor X), incompatible (target X, distractor N) or neutral (target X, distractor L). Distractor competition was found only under the low load condition i.e. incompatible distractors were associated with increased target detection RTs when search for the target among non-targets was efficient (low load), but not when it was inefficient (high load). Lavie and Cox suggested that these results demonstrate how the efficiency of attentional selection can be determined by the available attentional capacity.

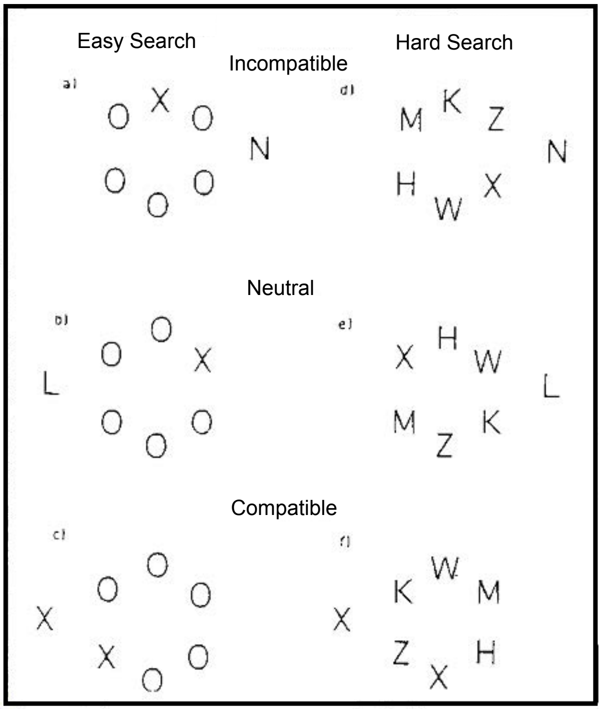

Figure 1.4: Perceptual load manipulation of visual letter search task (Lavie and Cox, 1997)

Over the past 15+ years numerous studies have confirmed that the processing of task-irrelevant distractor stimuli is dependent on the level of task-relevant perceptual load (e.g. Lavie and Fox, 2000; Lavie et al., 2003, see Lavie, 2005a, for a review) and load theory has also been expanded and applied to a wide range of different questions in cognitive psychology. However, as discussed and outlined in Chapter Two, there are still aspects of load theory which remain under-researched or under debate.

Chapter 2

Current Issues With Load Theory

Please note that the literature reviewed in the first three sections of this chapter (Sections 2.1, 2.2 and 2.3) corresponds to each of the three experimental chapters (Chapters 3, 45), respectively.

2.1 Visual perceptual load and subjective conscious awareness

Before moving forward to discuss perceptual load effects on subjective conscious awareness, it is important to briefly discuss the concept of conscious awareness and how this is thought to relate to selective attention. In their 2007 paper, Koch and Tsuchiya point out that despite attention and consciousness having very different functions, it still seems to be the case that many researchers think that attention is a necessary prerequisite for consciousness i.e. unattended items do not enter conscious awareness. The authors argue that although there is clearly a close relationship between attention and consciousness, they serve very different functions and are by no means one and the same thing. Whereas attention selects important, relevant information and appears to process this at the expense of less important, irrelevant information; consciousness involves functions such as summarising both the external and internal states of the organism, decision making, planning, and rational thought etc.

Koch and Tsuchiya put forward a framework detailing four different ways in which the processing of visual events can be classified, depending on a) if they involve endogenous selective attention or not, and b) if they invoke a subjective conscious experience or not. According to the framework, "attention with consciousness" refers to visual processing whereby focused attention is necessary for a subject to become consciously aware of a stimulus This is demonstrated by studies on inattentional blindness (e.g. Simons and Chabris, 1999; Mack and Rock, 1998; Cartwright-Finch and Lavie, 2007), whereby subjects fail to detect unexpected stimuli because they are not attending to them. It is this classification of the relationship between attention and consciousness that the subsequent work discussed in this thesis will be most closely aligned to. This contrasts with the three other ways in which visual processing can be classified under the Koch and Tsuchiya framework: "attention without consciousness", "consciousness in the near absence of attention" and "no attention, no consciousness" (see Koch and Tsuchiya for more information on these other elements of the framework).

Despite the current prominence of perceptual load theory as a key theory of selective attention, relatively few studies have addressed the role of perceptual load in conscious awareness. In a 2006 review paper Lavie discusses the fact that although studies based on the response competition paradigm (e.g. Lavie, 1995; Lavie and Cox, 1997; Tellinghuisen and Nowak, 2003) offer support for the effects of load on “unattended”, task-irrelevant distractor processing, they do not tell us anything about whether the distractors have reached conscious awareness. Interference from incompatible distractors is seen under low perceptual load but not high load. In order for them to interfere with the target processing, the distractors must be processed to the semantic level, but it is impossible to know using these indirect measures of RT whether the distractors have reached the level of conscious awareness or not. This section reviews a range of studies that have tested whether visual perceptual load impacts on conscious awareness.

2.1.1 Neuroimaging

Several imaging studies support load theory (e.g. Mitchell et al., 2004; Yi et al., 2004; Schwartz et al., 2005) by demonstrating that under high perceptual load the processing of task-irrelevant distractor stimuli in the visual cortex is attenuated. However, with the exception of one study (Rees et al., 1997), these paradigms only inform us about the nature of load effects on unattended stimuli, so it is possible that the RT effects and patterns of visual cortical activity demonstrated in these studies actually reflect unconscious, rather than conscious processing. Rees et al. (1997) asked participants to perform linguistic judgement tasks of either low load (respond when you see a capitalised word) or high load (respond when you see a bi-syllabic word), while ignoring task-irrelevant visual motion, in the form of white dots moving in one direction across the screen.

The study showed reduced activation of the cortical area associated with motion processing (V5) during the high load task, suggesting reduced visual processing under high load. Furthermore, when a group of participants were presented with a static display of dots after each trial the motion aftereffect was also reduced under high load. The motion aftereffect is a measure of attended processing, hence this finding does suggest reduced processing under high load, although it should be noted that this finding is strictly limited to explaining load effects on motion. Also, the task wasn't really "attended", in the sense that the visual motion stimuli were irrelevant and participants were told to ignore them - hence this was a measure of conscious processing of unattended stimuli.

2.1.2 Perceptual Load and Inattentional Blindness

Cartwright-Finch and Lavie (2007) designed a study to test whether perceptual load can impact on the likelihood of becoming aware of a task-irrelevant stimulus. In an adaptation of the IB paradigm used by Mack and Rock (1998), the authors presented subjects with the image of a blue and green cross over several trials and asked them to either discriminate which of the arms of the cross was green (low perceptual load) *or* which of the arms was longer (high perceptual load). On the final trial a small unexpected shape (the critical stimulus) was presented on the periphery of the display. In post-test questioning participants were asked whether or not they had detected the presence of the critical stimulus on the final trial. The results indicated that reporting of the shape dropped significantly in the high load condition, supporting the suggestion that high load can impact on awareness. However, Lavie (2006) points out that inattentional blindness measures the processing of a surprise object, hence this result is limited to supporting the role of perceptual load in awareness of *unexpected* objects. Furthermore, the nature of the IB task necessitates retrospective questioning to measure awareness of the critical stimulus. This would have placed demands on working memory, and it is possible that participants may have become aware of the critical stimulus but forgotten about it by the time they were asked about it. High perceptual load could have lead to generation of a smaller signal and thus weaker encoding of the critical stimulus into memory (Barber and Folkard, 1972), thus offering an alternative explanation for increased failure to detect the critical stimulus under high load.

Interestingly, load effects on IB have also recently been demonstrated outside of the lab. Chabris et al. (2011) required participants to run behind a confederate along a route near where a group of actors staged a mock fight. Participants were less likely to notice the fight if they were required to keep a separate count of the number of times the runner touched his head with his left or right hand (high load) than if they were just required to follow the runner (low load), suggesting that inattentional blindness is more likely to occur under conditions of high load[1].

2.1.3 Perceptual load and change blindness

There are clearly inherent problems with using IB as a measure of conscious awareness. In order to test perceptual load effects on awareness of *expected*

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[1] It is worth noting that the load task used in this study will have taxed working memory resources in addition to perceptual resources, hence it is referred to as an "attentional" load task, rather than "pure" perceptual load task. In contrast, Cartwright-Finch and Lavie (2007) used a task designed specifically to tax perceptual load.

attended stimuli, Beck and Lavie (as cited in Lavie, 2006) turned to change blindness (CB); the phenomenon whereby an observer can fail to notice seemingly obvious changes in a visual scene, especially if the change is accompanied by a brief visual disruption (see Simons and Rensink, 2005, for a review). Changes in the visual environment are typically accompanied by transient motion signals, and CB can occur when that signal is weakened for any reason. Examples include brief global occlusion (Rensink et al., 1997; Aginsky et al., 2000), partial occlusion (O'Regan et al., 1999), brief blurring of the scene (Schofield et al., 2006), saccades (Henderson and Hollingworth, 2003) or even just change over an extended period of time (Simons et al., 2000). Change-blindness also accounts for why continuity errors in movies are frequently missed by viewers, such as an actor's wristwatch suddenly disappearing during a cut between two different camera angles (Levin and Simons, 1997), and a classic study by Simons and Levin (1998) demonstrates that startling failures to detect changes can even happen during real-life interactions.

One particularly useful paradigm for testing change blindness was developed by Rensink et al. (1997). The authors noted that in a typical change blindness situation, change blindness occurred despite the individual having access to all the visual information needed for perception, which suggested that something else was preventing them from using the information to detect the change. The authors developed the flicker task - a paradigm that demonstrates how removal of low-level perceptual cues means that successful detection of seemingly obvious changes in a visual scene can be extremely difficult. This change blindness persists even if the observer is made aware that there definitely is a change in the scene, and even if the change cycle is repeated over many trials. In the flicker task (Fig. 2.1) two images quickly alternate in rapid succession - an original version of the image and a modified version. The two versions of the image are interspersed with brief blank fields (global transients) designed to “swamp” the low-level visual cues (local transients) and make the change between the two images very difficult to detect. The authors did indeed demonstrate that the flicker task induced very high levels of change blindness and they took this as an indication that focused attention is an important factor in this sort of change detection task (Rensink et al., 1997; Rensink, 2000). Additionally, Tse and colleagues further demonstrated that the likelihood of detecting a change at a particular location corresponds to the allocation of attention to that location(Tse et al., 2003; Tse, 2004). This means that change detection accuracy can be thought of as an indirect measure of the likelihood of attentional occurrence at any given location, and thus change-blindness is a indirect measure of the spatial distribution of visual attention.

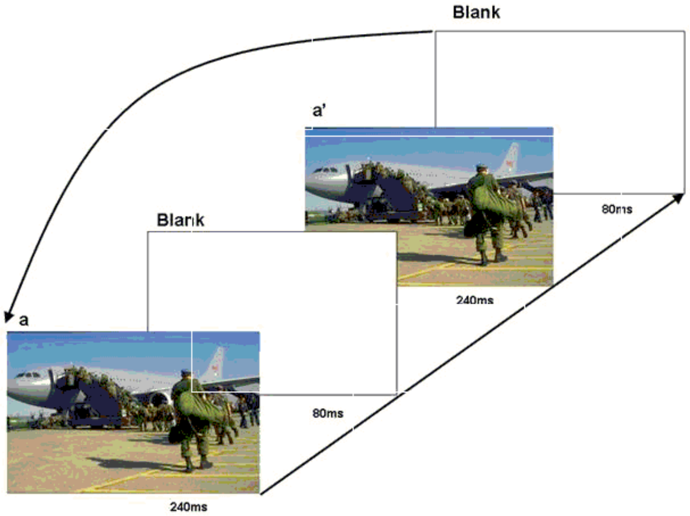

Figure 2.1: Probably the most well known examples of the Flicker Paradigm (Rensink et al., 1997). The original image (a) cycles with a modified version of the image (a') in which the jet's engine has been removed.

Accordingly, Beck & Lavie (as cited in Lavie, 2006)[2]adapted a change blindness "flicker" paradigm (Rensink et al., 1997) to include a perceptual load manipulation (see Figure 2.2). For each trial participants were presented with four cycles of a display featuring a central letter search task and two images. The main task was to monitor the display and respond to the presence of a target X appearing in the letter search task. Under low load, search was for X among visually dissimilar letters (O's); under high load search was for X among the visually similar letters (K, Y, V) In addition to monitoring the letter search task, participants were also required to monitor the images, and at the end of each trial were asked to report whether either image had changed. The change detection task remained consistent throughout all trials, meaning that any varia-

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[2] A relatively detailed description of the Beck and Lavie study is provided in Lavie (2006). However it should be noted that the Beck and Lavie study was never published in its own right.

tion in change detection performance between different conditions of load could be directly attributed to a limited set of attentional resources which had to be divided between the perceptual load task and the change detection task. The authors found than an increase in visual perceptual load in the letter search task reduced participants' change detection performance. If detection of change in a flicker task is considered to be a measure of awareness, then these findings provide strong support for the claim that perceptual load can impact on subjective conscious awareness. When load is high, attentional resources are fully focused on the task and change detection is less likely. When load is low, attentional capacity is able to "spill over", as overall capacity is not depleted to the same extent, this allowing for more accurate change detection.

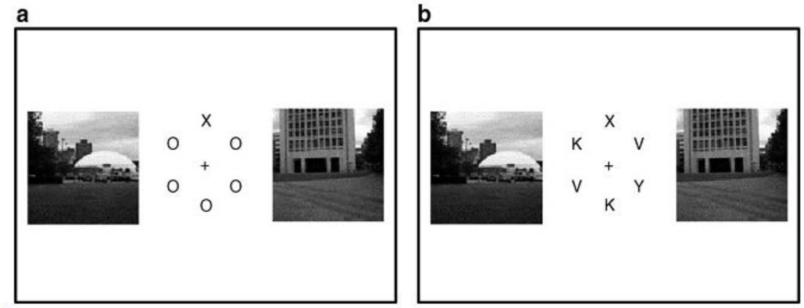


Figure 2.2: Examples of the low load (a) and high load (b) conditions in the Beck and Lavie change blindness study(unpublished, as cited in Lavie, 2006).

2.1.4 Load and the temporal dynamics of attention

Further evidence for the impact of perceptual load on awareness also comes from recent discoveries in research on the temporal distribution of attention. The Attentional Blink (AB) has been used extensively over the past 20 years to investigate fundamental capacity limitations in the processing of temporally distinct stimuli. Typically, identification of a first target (T1) in an Rapid Serial Visual Presentation (RSVP) stream hinders the subsequent identification of a second target (T2) when T2 is presented approximately 200 – 500ms after T1 (e.g. Raymond et al., 1992, 1995; Broadbent and Broadbent, 1987; Chun and Potter, 1995). A number of studies demonstrate that T2 items that go consciously undetected are still processed up to the semantic level in the visual cortex(see Marois and Ivanoff, 2005, for a review) and most findings up until a few years ago suggested that the AB reflects a bottleneck in post-perceptual processing i.e. information processing is intact at the earlier sensory registration phase, but limited at later stages such as response selection and working memory. For example, Luck et al. (1996) measured the magnitude of the N400 event related potential (ERP) component evoked by T2 words. The N400 is part of the brain's response to meaningful stimuli - it reflects the degree of mismatch between the current semantic representation of a word and and the previously established semantic context (Kutas and Hillyard, 1980), and is observed in the ERP as a negative deflection around 400ms after the presentation of a mismatched stimulus. A larger deflection is observed for words that do not match the context than for words that do e.g. a larger deflection would be observed for "CAR" preceded by "TREE" than "CAR" preceded by "VEHICLE". Luck et al. (1996) presented a context word at the start of each trial (e.g. CAR) followed by a matched/mismatched word at T2 in the RSVP stream and found that the N400 in response to T2 words presented inside the AB was of equal magnitude to T2 words presented outside the AB, suggesting that T2 was always analysed at the semantic level, despite subjects being less able to consciously identify T2 when presented during the AB. Additional evidence for post-perceptual selection in the

AB comes in the form of a study by Shapiro et al. (1997) which demonstrates reduced susceptibility of highly salient information to the AB. The study showed that while participants struggled to identify another person's name presented during the AB, their ability to identify their personal name was not affected. This is effectively a visual analogue of the "Cocktail Party" effect Cherry (1953).

This post-perceptual take on the AB has recently been challenged by a group at UC Santa Barbara (Giesbrecht et al., 2007, 2009; Elliott and Giesbrecht, 2010) who have tested perceptual load effects in the AB paradigm. Their experiments typically manipulate the level of perceptual load at T1 by flanking a target arrow with non-target arrows that either face the same way as the target ($> > > > >$) or a different direction ($> > < > >$). T1 load is low when the distractor arrows are congruent with the target (facing the same way) and high when the distractor arrows are incongruent with the target (facing a different direction). Giesbrecht et al. (2007) applied this load manipulation to a version of the N400 paradigm first used by Luck et al. (1996) and demonstrated that during the AB the N400 was completely attenuated under load, which suggests that words do not always necessarily receive processing up to the semantic level during the AB. Furthermore, Giesbrecht et al. (2009) applied the T1 load manipulation to a version of the task used by Shapiro et al. (1997)and found that personal names are less likely to survive the AB under high perceptual load. Finally, Elliott and Giesbrecht (2010) demonstrated that increased load at T1 results in reduced interference from task-irrelevant distractors presented at T2. The Shapiro et al. (1997) and Elliott and Giesbrecht (2010) studies both demonstrate the role of perceptual load in conscious awareness, and all the studies demonstrate perceptual load effects in the temporal domain.

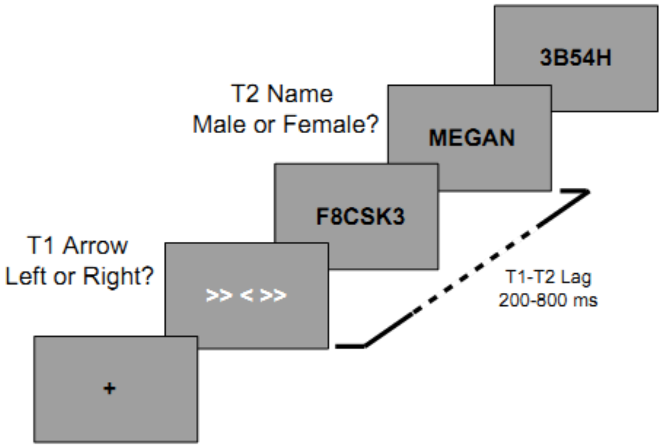


Figure 2.3: An example of the trial sequence used byGiesbrecht et al. (2009). In this trial T1 load is high (the direction of the flanking arrows does not match that of the target). Participants indicated whether the name shown at T2 was female or male (their own name appeared in 25% of trials).

2.1.5 Load effects across different sensory modalities

Up to now this review has only addressed the operation of selective attention in the visual modality. Despite it being just as crucial that we enhance our understanding of how attention operates between different sensory modalities, early research typically focused on attention within audition (e.g. Cherry, 1953; Broadbent, 1958) and then, with advancement in display technology, the focus shifted over to attention in vision (e.g. Treisman and Gelade, 1980; Mack and Rock, 1998). Comparatively little research has investigated how attention operates between different sensory modalities.

The McGurk Effect (McGurk and MacDonald, 1976) is a very well known example of integration across different modalities. If subjects are exposed to mismatched auditory (spoken speech) and visual (lip movements) information, then the visual information impacts on how the concurrent spoken speech is interpreted. For example, if you view a video of a person saying the syllable *ga,* but you see them saying *ba,* then the two sources may become fused and you may hear *da.* This effect is well documented for simple, single syllable information and also for more complex audiovisual scenes (e.g. Wright and Wareham, 2005), and is though to provide strong support for the automatic cross-modal integration of the vocal and visual aspects of speech into a unitary percept. However, there is evidence that this integration is subject to limited capacity demands in attention. Alsius et al. (2005) found that susceptibility to the McGurk effect could be reduced by getting participants to engage in either a concurrent visual or auditory load task designed to exhaust their attentional resources. Tiippana et al. (2004) showed that the McGurk effect is reduced when participants are required to attend a visual distractor stimulus that moved around the face, compared to when they are just required to attend the face. The McGurk effect was shown to be weaker in the unattended face condition, which further implies that visual attention can modulate audiovisual speech integration. According to the authors, this result either implies that the modulation of visual attention occurs at an early stage of uni-sensory processing, *or* that the the stage at which the visual and auditory information is integrated has been shifted. However, one caveat of both these studies is that they did not monitor eye movements, so is is possible that these effects could be explained by more eye movements in the high load condition. Furthermore, the results are specific to the intergration of visual and auditory speech information, and seeing as this involves faces it is questionable whether the cognitive mechanisms associated with this specific processing are generalisable to other instances of multi-modal integration. Finally, both studies just tested a dual-task “high load” condition against a single-task “no load” condition, so the two conditions would have involved different task demands, meaning that these studies do not allow the effects of low Vs high perceptual load to be compared.

One study does compare performance high and low auditory load performance between the visual and auditory modalities. Tellinghuisen and Nowak (2003) modified the response competition paradigm (Eriksen and Eriksen, 1974) to investigate the effects of both visual and auditory distractors on visual search task performance. In their first experiment they confirmed that visual distractors only impact on target detection RT and accuracy under easy search conditions - in line with perceptual load theory. However, they also demonstrated that auditory distractors had a larger distractor incompatibility effect under *high* visual load (hard search), than *easy* visual load (easy search). This effect was confirmed in two further studies, and suggests that processing of auditory distractor stimuli always takes place regardless of whether a concurrent visual task is being performed - but under high visual perceptual load our ability to inhibit auditory distractor processing is reduced. These findings are the exact opposite of what would be expected under perceptual load theory. Load theory would predict greater distractor interference under low load, but these results suggest greater distractor interference under high load for auditory stimuli.

In a follow up to the (1997) functional magnetic resonance imaging (fMRI) study testing the effects of load on motion processing, Rees et al. (2001) used both Positron Emission Tomography (PET) and a behavioural experiment to test the effects of auditory load on the perception of irrelevant motion distractors. Participants were required to monitor auditory stimuli while ignoring irrelevant motion presented on a screen. Under low load, participants were required to discriminate words on the basis of physical features (quiet voice Vs loud voice), whereas under high load they detected words with two syllables among words with either one syllable or three syllables. The PET results indicated that the irrelevant motion stimuli were processed to the same extent across conditions of both low and high auditory load. The behavioural results also demonstrated that auditory load had no discernible impact on the motion aftereffect experienced by participants in response to the moving dots suddenly becoming static. These findings, when considered alongside previous results Rees et al. (1997) indicate that whereas high visual perceptual load can reduce processing of task-irrelevant motion stimuli, high auditory perceptual load has no such impact. The implication is that perceptual load theory is limited to explaining load effects within modalities, although it must be considered that these results are constrained to explaining load effects of the processing of unattended motion stimuli. Furthermore, it is possible that the use of a more challenging, or different auditory task may not have led to a null result.

The results of Rees et al. (2001) and Tellinghuisen and Nowak (2003) suggest that perceptual load theory does not hold when applied across different sensory modalities, and both studies have conflicting implications for load theory. Whereas Rees et al. (2001) demonstrate that the level of task load in one sensory modality does not impact on processing in another modality, Tellinghuisen and Nowak show that not only does task load in one modality impact on processing in another modality, in fact the interference effect is the exact opposite of what perceptual load theory would predict. Furthermore, Rees et al. (2001) suggest that load theory is only applicable when competition for resources is within the same modality, Tellinghuisen and Nowak suggest that load theory needs to be modified in order to account for the effects of cross-modal distraction. The discrepancies in these two sets of findings are most likely due to fundamental differences in the paradigms used. While Rees et al. tested the the effects of an auditory load task on unrelated, unattended visual motion stimuli, Tellinghuisen and Nowak measured the effects of unattended yet relevant auditory stimuli on easy and hard visual search tasks. Aside from the fact that the load tasks in both studies were in opposing modalities, there was only response competition between the attended stimuli and distractors in Tellinghuisen and Nowak, which may account for the difference in results.

The discrepancies in these results highlight how important it is for load effects to be tested in a variety of different paradigms using visual and auditory load tasks, unattended/attended stimuli and unrelated/competing stimuli. So far, no study has yet tested the effects of visual and auditory perceptual load on an unrelated but attended visual task.

2.2 Selective Attention and Cognitive Control

2.2.1 WM and Selective Attention

Lavie et al. (2004a) point out that a comprehensive model of selective attention should also account for the effects of distractors on behaviour when the relevant task load is low and distractors are perceived. Under these circumstances the distractors can compete with the relevant stimuli and have an impact on behavioural responses; for example, in the low load condition of the response competition paradigm, participants take longer to respond on target-distractor incongruent trials than target-distractor congruent trials, which is presumed to reflect target-distractor conflict (Lavie, 1995). However, despite competition and increased response times, more often than not the participant is still able to respond correctly to the task. This implies the involvement of a separate cognitive control function that enables behaviour to be guided by task-relevant stimuli rather than task-irrelevant stimuli, even if the task-irrelevant stimuli are perceived under low load/late selection. This cognitive control function would involve higher "executive" cognitive functions, such as working memory (WM).

According to Engle (2002), WM is a multi-component system assumed to consist of a short-term-memory component (STM) and an executive attention component (e.g. see Baddeley, 2000) . Engle (2002) also operationally defines executive attention as the ability to actively maintain representations of relevant stimuli or goal states in memory regardless of interference from task or goal irrelevant information. Lavie et al. (2004a) point out that the frontal cortices appear to be directly involved in WM (e.g. Engle, 2002; Courtney et al., 1997) and they reasoned that these processes were critical in prioritising the processing of task-relevant information over task-irrelevant information. Lavie et al. (2004a) reasoned that if these cognitive control resources were depleted by increasing the level of cognitive load in a relevant task, then selection between task-relevant and task-irrelevant stimuli would be less efficient. Please note that the majority of the studies cited in this thesis use WM tasks to manipulate the level of cognitive load, hence "WM load" and "cognitive load" are used somewhat interchangeably.

2.2.2 Load Theory of Selective Attention and Cognitive Control

Lavie et al. (2004a) ran a series of five studies in which a selective attention task was combined with a working memory task. The selective attention task was based on the response competition paradigm (Eriksen and Eriksen, 1974), whereby participants were required to respond as quickly and as accurately as possible to a central target letter while trying to ignore task-irrelevant distractors presented in the periphery of the display. Congruence of targets and distractors was manipulated so that they were either congruent (both the same letter), or incongruent (the distractor was a different letter to the target). Slower responses are indicative of distractor competition. In Experiments one, two and three the selective attention task was interleaved by a WM load task which will be referred to throughout this thesis as the “WM set/probe task”. Participants were shown a set of digits which they were required to memorise (WM Task), they then performed the target detection task (Selective Attention Task), and finally they were presented with a digit and asked whether or not the digit had appeared in the preceding WM set (WM Probe Task). In order to manipulate WM load the size of the WM set was varied between one digit (low load) and six digits (high load). Across all three studies the results demonstrated that increasing WM load leads to increased interference from incongruent distractors in the selective attention task. In Experiments four and five the authors also demonstrated the same effect when the WM task and selective attention task were not interleaved but performed in quick succession instead. Participants either performed under dual-task conditions, which involved carrying out a WM task then the selective attention task, or single-task conditions, where they ignored the WM task and just performed the selective attention task. The increased cognitive load that resulted from the dual-task coordination meant that participants experienced greater distraction in the selective attention task when they were required to dual-task, compared to when they were only required to perform the selective attention task.

Similar effects of WM are demonstrated on auditory selective attention. Dalton et al. (2009b) gave participants an auditory selective attention task which involved responding to an auditory target while ignoring an auditory distractor, and manipulated the level of concurrent WM load using a set/probe task as described above. The authors demonstrated that increased WM load results in increased interference from auditory distractors. In a further study, Dalton et al. (2009a) also demonstrate that increasing WM load leads to increased distraction in a tactile response competition task, where participants are required to respond an elevating sequence of target vibration presented to one hand, while ignoring a vibrating distractor in the other hand, with distractor vibrations being either congruent (same elevation as target) or incongruent (different elevation to target). All this research suggest that WM load can impact on selective attention both within and between different sensory modalities.

These results concur with evidence from neuroimaging. de Fockert et al. (2001) presented participants with a selective attention task that required them to categorise written names that appeared on screen as either politicians or pop stars, while ignoring distractor faces presented in the background. Again, this selective attention task was interleaved with a WM set/probe task as described above. An increase in interference was observed in the high WM load conditions; the behavioural data suggested an increase in distraction by incongruent faces under high WM load, and the fMRI data confirmed that areas of the brain typically associated with face processing, such as the left lingual gyrus, bilateral fusiform gyri and right inferior occipital lobe were significantly more active under high WM load than low WM load. It is worth noting, however, that although this study claims to measure low WM load vs high WM load, the low load task does not actually require any WM monitoring at all due to the consecutive nature of the recall, hence it is really measuring no WM load vs high WM load. This point is also applicable to many other studies that employ the WM set/probe load manipulation.

Figure 2.4: Example of a high working memory load trial in de Fockert et al. (2001). The memory set was displayed for 1500ms - under low WM load the order was always consecutive (e.g. 0 1 2 3 4), whereas under high WM load the order was varied (e.g. 0 3 1 2 4), as is typical in a WM set/probe task. A fixation display was then presented, followed by 2, 3 or 4 attention task displays. The amount of attention displays shown per trial was manipulated so that the the memory probe onset was unpredictable, hence participants would have to rehearse the memory set for the entire duration of the trial. Each attention set was presented for 500ms then followed by a response interval of 1250 ms. After the final attention task display, participants were presented with the memory probe task and asked to report the digit that followed on from the probe (in this example, the correct response would be "4").

Further evidence that cognitive control has a critical role in efficient selection between relevant and irrelevant visual information also comes from behavioural and neuroimaging studies that demonstrate that increased WM load leads to increased capture of attention by a task-irrelevant "colour singleton" during a visual search task. A colour singleton is an irrelevant distractor with a unique colour (e.g. a blue singleton among red search stimuli) that makes it "pop out" in a visual search display, thus capturing attention away from target search (e.g. Johnson et al., 2001; Horstmann, 2002; Folk and Remington, 2006). Lavie and De Fockert (2005) demonstrate increased attentional capture by an irrelevant colour singleton during visual search under high WM load. A further study by Lavie and Fockert (2006) provides evidence from fMRI that activity in both the parietal and frontal cortices is involved in cognitive control - under conditions of high WM load interference by a task-irrelevant colour singleton in a search task is increased, and the amount of distraction by the colour singleton negatively correlates with activation in the frontal cortex.

Finally, there is evidence that switching tasks between different sensory modalties can also lead to increased interference in selective attention. Brand-D'Abrescia and Lavie (2008) employed a similar procedure to Lavie et al. (2004a, experiments four and five); participants either completed dual-task conditions, where they completed a perceptual discrimination task immediately followed by a selective attention task, or single-task conditions, where they ignored the perceptual discrimination task and just engaged in the selective attention task. Importantly, the perceptual discrimination task was either presented in the visual or auditory modality, allowing the effects of cognitive control on visual selective attention to be tested both within and between modalities. Although the visual and auditory perceptual discrimination tasks did not load WM or directly interfere with the visual selective attention task, the authors argued that the act of suddenly switching between the discrimination task with one set of demands, to the selective attention task with a different set of demands, should result in greater distractor interference in the selective attention task due to reduced cognitive control. The results indicated that dual-task coordination with either the visual or auditory perceptual discrimination task led to increased interference from task-irrelevant distractors in the selective attention task - a finding that extends the load theory of cognitive control to also account for cross-modal interference from the auditory domain. Interestingly, greater interference in the visual selective attention task was found when the task was preceded by the auditory discrimination task than the visual discrimination task (the difficulty of the auditory task was irrelevant) suggesting that task co-ordination between modalities taxes cognitive control to an even greater extent than task co-ordination within modalities.

This evidence all supports Lavie et al.'s updated load theory, which incorporates two distinct mechanisms: a passive perceptual mechanism that attenuates the processing of distractors under high task-relevant perceptual load, and an active cognitive control mechanism that reduces interference from distractors that are processed under low task-relevant perceptual load. According to the model, an increase in the level of perceptual load should reduce interference from distractors, because they are less likely to be processed; whereas an increase in the level of cognitive load should increase interference from distractors, as a result of depleted cognitive control resources. Thus the model suggests that the effects of perceptual and cognitive load are diametrically opposed.

The updated load theory is referred to as the "load theory of selective attention and cognitive control". For the sake of consistency, throughout this thesis I will use "load theory" to refer to this updated model which includes both passive and active mechanisms, and "perceptual load theory" to refer exclusively to the passive perceptual mechanism.

2.2.3 WM Load Effects on Unattended Stimuli

2.2.3.1 The "Indirect Load" argument

Not all the evidence supports the claims made by the updated load theory. Rose et al. (2005) suggest that the effects of cognitive load are only opposed to those of perceptual load when the experimental design involves the WM task being incorporated into a selective attention task. In the typical experiments that show support for perceptual load effects, the load was always related to the relevant task; whereas in the experiments on cognitive load, the WM task was designed to interfere with selection between the relevant and irrelevant stimuli. For example, in de Fockert et al. (2001) the WM task would have interfered with participants' ability to selectively attend to and categorise the name stimuli as pop stars or politicians, while ignoring the distractor faces in the background. Rose et al. reasoned that Lavie and colleagues' cognitive control studies actually test the effect of a third task (the WM task) on selection between two other tasks (selecting between relevant and irrelevant stimuli), meaning that the load was not directly relevant to the selection task. This contrasts with the typical flanker task based perceptual load studies, where the load was related to the relevant task. Rose et al. suggested that perhaps if the WM load was directly imposed on the relevant task this may challenge the idea that cognitive load effects are diametrically opposed to perceptual load effects.

2.2.3.2 WM load and unattended image processing

Accordingly, Rose et al. (2005) designed a study to test the effects of relevant WM task-load on the processing of task-irrelevant background stimuli that were presented simultaneously (see Figure 2.5 for an example of their experimental procedure). Participants performed a *1*-Back or *2*-Back WM load task, where they were required to match a target letter with a letter that had been presented either 1 position back in the sequence (low load) or 2 positions back (high load). They also viewed background images that were simultaneously presented on screen at one of five different visibility levels (0, 25, 50, 75 and 100% visibility). Subjects were required to focus their attention on the letters (the relevant WM task) and to ignore the task-irrelevant background images. The modulatory effects of WM load on the processing of the background images was tested behaviourally with a surprise recognition task, and also with neurophysiological measures (ERPs and fMRI). The results from all three measures indicate that an increase in WM load leads to reduced processing of the visual images. Image recognition rates decreased significantly under high WM load. The enhanced blood oxygen level dependence (BOLD) signal associated with an increase in image visibility in the right lateral occipital complex (LOC) was also modulated by load, in that under high WM load the increase was less significant. Furthermore, the amplitude of the occipito-temporal N1 component (a negative potential occurring approximately 150-200ms post stimulus thought to be associated with LOC function) was reduced under high WM load. In summary, all three measures suggest that processing of task-irrelevant stimuli is reduced under high WM load. These findings directly oppose load theory, (Lavie, et al., 2004), which predicts increased processing of task-irrelevant stimuli under high

WM load.

Further evidence against increased task-irrelevant processing under high WM load comes from a study by Yi et al. (2004). They found that an increase in task-relevant perceptual load attenuated the processing of a task-irrelevant background image, whereas increasing WM load had no effect. Although these results are in line with typical perceptual load effects, they conflict with research by Lavie and colleagues (de Fockert et al., 2001; Lavie et al., 2004a), and also, surprisingly Rose et al. (2005). Yi et al. and Rose et al. used fairly similar WM paradigms that involved attending to a *1*-back or *2*-back WM load task while ignoring a background image, so the "indirect load" argument put forward by Rose et al. that was outlined earlier in this section can account for why Yi et al.'s findings do not support load theory. However, it is difficult to account for why Rose et al. demonstrated reduced image processing under high WM load whereas Yi et al. found no effect of WM load, especially considering Yi et al.'s high WM load task was more challenging (as measured by increased error rates) than Rose et al.'s study.

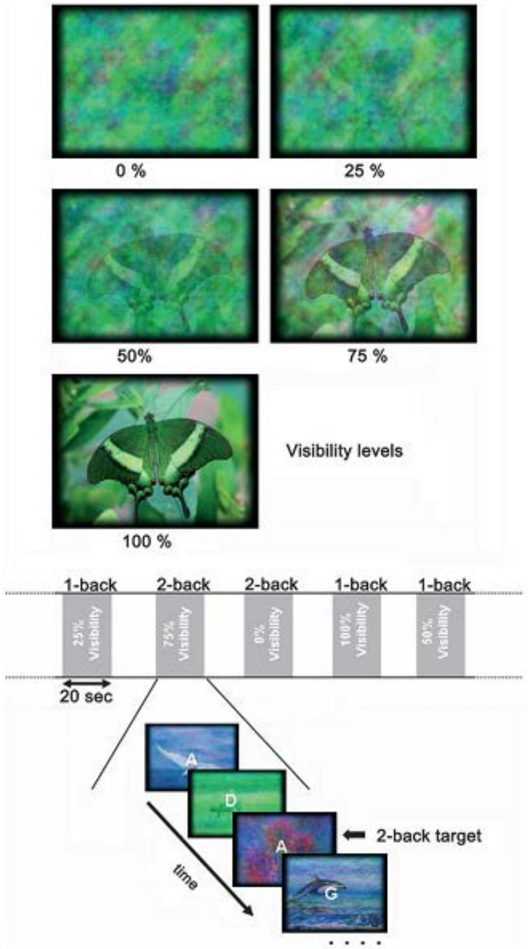


Figure 2.5: Examples of the procedure and background images used by Rose et al. (2005). 5 levels of image scrambling were used (0, 25 50, 75 and 100%). Images were presented as an irrelevant background for the attended *n*back task. Participants were required to respond to the letter targets according to either the 1-back or 2-back rule (an example of a 2-back task is shown here). The different scrambling levels and *n*-back tasks were presented in a pseudo random order in blocks of 20 seconds, and the *n*-back difficultly level (low, high) was indicated before each block.

Klemen et al. (2010) draw attention to a important methodological confound with the Rose et al. (2005) paradigm and two further studies that also employ a similar method of stimuli presentation which are discussed later in this section (Bingel et al., 2007; Gläscher et al., 2007). Typically, the task-relevant stimuli (WM task) and task-irrelevant stimuli (ignored background images) are both presented within the visual modality, which may result in a degree of perceptual interference between the two tasks. It is possible that this perceptual interference may have had some degree of influence on the modulatory effects of WM on the irrelevant task. In order to investigate this, Klemen et al. (2010) modified the paradigm so that the WM load task was presented in the auditory modality as opposed to the visual modality, thereby eliminating perceptual interference with the visually presented task-irrelevant stimuli. Participants matched a target tone to a tone presented either 1 position back in the sequence (low WM load) or 2 positions back (high WM load), while simultaneously viewing images that were at varying states of degradation on screen (which they were instructed to ignore). The behavioural and neuropsychological outcomes of this experiment were comparable to those of the Rose et al. (2005), demonstrating that an increase in auditory WM load leads to reduced processing of task-irrelevant visual stimuli and providing a further challenge to load theory.

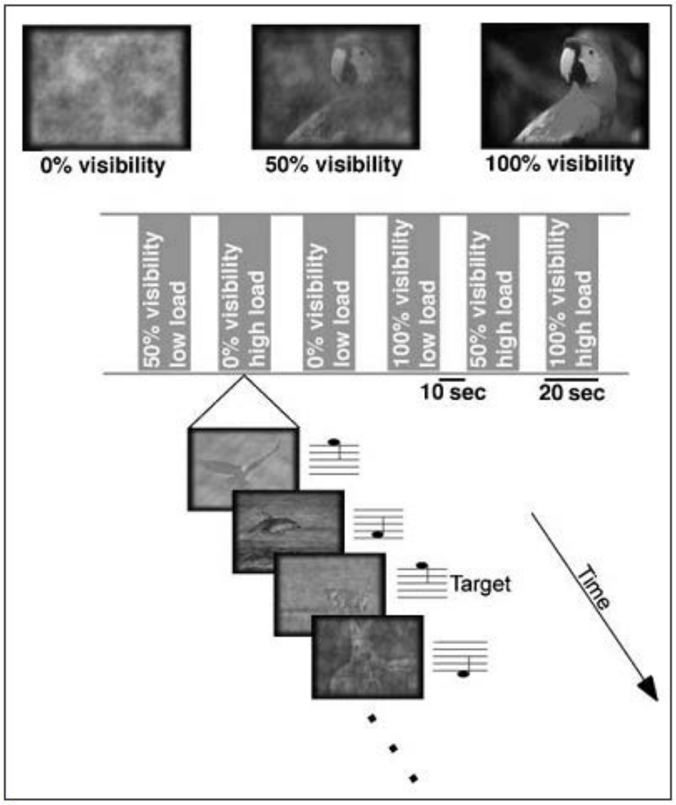


Figure 2.6: Example of the procedure used by Klemen et al. (2010). Participants were required to perform the *n*-back auditory matching task (this involved pressing a button whenever a tone was repeated in the sequence) while viewing objects on a screen. WM load (low, high) and object visibility (0%, 50% and 100%) were both manipulated across conditions.

2.2.3.3 WM load and auditory distraction

Further evidence in line with Rose et al. and Klemen et al. comes from a study by SanMiguel et al. (2008) that investigated whether introducing WM load in a relevant visual task can reduce distraction from a task-irrelevant auditory stimulus that varies at rare and unpredictable times. Participants ignored the auditory stream while engaging in a *0*-back (no- load) task, which involved comparing whether two digits presented either side of a screen were the same or different, or a *1*-back task (load) which involved matching one of the digits with the digit that appeared one place back in the sequence. Distraction from the auditory stimuli occurred under both the *0*-back and *1*-back conditions, but was significantly reduced in the *1*-back condition, as indexed by reduced task performance and attenuation of the P3 ERP component, which is associated with the effective orienting of attention (Escera et al., 1998, 2000). According to load theory predictions an increase in visual WM load should have resulted in increased distraction from the auditory stream, but this was clearly not the case.

However, Muller-Gass and Schröger (2007) used a uni-modal auditory distraction paradigm to demonstrate that distraction effects from task-irrelevant changes in an auditory stimulus increase with WM load when the relevant task involves discriminating between the durations of the same tones. SanMiguel et al. (2008) suggest that the key reason these two studies reach opposing conclusions is due to the relationship between the task-relevant stimuli and task-irrelevant distractors. In their study, the distractor stimuli were completely irrelevant to the main load task, so there was no response conflict between the two sets of stimuli and the participants "benefited" from reduced distraction under high WM load. Conversely, Muller-Gass & Schroger (2007) placed their distractor stimuli within the relevant WM load task, thus inducing conflict between the relevant and irrelevant stimuli. Under these conditions, increasing WM load leads to increase conflict between stimuli and decreased distraction. Once again, this mirrors the "indirect load" argument outlined by Rose et al. (2005), but this time in the auditory, rather than visual domain.

2.2.4 The Role of WM load in Awareness

This review of the WM/cognitive load literature has been concerned with the effects of WM load on unattended/ignored stimuli. The focus will now shift to literature that examines the impact of WM load on the processing of attended stimuli.

2.2.4.1 Inattentional Blindness

There is also evidence that increased visual WM load leads to suppression of activity in the right temporal-parietal junction and induces increased IB (Todd et al., 2005), suggesting that increased WM load results in attenuation of the stimulus driven attentional network (Marois et al., 2000; Corbetta and Shulman, 2002). This network is thought to be involved in the detection of relevant unexpected or highly salient visual stimuli, and is thought to act as a "circuit breaker" in that it directs attention towards the salient or unexpected stimuli (Corbetta and Shulman, 2002). Hence why suppression of this network induces increased inattentional-blindness. However, a recent behavioural study has demonstrated the opposite effect, in that increasing WM load can actually reduce inattentional blindness (de Fockert and Bremner, 2011). The authors suggest that the reason for the discrepancy in results may be because Todd et al. (2005) presented the unexpected stimulus in the retention interval of the low or high load WM task, meaning that WM load directly impacted on detection of the unexpected stimulus, and there was no competition between the visual stimuli presented as part of the load task and the critical stimulus. In contrast, (de Fockert and Bremner, 2011) presented a selective attention task (judging which of two lines is longer) interleaved between a WM task, and then presented the unexpected stimulus once at the side of the line judgement task, meaning that the paradigm tested the effects of WM on competition between the line judgement task and the unexpected stimulus. This argument is analogous to the indirect load argument and suggests that cognitive load theory only applies when the paradigm tests WM load effects on selection between two other tasks.

Furthermore, there is crossmodal evidence that increasing auditory WM load leads to increased inattentional blindness. (Fougnie and Marois, 2007) presented an unexpected visual stimulus while participants were engaged in a WM task that either required them to simply maintain a set of verbal information in WM (low WM load) or rearrange the material into alphabetical order (high WM load). They discovered that the likelihood of participants detecting the unexpected stimulus decreased under high load. The authors suggest that detection of unexpected stimuli in a typical IB paradigm is linked to central, amodal processing. Again, this study directly tests the effects of WM load on detection of an unexpected stimulus, so it may be a the case that a cross-modal version of de Fockert and Bremner (2011)'s paradigm, which tests the effects of WM load on a selective attention task that competes for attention with the unexpected stimuli, may demonstrate the opposite effect i.e. that auditory WM load increases the likelihood of detecting an unexpected object.

2.2.4.2 Visual Search

Woodman et al. (2001) demonstrate that visual search remains efficient when WM is full. However, Han and Kim (2004) have demonstrated that this is only the case when the WM task requires relatively straightforward storage of information, such as in the set/probe task. In a series of studies participants carried out visual search tasks while carrying out various different WM tasks that either required manipulation of the information held in WM (counting backwards from a target digit/sorting a sequence of numbers into alphabetical order) or just maintaining information held in WM (remembering a sequence of digits/letters). The authors demonstrated that although visual search remained efficient when the WM task just required storage, efficiency was reduced when the WM task required information to be manipulated. Evidence from Peterson et al. (2008) suggests that WM load leads to increased gaze durations, suggesting that increasing WM workload reduced the speed at which items are processed. Note that both these studies test unattended (no WM load) vs attended (WM load) conditions, therefore one must be cautious when drawing parallels between these findings and other studies on WM and attended/unattended stimuli processing.

2.2.4.3 Attentional Blink

The evidence for WM load effects on the AB is somewhat mixed, and this is important because (just like in the literature on IB and visual search) it highlights key differences between WM tasks that just require storage (such as the typical set/probe task used by Lavie and colleagues) when compared to WM tasks that impact more on processing capacity. Given that WM is implicated in the correct identification of targets in the AB, one might predict that loading WM with a set of items to be remembered prior to them carrying out an AB task would impact on the magnitude of the AB i.e. increased WM would impact on the time taken to process and consolidate T1 into WM, meaning that increased WM load would lead to a greater AB magnitude when T2 was presented 200-500ms after T1 (i.e. within the AB window). Akyürek and Hommel (2005, 2006) tested this by manipulating the effects of WM load on the AB using a WM set/probe task. On each trial they presented either two, four or six items to be remembered, followed by an AB task which required two target digits to be identified among a series of rapidly presented letters, and then finally a WM probe. The authors found that although WM load had an overall impact on both T1 and T2 accuracy, there was no WM load*lag interaction. However, (Akyürek et al., 2007) argued that the AB may result from limitations in WM processing capacity, rather than limits in storage, and that the set/probe paradigm used in these studies only loads WM storage capacity, which doesn't impact on the processing capacity. Accordingly, (Akyürek et al., 2007) devised a version of the set/probe/AB task that required participants to determine whether the T1 stimulus was part of the WM set. This task meant that the T1 stimulus had to be compared to the WM set, meaning that active processing of the data in WM had to happen during the trial, rather than in the previous studies where the WM set was just stored in memory. Under these task conditions the authors found that the number of items stored in the WM set did interact with lag in the AB task. The magnitude of the AB was was increased under high WM load when compared to low WM load. These results imply that WM can impact on the AB, but only if the WM task directly interferes with the AB task. Given that identification of targets in the AB requires conscious awareness of the stimuli, this suggests that WM load only impacts on awareness if there is some overlap between the two tasks. Further evidence that WM load impacts on the magnitude of the AB also comes from studies by Colzato et al. (2007) and Visser (2010).

2.2.5 A Generalised Theory of Load?

In addition to perceptual and cognitive load, the effects of various other types of load on selective attention have also been examined. Gläscher et al. (2007) used a similar paradigm to Rose et al. (2005), but in addition to varying object visibility and WM load, they included a manipulation of the emotional content of the background images. The images were either neutral (low emotional load) or highly negative (high emotional load). The authors predicted that the highly negative images would automatically capture attention and overcome the WM load modulation in the LOC that was seen in Rose et al. (2005). However, the data indicated that increased emotional salience had a general multiplicative effect on the processing of the images, with highly negative images being processed to a greater extent than neutral images regardless of the level of WM load. In another extension of the Rose et al. paradigm, Bingel et al. (2007) used an infrared laser to add the factor of acute concurrent pain (the laser delivered a "pin-prick-like" sensation) to the existing WM and image visibility factors, and found that increased pain had a similar general multiplicative modulatory effect on WM to that of increased emotional salience.

Klemen et al. (2010) suggest that that these findings concur with original perceptual load model, in that task-relevant stimuli, such as congruent distractors in a flanker task, are increasingly likely to attract attention and be processed if they are high in primary task-relevance. The authors propose that these studies provide converging support for a more generalised theory of load, where the effects of different types of load (perceptual, WM, emotional, pain), are all governed by a similar cognitive mechanism. According to this theory, an increase in the level of load in a relevant task results in reduced processing of task-irrelevant stimuli, regardless of the type of load. This contradicts the load theory of selective attention and cognitive control Lavie et al. (2004b), which suggests that perceptual load and cognitive load effects are diametrically opposed. However, throughout this section the paradigm differences in studies that support Lavie et al. (2004b) and studies that support a more generalised theory of load have been highlighted, so rather than being in competition, it appears more likely that the different accounts are just explaining WM load effects on different types of task processing.

The reasoning in the Klemen et al. (2010) paper is based exclusively on tasks that demonstrate that increasing WM load in an n-back task leads to reduced processing of unattended images. Interestingly, the evidence outlined in this section that measures WM load effects on visual search, AB and IB paradigms suggests that the generalised theory of load suggested by Klemen et al. 2010 may also account for WM effects on subjective conscious awareness. However, each of these studies is limited with regards to exactly what conclusions can be drawn from it. The research into IB can only account for the effects of WM load on unexpected stimuli. The visual search tasks all manipulate WM load by either requiring participants to attend/ignore a WM task while also performing a visual search task. Finally, WM effects have only been demonstrated in the AB when items in the WM set have to be compared with T1, meaning that there is competition between the WM and AB tasks for attentional resources. In order to accurately test whether the generalised theory of load proposed by Klemen et al. 2010 can fully account for the effects of WM load on attended stimuli, there needs to be a study that investigates the effects of WM load on awareness, using a WM task such as the n-back task to manipulate WM load without changing task demands, and employing a task that measures processing of fully attended stimuli.

2.3 Perceptual Load Theory and Fearful Stimuli

2.3.1 Emotional Stimuli

There is extensive evidence to suggest that the processing of emotional, highly salient visual information can be prioritised over the processing of more neutral information (seeVuilleumier, 2005, for a review). For example, face stimuli with fearful expressions have been shown to capture attention over and above faces with more neutral expressions; participants with relatively high levels of trait anxiety demonstrate an attentional bias towards faces with fearful expressions Fox (2002), and attentional focus can be guided to the location of a fearful face, even if the fearful face is initially outside of the focus of attention Eastwood et al. (2001). Visual search experiments have also demonstrated faster orienting and detection for fear-relevant threat stimuli, such as snakes and spiders. For example, snake and spider targets were detected more rapidly than fear-irrelevant targets when presented in a grid-pattern array Öhman et al. (2001), and recent evidence from change-blindness research also suggests enhanced detection of spider targets when these targets were presented as part of busy visual scene (Mayer et al., 2006). Threatening and emotional stimuli can also create an automatic and involuntary distraction which may impinge on visual processing. Snake-fearful participants find it difficult to search for a non-snake target if they believe a snake may be present in a visual scene (McGlynn et al., 2008), and briefly presented unpleasant images (e.g. depicting frightening animals, angry faces, accident scenes etc) can impair performance on a subsequent visual discrimination task (Hartikainen et al., 2000), despite the negative stimuli being completely task-irrelevant.

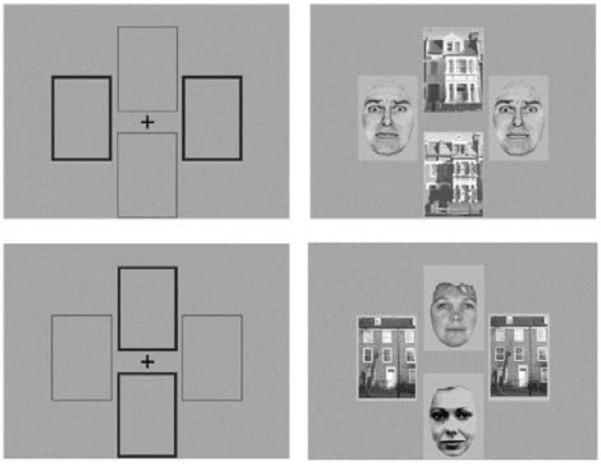
2.3.2 Does Perceptual Load Modulate the Processing of Emotional Images?

Whether or not perceptual load modulates the processing of emotional images is currently under debate. Load theory (Lavie, 1995) stipulates that the degree to which attended (task-relevant) stimuli create a load on perception is a critical factor in selection. If a relevant task consumes all attentional capacity (high load) then task-irrelevant stimuli are less likely to be processed, whereas if the task requires less attention (low load), then attentional capacity is not exhausted, thus allowing task-irrelevant stimuli to be processed. There is some evidence to suggest that load theory can be applied to emotional image processing i.e. high perceptual load can modulate distraction by emotional images. However, there is also contrasting evidence that suggests that there may be a "limit" to load theory, in that highly emotional images are able to overcome the effects of high perceptual load. Both sides or the debate are supported by various behavioural, fMRI and EEG studies which are described in the following paragraphs.

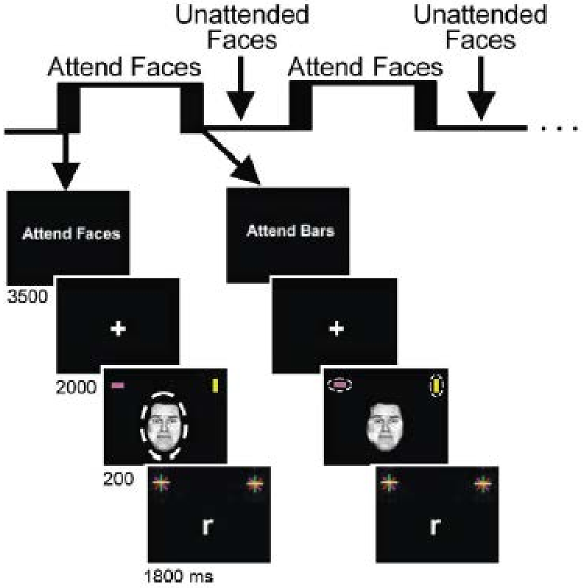
Note that the vast majority of research on load and emotional image processing covered in this thesis is concerned with *perceptual* load, rather than cognitive load; hence all references to "load theory" in this section are really just references to the passive perceptual load mechanism proposed by Lavie (1995), not the active cognitive control mechanism proposed by Lavie et al. (2004a). To my knowledge there are only a couple of studies that assess the role of cognitive control in emotional image processing (Doallo et al., 2006; MacNamara et al., 2011) - these are specifically discussed later in the thesis.

2.3.2.1 Evidence from manipulations of attentional task demands

Pessoa et al. (2002a) presented face stimuli (fearful, happy, neutral) at fixation flanked with a visual bar discrimination task and used fMRI to measure activation in brain regions that normally respond differentially to faces with emotional expressions, such as the amygdala. Participants were cued to either attend to the faces or attend to the bars. In trials where participants performed a gender discrimination task on the faces and ignored the bars, fearful faces were shown to evoke a more substantial amygdala response than the response to neutral faces.. However, when participants were required to perform the bar discrimination task and ignore the faces, the fearful faces did not elicit enhanced activation in fear-associated brain regions, suggesting that emotional processing of fearful faces is contingent on attentional capacity. These findings contrast with a study by Vuilleumier et al. (2001) that employed a very similar paradigm. Participants were required to attend to pre-specified locations and match images of faces (fearful/neutral) or houses that appeared randomly at either relevant or irrelevant locations. In this instance the amygdala response to fearful faces was not affected by whether or not participants were required to attend to the faces or not. Pessoa et al. suggest that the contrasting results may be due to differences in task difficulty. In the Vuilleumier et al. study when houses appeared in the pre-specified location and the faces were task-irrelevant, participants' image matching accuracy was 86%, which implies that the task may not have been demanding enough to sufficiently deplete participants' attentional resources. In contrast, mean accuracy at the Pessoa et al. bar discrimination task was 64%. This suggests that when the demands of the relevant task are very high, emotional image processing can be modulated. This also highlights the importance of using suitably difficult tasks when investigating the interaction between attention and emotion.



(a) Faces/Houses paradigm used byVuilleumier et al. (2001).



(b) Faces/Bars Paradigm used by Pessoa et al. (2002a).

Figure 2.7: Examples of neuroimaging attention/emotion procedures. In (a) participants were required to attend to pre-specified locations and match images of faces (fearful/neutral) or houses that appeared randomly at either relevant or irrelevant locations. In (b) participants were cued to attend to and perform either a gender discrimination task on the faces or an orientation discrimination task on the bars.

Holmes et al. (2003) also used the faces/houses paradigm as described above, but measured brain activity using electroencephalography (EEG) instead of fMRI. When attention was focused on the face pair an enhanced frontal positivity from 100ms onwards was seen in response to the fearful faces but not the neutral faces. However, in trials where attention was focused on the houses the enhanced ERP response to the fearful faces was eliminated. A further ERP study has also revealed that a late positive potential (LPP) commonly elicited after approximately 250ms was stronger in response to attended emotional than attended neutral faces (Eimer and Holmes, 2007). This LPP is often associated with highly valent and arousing positive and negative stimuli, such as mutilated bodies and erotic imagery (Olofsson et al., 2008) and can therefore be considered an index of affective response to emotive stimuli. However, when the face stimuli were presented with a concurrent fully attended bar discrimination task, the LPP effect in response to the emotional stimuli was eliminated (Eimer and Holmes, 2007), suggesting that spare attentional capacity is critical for the processing of emotional stimuli.

These patterns of results are not just limited to fearful face stimuli presented in the periphery. Wiens et al. (2011) presented participants with emotional and neutral images taken from the International Affective Pictures System (IAPS, Lang et al., 1999) at fixation, surrounded by a ring of six letters. In one condition participants pressed a button to indicate whether the picture that had been presented was the same as the one presented previously (the “attended images” condition), whereas in another condition participants pressed a button in response to the presence of a target letter (the “unattended images” condition). In line with the other findings, the authors report that the LPP was present while the the images were attended, but significantly reduced when the letter search task was attended. The Early Posterior Negativity (EPN), which is also associated with attention to emotional/arousing stimuli (Eimer et al. (e.g. 2003); Wiens et al. (e.g. 2011, 2012)) was also completely eliminated when the letter search was attended. Together, these studies provide converging evidence that spare attentional capacity is required for the processing of emotionally salient stimuli.

Critically however, none of the aforementioned studies really test whether high perceptual load of a relevant task can modulate the effects of emotional stimuli when compared to low perceptual load of a relevant task - instead they test whether "load" (concurrent task attended, emotional stimuli ignored) can modulate the effects of emotional stimuli when compared to "no load" (emotional stimuli attended, concurrent task ignored).

2.3.2.2 Evidence from manipulation of perceptual load

Erthal et al. (2005) and Pessoa et al. (2005) draw attention to the task differences between the "attended" and "unattended" conditions and question whether the comparison is fair, given that the different decision type associated with the tasks in each condition may compromise the interpretation of the imaging results (Compton, 2003). Okon-Singer et al. (2007) also highlight that it is critical that manipulations of task-relevance are differentiated from manipulations of attentional load, and that previous studies, like those mentioned above, may have confused them. For example, in Pessoa et al. (2002a) the "attended" condition required gender categorisation, whereas the "unattended" condition required bar discrimination; two very different tasks.

Pessoa et al. (2005) addressed this issue by presenting fearful and neutral face stimuli at fixation, flanked by a bar discrimination task that was manipulated between easy, medium and hard difficulty by manipulating the difference in orientation between the two bars. Critically, this manipulation meant that perceptual load could be manipulated between different degrees of difficulty *without* changing any of the other task demands. The authors found that an effect of image valence was observed in the right amygdala while participants were in the low perceptual load condition, but not while they were in the medium or high load conditions; suggesting that task-relevant perceptual load modulates the processing of unattended emotional faces in the amygdala. However, the use of faces as emotional stimuli in this study raised an important question with regards to the potency of the stimuli. Fearful faces are considered to be relatively weak emotional stimuli (Ochsner et al., 2002; Davidson and Irwin, 1999) and it could therefore be argued that this study merely demonstrates that distraction from weak emotional stimuli can be eliminated by high perceptual load. Perhaps more highly negative and arousing visual stimuli would be processed more automatically and therefore less susceptible to the effects of attentional load?

Accordingly, both the issues of different task demands and emotional image potency were addressed; first by Erthal et al. (2005) and later by Sand and Wiens (2011). Erthal et al. used a similar paradigm to Pessoa et al. (2005) i.e. the perceptual load of a bar discrimination task was manipulated between easy, medium and hard by varying the degrees difference in bar orientation - however, in their study highly negative and arousing images depicting accidents and mutilation were used in place of fearful faces. Given the “weak emotional faces” criticism of the preceding Pessoa et al. study it was necessary for Erthal et al.

to use the most emotionally salient images possible, and images of mutilated bodies are known to be rated as highly negative and arousing Lang et al. (1999). Participants were instructed to attend to the bar discrimination task and ignore the centrally presented image, thus allowing the modulatory effects of load on affective image processing to be directly assessed. Under low load the emotional images interfered with the bar discrimination task to a greater extent than the neutral images, as indexed by increased RTs to the bar discrimination task on negative image trials. Conversely, in the very high load condition the effect of the emotional images was eliminated, as indexed by no difference in RTs on negative and neutral trials. This suggests that emotional stimuli are only processed when there is the spare attentional capacity to do so, which suggests that the perceptual load model holds even in the face of distraction from highly potent emotional stimuli.

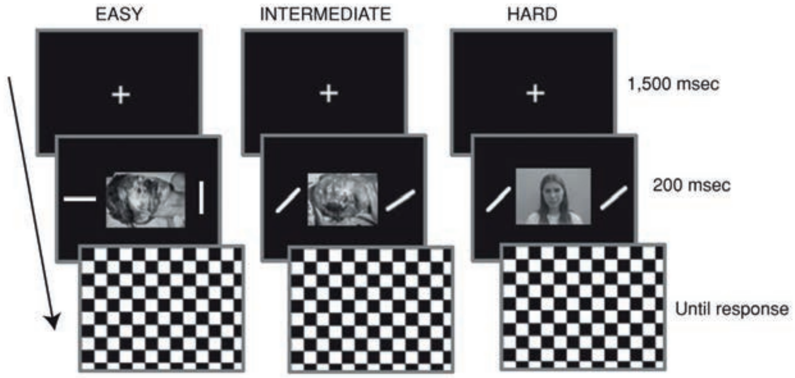


Figure 2.8: Examples of the low, medium and high load conditions in Erthal et al. (2005) paradigm (Experiment 2). In each trial a fixation point was presented for 1500 (±200)ms, followed by an image (either neutral or negative) which was flanked on either side by two bars, and finally a checker board mask, which remained on-screen until the participant made a response *or* 1500ms elapsed. Participants were required to respond as quickly and as accurately to the bars task by using the keyboard to indicate whether the bars with in the "same" or "different" orientation. They were told to ignore the image presented in the centre of the screen and to try and concentrate on the bars.

However, contrasting evidence comes from Sand and Wiens (2011) - they presented simple negative and neutral IAPS images at fixation surrounded by one, two or three letters ("simple" in the context of this study implied that a group of participants had rated the figure-ground composition of each image to simple, rather than complex). When participants were required to attend to the images, the EPN and LPP were apparent on negative image trials compared with neutral image trials. When participants were required to attend to the letter search task and ignore the images the LPP was reduced, but importantly when the perceptual load of the letter discrimination task was increased (by raising the number of distractor letters from one to three), neither the LPP or EPN were modulated any further, suggesting that in fact processing of the emotional content of images is not modulated by perceptual load. Mean accuracy dropped to 66.4%

in the high perceptual load condition, which confirms that participants found the high load condition very challenging (this is important, as a "high "perceptual load task must be sufficiently demanding to exhaust participants' attentional resources). The behavioural findings also support the ERP findings - the authors report no interaction effects of perceptual load and emotion for either the accuracy or RT data.

Finally, further support for the claim that there is a limit to load theory comes from Norberg et al. (2010) - they demonstrate that pictures of spiders (phobic stimuli) presented to spider fearful participants evoke a greater LPP than pictures of mushrooms (neutral stimuli), and that the magnitude of this LPP is not modulated by perceptual load.

2.3.2.3 Evidence for cross-modal perceptual load effects

Very few studies test whether emotional visual stimuli can impact on the processing of information in another sensory modality, namely audition. To recap, research on this topic with standard neutral stimuli is mixed. It has been demonstrated that the level of load in an attended auditory task has no impact on the processing of task-irrelevant (ignored) visual motion stimuli (Rees et al., 2001). In contrast, work by Yucel et al. (2005) where participants were required to engage in a continuous perceptuo-motor tracking task while ignoring a series of auditory tones that included infrequent pitch-deviant tones, demonstrated that while unattended deviant tones led to activation in the frontal and temporal cortex, this activation was reduced under high visual perceptual load, suggesting that load can modulate processing across modalities. There are no studies that directly manipulate the level of auditory load and test whether distraction from visual emotional stimuli is modulated under high load. However, Domínguez-Borràs et al. (2009) have shown that presenting participants with fearful faces can actually serve to enhance the processing of novel auditory stimuli, as indexed by increased activation in the superior temporal gyrus – a brain region commonly associated with novel stimulus processing (Bledowski et al., 2004; Downar et al., 2001). It is therefore possible that auditory perceptual load may interact with the processing of emotional visual stimuli, although this remains to be tested.

2.3.3 Is there a limit to load theory?

The research reviewed in the previous section is most relevant to perceptual load theory, as the tasks all involve perceptual load manipulations within the same task, rather than manipulations of attention between different tasks. More recent EEG studies by Sand and Wiens (2011) and Norberg et al. (2010) provide convincing evidence that, under certain conditions high perceptual load does not modulate distraction by emotional stimuli in the same way that it typically modulates distraction by neutral stimuli, indicating that there may be a limit to load theory. However fMRI and behavioural evidence from studies by Pessoa et al. (2005) and Erthal et al. (2005) suggests that high load can eliminate interference from task-irrelevant emotional stimuli.

The contradictory findings may result from a number of different factors. First, both studies that demonstrated a “breakthrough” effect (i.e. no load modulation) of the emotional images (Sand and Wiens, 2011; Norberg et al., 2010) used stimuli that were of simple figure-ground composition[3], and it is also important to take into consideration that the participants in Norberg et al. (2010) were being presented with highly salient phobia-specific stimuli. The fact that these studies used simple, potent stimuli is important, as it suggests that if an image is really obviously highly negative, then it may be able to have a stronger "break-through" effect under high perceptual load, compared to the relatively weak face stimuli used by Pessoa et al. (2005) or the more complex stimuli used by Erthal et al. (2005)[4]. Second, a whole host of other factors, such as the types of tasks used and spatial characteristics of the stimuli and timing may have contributed to the conflict.

Interestingly, although studies have manipulated attention between different unattended and attended emotional stimuli, and other studies have tested the effects of manipulating perceptual load on unattended stimuli, no study has tested whether perceptual load can modulate the distracting effects of attended emotional stimuli. Typically, a relevant attention task is presented along with a task-irrelevant emotional or neutral image, and an increase in RT in the attention task when presented with an emotional image is thought to indicate distraction by the emotional image. According to (Pessoa et al., 2005) and Erthal et al. (2005), if the perceptual load of the relevant task is high enough, then the emotional image no longer receives sufficient processing to have a distracting effect, hence why emotional images do not impact on RT under high perceptual load. However, these findings, and the evidence from neuroimaging, does not inform us about the extent to which these stimuli reach subjective conscious

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[3] In this context "simple figure-ground composition" means that each image contained a single item of interest and a relatively uncluttered background

[4] This issue of image complexity is explained in Chapter 4

awareness under high load. Furthermore, to my knowledge there are no studies that directly test whether high perceptual load can modulate processing across different sensory modalities.

2.4 Thesis Aims

Broadly speaking, the research presented in this thesis has three main aims. First, to directly test perceptual and cognitive load effects on the processing of fully attended stimuli. Second, to determine under what circumstances highly negative and arousing emotional stimuli are able to overcome the effects of perceptual load. Third, to test both perceptual and cognitive load effects both within and between different sensory modalities.

2.5 General Methods

2.5.1 Ethics and participant recruitment information

Ethical approval was obtained for all studies from the University of Sheffield Department of Psychology Ethics Board. Participants in all studies (with the exception of 5b, 5c, 5d, 5e and 5g) were undergraduates studying Psychology at the University of Sheffield who took part in the study in exchange for course credit. Participants in Studies 5b, 5c, 5d and 5e were postgraduate colleagues who volunteered to participate for no reward. Participants in study 5g were University of Sheffield Undergraduates recruited via a volunteers mailing list and paid five pounds for their participation. Participants signed a consent form before the experiment began and were fully debriefed at the end of the study. Each study used a new set of participants in order to avoid anyone being exposed to a set of images more than once. All participants reported having normal or corrected to normal hearing and vision and being non-dyslexic, native English Speakers.

2.5.2 Equipment

All experimentation took place in a quiet room with minimal visual distraction. A Sony 22" CRT monitor (resolution 1280x1024, Frame Rate 60 Hz) was used to display the visual stimuli, and auditory stimuli were presented through a pair of Sennheiser closed ear stereo headphones. Participants were always seated 60cm from the monitor screen. E-Prime Version 1.2 (Psychology Software Tools, Pittsburgh, PA) was used in all studies to present stimuli and log responses. A wired keyboard was used to record all responses in all the studies in Chapters 3 and 5. A combination of keyboard and PST Serial Response Box were used to record responses in Chapter 4.

2.5.3 Statistics

All data were normally distributed unless otherwise stated. Appropriate non-parametric tests were applied in all cases where the data were non-normal. The measures of effect size provided throughout this chapter are partial eta squared ($\eta_p{}^2$),(.01 is small, .06 is medium and .14 is large), and Cohen's *d,* (.2 is small,

.5 is medium, .8 is large), Field (2009). All error bars on graphs represent ± one standard error from the mean.

Chapter 3

Perceptual Load and Change-Blindness

The discussion in Chapter 2 (section 1.3) clearly indicates that the effects of perceptual load on subjective conscious awareness have only been tested in a handful of studies, (Beck and Lavie, as cited in Lavie, 2006; Cartwright-Finch and Lavie, 2007) and no study has tested load effects on task-relevant stimuli across different sensory modalities. The relatively new paradigms based on change and inattentional blindness may offer an interesting new way to directly test perceptual load effects on awareness, and given that the load task is independent and physically distinct from the awareness task, these paradigms would lend themselves well to a cross-modal load manipulation. Given the issues outlined earlier with the Cartwright-Finch and Lavie IB paradigm (it is limited to explaining the effects of load on unexpected stimuli, and awareness of the critical stimulus is measured by means of retrospective questioning) I decided to base the current study on the Beck & Lavie change detection paradigm, which directly tests visual perceptual load effects on awareness of a change.

To recap, Beck & Lavie presented a visual search task (either low or high perceptual load) at fixation, flanked by two faces. Participants were required to monitor the visual search display for a target "X" while also looking for a change in one of the flanking faces. In each trial the search task and the flanking faces would appear and disappear multiple times, and each change was interspersed with a brief blank display, thus creating a "flicker task" effect (Rensink et al., 1997). This effect induced a striking inability to detect changes, indicating that attention is indeed a key feature of change detection in this task. As demonstrated by Tse et al. (2003) and Tse (2004), change-blindness is useful for studying the spatiotemporal characteristics of attention as changes are only ever detected at attended locations; therefore change detection accuracy can be considered a measure of distribution of visual attention.

Before I go any further, I think it is important to consider that while the change-blindness flicker paradigm may offer a unique way to assess likelihood of change detection in a visual scene, this does not necessarily make it a straightforward measure of subjective conscious awareness per-se. While it may be the case that changes are only detected at attended locations; change detection also relies on the successful representation of and comparison between the two different versions of the visual scene that cycle in the flicker paradigm - processes that rely on visual short term working memory. Given the likely interaction between attention and memory when completing the flicker task, it is perhaps theoretically problematic to refer to this task as a measure of "visual attention" or "visual awareness". Accordingly, throughout the remainder of this thesis I will simply refer to the change-blindness flicker task as a measure of "change detection".

The Beck & Lavie paradigm is useful for testing the effects of visual perceptual load on change detection. It also appeared that this set-up could also lend itself well to cross-modality testing, so the current study was based on a similar design. The visual change detection task remained constant, but in order to test the effects of auditory perceptual load on change detection the visual perceptual load task was replaced with an analogous auditory task designed to create low or high load on auditory attention, thus enabling the effects of auditory and visual perceptual load on change detection to be directly compared. The auditory load task used in the current study was based on an auditory search task used by Dalton and Lavie (2007, 2004), where in each trial participants were required to monitor a short sequence of sounds for a target that was of lower frequency than the non-targets. The adaptation and load manipulation of this auditory task are discussed in more detail in the the methods section (3.4.2).

It was necessary to make some changes to the Beck and Lavie paradigm in order to make cross-modal testing viable. The original paradigm relied on participants engaging in the central visual search task, and thus keeping their eyes fixated on the centre of the screen. If the visual search task were swapped for a load task that required auditory attention, there would be no reason to fixate on the centre of the screen, and participants would therefore be free to move their eyes between the face images. Eye movements in the auditory load conditions could potentially impact on visual change detection performance, meaning that comparison with performance in the perceptual load conditions, where the eyes are more likely to remain centrally fixated, would not be possible. With this in mind, the paradigm was adapted so that full images of the type typically associated with the flicker paradigm were used (i.e. images depicting natural, often complex scenes). This meant that ensuring central fixation throughout each trial was no longer an issue.

Beck and Lavie cycled two face images interspersed with brief blank screens to create the “flicker” effect; in the current study a single full-screen image is presented interspersed with brief blanks. Whereas a change in the Beck & Lavie paradigm consisted of a new face appearing one side of the display, a change in the current study consisted of an object in the image either appearing/disappearing or changing colour. Again, this is more in line with the typical “flicker” paradigm (Rensink et al., 1997; Aginsky et al., 2000). In the visual perceptual load conditions search was for a target letter among non-targets that were overlaid across the image; in the auditory load conditions participants searched for a spoken target among non-targets. Load was manipulated by increasing the visual similarity of the non-targets to the target in the visual conditions, and by increasing the phonological similarity of the non-targets to the target in the auditory conditions. Importantly, regardless of the load manipulation, the change detection task remained consistent throughout.

This study is the first to investigate perceptual load effects on task-relevant stimuli both within and between different sensory modalities. Load theory suggests that under high visual perceptual load, attentional capacity is exhausted and other unrelated stimuli are less likely to be perceived. Beck and Lavie found that change detection accuracy declined under high visual perceptual load - a result that is in-line with the perceptual load model. It therefore follows that an increase in visual perceptual load in this paradigm should lead to reduced change detection accuracy. High load is also predicted to lead to an increase in change detection RT, as it is expected that the high load tasks will mean that participants have to view more image cycles before they spot the change.

It is harder to predict whether auditory perceptual load will impact on change detection accuracy or RT. The only study with a similar cross-modal design is Makovski et al. (2006) - they demonstrated that both visual and auditory task-relevant stimuli can disrupt change detection in a “one shot” change detection paradigm, where the visual or auditory distraction task was inserted in the gap between the pre and post change displays. Given that the current study also requires attendance to an auditory task while simultaneously attempting to detect a change, one might predict that requiring participants to perform the auditory load task in addition to the change detection task will have a negative impact on change detection performance. It follows that increasing the level of auditory perceptual load in the current study should further impact on change detection accuracy, although given that Makovski et al. (2006) did not manipulate the level of auditory load per-se in their study, it is difficult to make a firm prediction. High auditory load is also expected to impact on change detection RT as participants will have to view more image cycles in order to detect the change.

If auditory perceptual load does impact on change detection, this would contrast with Rees et al. (2001) which demonstrates that auditory perceptual load does not impact on visual motion perception. Furthermore, given that the load task and change blindness task are not associated (i.e. there is no response competition), it is highly unlikely that the reversal of the perceptual load effect seen in Tellinghuisen and Nowak (2003) cross-modal response competition paradigm will occur.

Study 3a - Stimuli Set Development

Ron Rensink kindly sent me through the set of change blindness images used in the original flicker paradigm paper (Rensink et al., 1997). I used these images in a pilot study when I first tested the load/change-blindness paradigm described above and it quickly became apparent that some of the images were unsuitable for the purposes of this study. This was because some of the more obvious changes in certain image can be detected very rapidly - for example, in one scene depicting a man paddling a canoe on some rapids, the colour of his life-jacket changes from blue to bright pink. For the new paradigm to work the changes needed to be more challenging to detect (the reason for this is explained in Section 3b). Furthermore, the images were produced in the mid 90s when computer display technology was still improving and memory was at a premium - hence the images are grainy and relatively low-grade (they most likely needed to be small files in order to be presented rapidly in the flicker paradigm on a mid 90s machine). While the images are certainly suitable for a standard flicker paradigm (no disrespect to the original authors intended!), I decided that for the purposes of this new hybrid load/flicker paradigm I would create my own set of images.

3.1 Method

3.1.1 Participants

10 postgraduate students (3 male, mean age = 24 years, SD = 1.8 years).

3.1.2 Design and Procedure

40 pairs of images were created to be used in the change blindness task. Image pairs consisted of the original image and modified version where an object either disappeared or changed colour (see 3.1 for examples). The original image (A) and the modified image (A') were cycled repeatedly on screen, interspersed with brief "flickers" (blank gray screens). Each image pair was cycled repeatedly in a flicker task (see Figure 2.1). Participants were required to monitor the cycling images and press space bar when they had detected the change. In order to confirm that they had correctly identified the change, participants were then required to click on the location of the change with the mouse. If the change remained undetected for 40 seconds the trial timed out and the participant was prompted to get ready for the next trial. The image pairs were presented in a randomised order and each participants attempted to detect the change in all 40 pairs.

In their 1997 paper Rensink et al. displayed each image for 240ms with an 80ms ISI (flicker). This rate of presentation was far too rapid for the new dual task paradigm, so while the ISI remained at 80ms, the image presentation duration was increased to 2600ms[1].

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[1] Pilot testing using the dual-task and some of the original Rensink et al. (1997) images suggested that these timings would be suitable for the dual task, so it also made sense to use them in the stimuli development pilot study.

Figure 3.1: Examples of change-blindness image pairs. In the first pair the tower crane on the right disappears. In the second pair the vehicle on the right changes colour from yellow to red.

3.2 Results and Discussion

Four image pairs were discarded because change detection was considered too difficult (less than half the participants successfully detected the change). The remaining 36 image pairs were divided into four image sets (labelled A, B, C and D) based on the data for change detection accuracy and reaction time. Every effort was made to ensure that the image sets were well balanced i.e. each set contained images ranging from easy to hard to detect. A one way repeated measures ANOVA with the within-subjects factor of set (A,B,C,D) confirmed that there were no significant differences between the four image sets in terms of change detection accuracy, F(3,7) = .04, p=.99, and reaction time, F(3,7) = .02, p=.99.

Image Set	Accuracy (% changes detected)	Reaction Time (s)
A	87.8	13.51
B	87.8	13.55
C	86.7	13.57
D	87.8	13.70

Table 3.1: Mean change detection accuracy and reaction times for the four sets of change blindness image pairs

Study 3b - Perceptual Load and Change Blindness

This section describes the development and implementation of a new paradigm that will allow the effects of visual and auditory perceptual load to be tested on change detection.

3.3 Participants

16 undergraduate students (2 male, mean age = 19.2 years, SD = 1.1).

3.4 Design

A 2 [load: low, high] x 2 [modality: visual, auditory] within participants design was used. The four conditions were completed in separate blocks, with nine trials in each condition. Four sets of nine change-blindness image pairs were created. A pilot study was performed to ensure that each of the four sets contained images matched for difficulty and speed of change detection. Each image pair consisted of an original image (image A) and a modified version where an object either disappeared or changed colour (image A'). Importantly, the image sets and presentation order were counterbalanced so that during the experiment each image set appeared in every load condition and order.

3.4.1 Visual perceptual load conditions

Each trial consisted of image A cycling with modified image A' interposed by an 80ms blank screen (flicker), and two sets of six pseudo-randomly positioned rectangles incorporating the six visual load task letters. The change blindness image subtended 35.1° x 28.5° visual angle, the rectangles subtended 1.91° x 1.91° visual angle and each letter subtended approximately 1.43° x 1.67° visual angle In the low load condition participants searched for a target letter X among five visually dissimilar distractor letter O's. In the high load condition, search was for X among five visually similar distractor letters (K, Y and V). Participants pressed the M key after each load task display to indicate "target present" or the Z key to indicate "target absent". The perceptual load tasks are based on the visual letter search tasks used by Lavie and Cox (1997).

3.4.2 Auditory perceptual load conditions

The auditory load conditions were designed to be analogous to the visual conditions. The auditory load tasks were based on an auditory search task used by

Dalton and Lavie (2004, 2007), where search was for a target defined by a different frequency, duration of intensity to non-targets. In the Dalton and Lavie experiments the sequence consisted of 5 sounds and target/non target duration varied between 100 - 300 ms in different version of the task. In the current study, every effort was made to make the auditory search task as similar to the visual search task as possible. Accordingly, sequences of six sounds were used, and search was for a spoken target letter among non-target letters. Each sound was played for 200ms, with a 50ms ISI (pilot testing revealed that this was the fastest possible presentation speed at which the spoken letters could be accurately discriminated). All sounds were presented at 72db. Auditory load was manipulated across conditions by requiring participants to search for a the target **D** among a set of homologous phonetically dissimilar non-target **O's** in the low load conditions, and for the target **D** among a set of hetrologous, phonetically similar non-target **P, B and E's.** As before, participants responded to the presence or absence of the target in each load task display by pressing the M or Z keys, respectively.

The auditory load task sequence was presented for the same duration as the visual load task (1600ms). In the auditory conditions the targets and distractors used in the visual load task were replaced with "dummy" stimuli to ensure that the amount of visual information on display remained consistent across visual and auditory load conditions. Auditory load was manipulated by asking participants to listen and respond to the presence or absence of the spoken target D amongst a set of five distractors. In the low load condition participants listened for a target D amongst dissimilar sounding distractor O's. In the high load condition, participants listened for D amongst pseudo-randomly drawn similar sounding letters P, E and B. As before, participants responded to the presence or absence of a target in each cycle.

3.5 Procedure

Participants were informed that they were about to take part in an experiment investigating the nature of the spatial distribution of attention. Full instructions were given and the participant was positioned 50cm from the screen. Prior to the main trials they completed a series of practice trials in order to help them get used to performing the various different tasks. First they were familiarised with the change detection task. Four example change-blindness image pairs (not images that were used in the main experiment) were presented in a flicker task and participants were required to detect the changes as quickly and accurately as possible. Then, prior to the visual and auditory conditions, they were given practice at performing the perceptual load task on its own (3 trials) and then finally practice at performing both the load task and change detection tasks concurrently.

3.5.1 Main Trials

All participants completed four blocks of nine main trials (low visual, high visual, low auditory, high auditory). Order was fully counterbalanced between participants. Each trial began with two presentations of either the visual or auditory perceptual load task (the aim of these preliminary displays was to ensure that participant was engaged in the load task prior to the onset of the change blindness images) followed by the simultaneous presentation of up to 16 load stimulus sets and 16 visual change detection cycles (8 each of Image A and A'), as detailed in Figure 1. Total trial duration and number of cycles seen per trial was contingent on change detection speed; if a participant failed to detect the change the trial ended on the 8th change cycle (total trial duration = 42.9 seconds). Throughout each trial participants pressed the "M" key to indicate "target present" and "Z" key to indicate "target absent" in response to each of the visual or auditory search tasks. They pressed space bar as soon as they detected the change in the image. When the space bar was pressed, the image then froze and the mouse was used to indicate the location of change. The next trial followed after a short pause. At the start of each block of trials participants viewed instruction screens providing details of the tasks and encouraging accuracy on the visual/auditory search tasks. Visual feedback (percentage accuracy of search task performance) and motivating messages e.g. "You are performing well on the search task, please keep this up", were also displayed after each trial, in order to encourage engagement in the load task. Pilot testing indicated that instructions and feedback were important for ensuring that participants fully engaged in the load task, as this was the key to successful load manipulation.

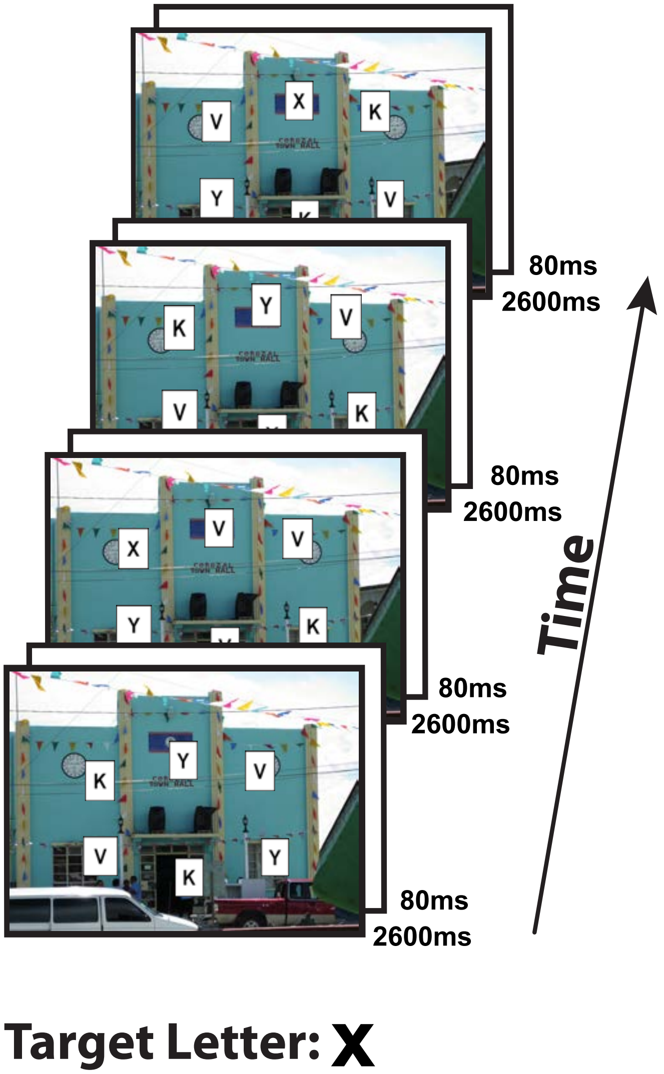

Figure 3.2: Example of trial procedure in the high visual perceptual load (unimodal) condition. The primary task was to monitor the visual search task for the target letter "X" while also attempting to detect the change between the two different versions of the image cycling on screen (in this example the occluded building disappears). High load conditions involved search for a target among visually similar letters; low load conditions involved search for a target among visually dissimilar letters.

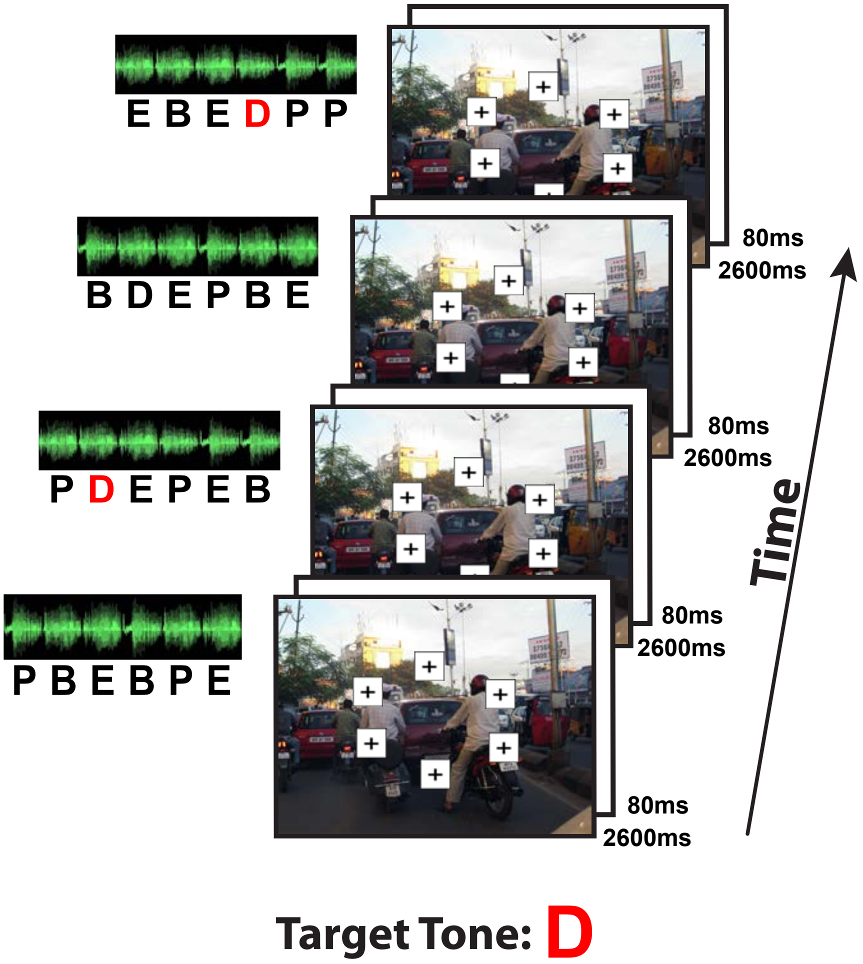

Figure 3.3: Example of trial procedure in the high auditory perceptual load (cross-modal) condition. The primary task was to monitor the auditory stimuli for the target letter "D", while also attempting to detect the change between the two versions of the image cycling on screen (vehicle on left changes colour from yellow to red). High load conditions involved search for a target among phonetically similar non-targets; low load conditions involved search for a target among phonetically dissimilar non-targets. Please note that the only purpose of the white boxes with "+" stimuli is to ensure that the amount of visual formation in these cross-modal conditions was as close as possible to the amount of visual information in the uni-modal conditions

3.6 Results

3.6.1 Load Task Analysis

2x2 repeated measures ANOVAs with the within-subjects factors of modality [visual, auditory] and load [low, high] revealed significant main effects of modality, F(1,15) = 11.57, $p<.01$, $\eta_p{}^2$=.44, load, F(1,15) = 32.98, $p<.001$, $\eta_p{}^2$=.69, and modality*load, F(1,15) = 5.85, p=.03, $\eta_p{}^2$=.28 for the load task accuracy data. Bonferroni corrected paired-samples t-tests confirmed that both the visual and auditory load manipulations were successful, t(15) = 5.52, 5.09, $p<.001$, respectively. There were also significant main effects of modality, F(1,15) = 107.21, $p<.001$, $\eta_p{}^2$=.88, load, F(1,15) = 75.47, $p<.001$, $\eta_p{}^2$=.83, and modality*load, F(1,15) = 39.95, $p<.001$, $\eta_p{}^2$=.73, for the load task RT data. Bonferroni corrected paired-samples t-tests also confirmed that both the visual and auditory load manipulations were successful, t(15) = 9.6, 2.95, $p<.01$, respectively. Participants made more errors and took longer to react to the targets in the high visual and auditory conditions, confirming that the load manipulation was effective.

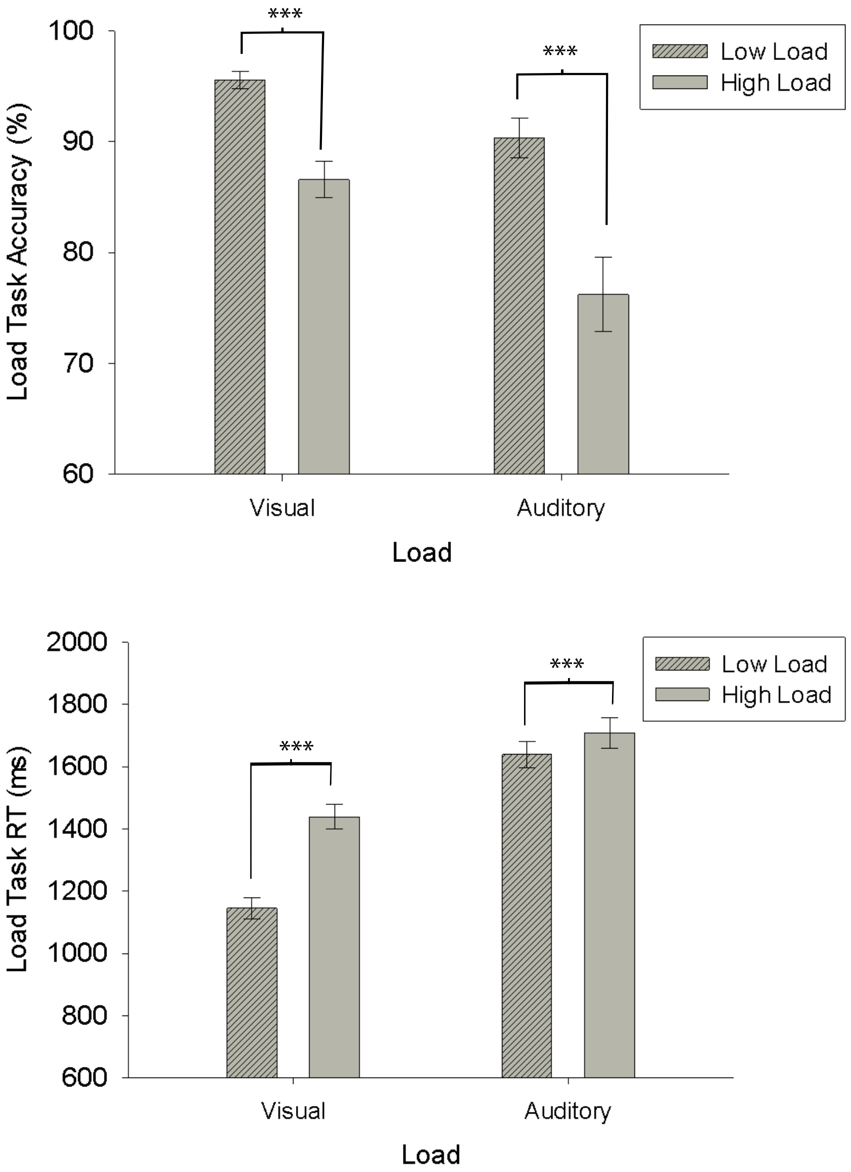

Figure 3.4: Mean load task accuracy and RT across low and high load conditions. ***$p<.001$

3.6.2 Change Detection Analysis

3.6.2.1 Change Detection Accuracy

A 2x2 repeated measures ANOVA with the within subject factors of modality [visual, auditory] and load [low, high] revealed significant main effects of modality, F(1,15) = 11.25, p=.004, $\eta_p{}^2$=.43 and load, F(1,15) = 9.62, p=.007, $\eta_p{}^2$=.39, but no significant load*modality interaction, F(1,15)=1.15, p=.30, $\eta_p{}^2$=.07. These results indicate that change detection accuracy was significantly reduced under conditions of both visual and auditory high perceptual load.

3.6.2.2 Change Detection RT

A 2x2 repeated measures ANOVA with the within subject factors of modality [visual, auditory] and load [low, high] revealed no main effects of modality, F(1,15) = 2.34, p=.15, $\eta_p{}^2$=.40, or load, F(1,15) = 1.64, p=.22, $\eta_p{}^2$=.10, but a significant modality*load interaction, F(1,15)=7.24, p=.02, $\eta_p{}^2$=.33. Paired-samples t-tests revealed that change detection was more rapid under low visual load than high visual load, t(15)=-2.18, p=.046, *d*=.79[2]. Change detection RT was not affected by auditory load, t(15)=1.04, p=.32, *d*=.28.

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[2] This statement assumes that the Bonferroni correction was not applied, given that these t-tests are planned comparisons rather than post-hoc t-tests.

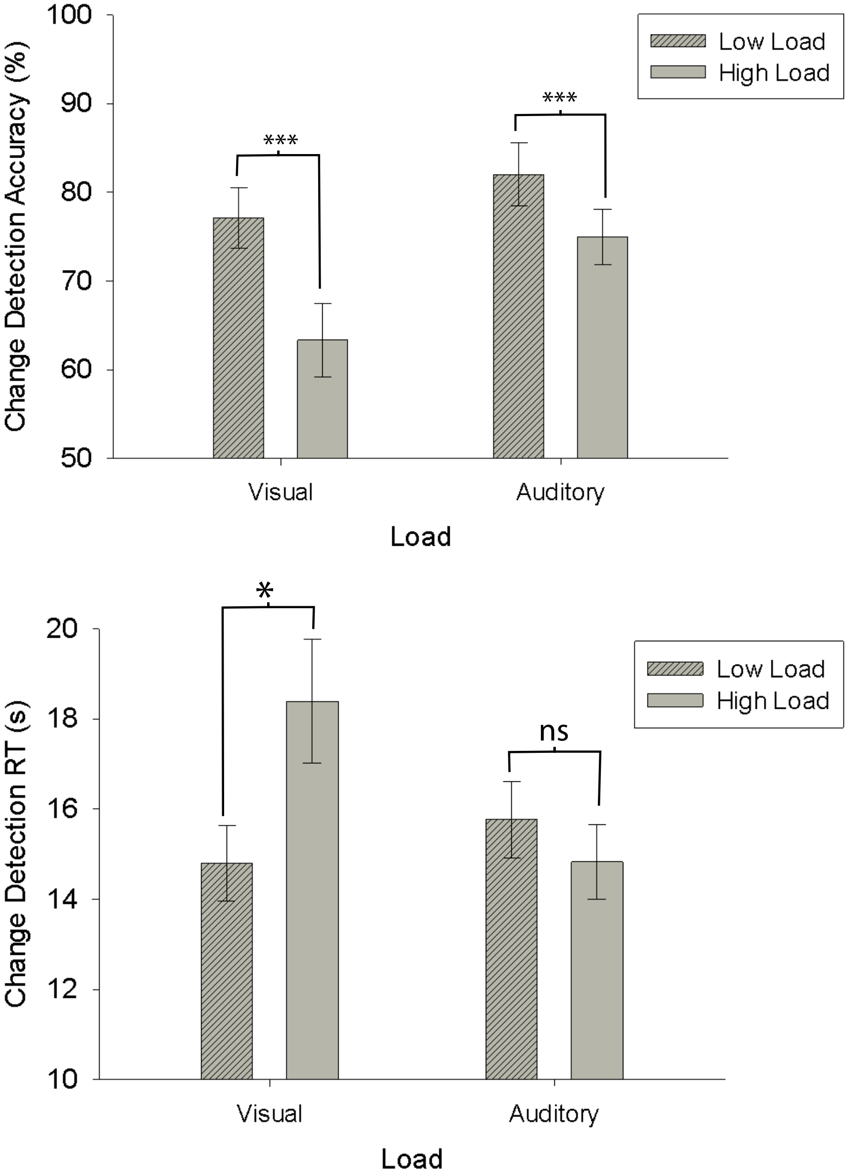

Figure 3.5: Mean change detection accuracy and RT across low and high visual and auditory load conditions. ***p<.001, *p<.05

3.7 Discussion

This study aimed to test the effects of visual and auditory perceptual load on change detection performance by using easy/hard target detection tasks to manipulate load and change blindness as a measure of conscious attendance to relevant stimuli. Change blindness was measured as both the number of changes correctly detected (accuracy) and change detection speed (RT).

3.7.1 Relationship to existing perceptual load literature

The results support the hypothesis that visual perceptual load can directly impact on change detection, as evidenced by a decline in change detection accuracy and an increase in change detection RT under high visual perceptual load when compared to low visual perceptual load. This result is in line with perceptual load theory, which predicts that when visual attentional capacity is exhausted under conditions of high perceptual load, fewer attentional resources are available to process task-irrelevant stimuli. In the present study it appears that the reduced visual attentional capacity under high load results in fewer changes being detected, and longer change detection RTs. The current findings concur with Beck & Lavie (as cited in Lavie, 2006), who also demonstrated evidence for reduced change detection accuracy under high visual perceptual load[3].

The results also offered some support for the hypothesis that auditory perceptual load can directly impact on change detection, as evidenced by a decline

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[3] Beck and Lavie relied on a retrospective measure of change detection (participants were required to indicate whether they had detected any changes at the end of each trial), so there is no measure of load effects on change detection RT, and hence our findings cannot be compared on this index.

in change detection accuracy under high auditory perceptual load when compared to low auditory perceptual load. However, unlike visual perceptual load, auditory perceptual load did not impact on change detection RT. This finding *tentatively* suggests that the effects of auditory perceptual load on task-relevant visual stimuli can also be accounted for by the perceptual load model, although the null effect of auditory perceptual load on change detection RT means that this finding is not as conclusive as it could be. However, the findings are in-line with the predictions for change detection accuracy based on Makovski et al. (2006), who also demonstrated that auditory load impacts on change detection accuracy. Makovski et al. (2006) presented their auditory task within the gap between pre and post change image displays. There is evidence that one of the factors that contributes towards CB is failure to compare representations of a scene across brief delays (Angelone et al., 2003; Varakin and Levin, 2006; Varakin et al., 2007), so the Makovski et al. (2006) study demonstrates that placing an auditory disruption between scenes increased change blindness. The current results complement this by also suggesting that high auditory perceptual load in a task delivered while the visual scene is being encoded, can also disrupt change detection in a similar way. Furthermore, whereas Makovski et al. compared the impact of task-irrelevant vs task-relevant auditory tasks on change detection, which is a task type manipulation in addition to a auditory perceptual load manipulation, the current results indicate that manipulating the level of auditory perceptual load alone is enough to impact on change detection.

As predicted, the auditory results are not in-line with Rees et al. (2001), who demonstrated that auditory load has no impact on the processing of task-irrelevant motion stimuli. This discrepancy may be due to big differences between our paradigms. Rees et al. (2001) tested auditory perceptual load effects on ignored motion stimuli - a task that does not require any specific attentional focus. In contrast, detecting a change between the two images required attention to be allocated specifically to the change (Rensink et al., 1997; Tse, 2004). It is possible that in the current paradigm high auditory perceptual load impacted on the processes involved in change detection, whereas high auditory load in Rees et al. (2001) had no effect on the ignored task, because it did not require similar cognitive processes. As expected, there were also no reversed perceptual load effects as seen in Tellinghuisen and Nowak (2003), probably because there was no interference in terms of response competition between the change blindness stimuli and load tasks.

3.7.2 Relationship to spatial cuing literature

The decline in change detection performance under high visual perceptual load in the current study is also consistent with findings from studies on spatial cuing, which demonstrate that exogenous cues are unable to capture attention under high visual perceptual load. In a study by Santangelo and Spence (2007), participants were required to discriminate the location of a peripherally presented target which was either preceded by a uni-modal visual or auditory cue, or a multi-sensory audiovisual cue, while under conditions of high visual perceptual load (attend to an RSVP stream presented at fixation and identify target digits), or no visual perceptual load (attend to a fixation point). The results indicated that while all three types of cue captured visual attention under low visual perceptual load, neither the uni-modal visual or auditory cues captured attention under high visual perceptual load, although interestingly, the multi-sensory audiovisual cues were able to overcome the effects of high perceptual load. Spence and Santangelo (2009) also describe similar effects of high visual perceptual load on uni-modal auditory, tactile and multi-sensory audiotactile stimuli - auditory and tactile cues were prevented from capturing attention, but the audiotactile cues were able to override the effects of high perceptual load. These findings from the cuing literature indicate that high visual perceptual load prevents the processing of explicit exogenous cues. Hence, it is perhaps not surprising that high visual perceptual load in the current study impacts on change detection, given that the exogenous cues that would normally indicate the presence of a change (the local motion transients) are dramatically reduced in the change-blindness flicker task due to the blank screens placed between the original and manipulated versions of the image (the global transients). These two areas of research converge to suggest that high visual perceptual load can significantly impact on visuo-spatial attention, both in preventing the processing of exogenous cues, and preventing change detection in a flicker-task. To my knowledge, there are no studies that test the effects of auditory perceptual load on uni-modal/multi-modal cues, so it is not possible to draw parallels between the current auditory load results and any existing cuing literature.

3.7.3 Methods Critique

There were a number of confounds with the current study. Attempting to match perceptual load task performance across the different modalities was problematic. The six letters forming the visual perceptual load displays were presented simultaneously, which meant that in a straightforward uni-modal paradigm like the one used by Beck and Lavie the display could be presented quite rapidly. However, the aim of the current study was to create an auditory perceptual load task that was analogous to the visual perceptual load task, and given that the six spoken letters in the auditory load task had to be presented sequentially, this meant that the speed of the flicker paradigm had to be considerably reduced in both the visual and auditory versions of the paradigm in order to accommodate for the extended duration of the auditory task. The long presentation duration of each image in flicker paradigm may have meant that participants had time to execute eye movements during each image presentation, and it is possible that there could have been more eye movements under low visual load than high visual load, given that the low load display was a feature search whereas the high load display was a conjunction search. Eye movements may have had a significant impact on performance, so ideally an eye-tracker would have been used to monitor eye movements[4] and check whether there was a discrepancy between conditions. Alternatively, the duration of the image presentations in the flicker paradigm could have been reduced to the point where and the ISI (blank screen) between images increased to accommodate for the longer presentation duration of the load task, although this probably would have made change detection exceptionally difficult.

Although eye movements potentially confound the visual perceptual load data due to differences in the type of search task between low and high load conditions, this was not the case in the auditory conditions, where the visual information presented on screen did not change between low and high auditory load conditions. Furthermore, in defence of the slow presentation rate of the flicker

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[4] Note that I didn't have access to a working eye-tracker when I ran this study

paradigm, a task with very similar stimuli timings was also used recently by Koustanaï et al. (2012). The authors intentionally reduced the presentation rate of the flicker paradigm in order to measure the precision of change detection, rather than measuring the effects of memorisation of two scenes. One might argue that a flicker task with longer display durations emphasises the uses of focused visual attention to detect the change; whereas a flicker task with shorter display durations, such as the original task used by Rensink et al. (1997) relies more on the building up of visual representations in the brain for each different version of the image (Vierck and Kiesel, 2008; Blackmore et al., 1995). The aim of the current study was to test perceptual load effects on awareness of change, rather than representation of changes in VSTM, so this suggests that a slow flicker task may have been a more appropriate measure than flicker task presented at the standard rate.

Another issue was that even though the load tasks in the different modalities did contain similar elements (i.e. both had one target letter and five non-target letters, and load was manipulated by making the non-targets more or less similar to the target), they were not entirely similar in nature, given that search in the visual load task was for a target among simultaneously presented non-targets, whereas search in the auditory load task involved monitoring the stream of letters for a target. Additionally, participant performance on the visual and auditory perceptual load tasks was not matched - both accuracy and RT varied between the two tasks, and overall performance in the auditory task was significantly worse than performance in the visual task. Reduced auditory load task performance, coupled with improved change detection performance under auditory load suggests that there may have been a trade-off between the two tasks i.e. participants may have allocated more overall attention to the change detection task in the auditory conditions when compared to the visual conditions. Ideally baseline performance data on the visual and auditory conditions would have been collected, so that these effects could have been further investigated. Furthermore, mean performance in the high visual load condition was still reasonably high (86% mean accuracy). It is likely that a more challenging visual load task would impact on change detection to an even greater extent than the load task in the current study, and lead to a more conclusive set of results. The high auditory load task was more challenging (75% mean accuracy), but this could also be made more difficult, in order to test whether change detection performance remains intact under conditions of very high auditory load.

3.8 Conclusion

In conclusion, these data suggest that load theory can account for the effects of visual perceptual load on change detection performance (both accuracy and RT). The data also tentatively suggest that load theory can account for auditory perceptual load effects on change blindness, although load only impacted on accuracy and not RT.

Chapter 4

WM Load and Change-Blindness

4.1 General Introduction

Literature relating to the role of working memory load in selective attention is reviewed in section 2.2. To recap, Lavie et al. (2004a) expanded perceptual load theory to account for the effects of task-irrelevant distractors on behaviour when the perceptual load of the relevant task is low and the distractors are still perceived. The authors noted that under low perceptual load, despite greater competition from the distractors (as indexed by increased RTs), participants were still largely able to respond accurately to the relevant task. This suggests the involvement of a separate cognitive control mechanism that involves higher executive functions, such as WM and response selection, and allows behaviour to be guided by task-relevant stimuli, rather than task-irrelevant stimuli. Lavie and colleagues (de Fockert et al., 2001; Lavie et al., 2004a) have demonstrated that under high WM load participants are subject to *more* interference in a flankers task, and this has lead to the claim that the effects of WM load are diametrically opposed to those of perceptual load i.e. while high perceptual load is associated with reduced distractor interference, high WM load is associated with increased distractor interference. Furthermore, Muller-Gass and Schröger (2007) demonstrate that this claim holds when tested within the auditory modality and Brand-D'Abrescia and Lavie (2008) have demonstrated both uni-modal and cross-modal effects of increasing cognitive load when task switching from a visual or auditory discrimination task to a selective attention (flankers) task. de Fockert and Bremner (2011) have also demonstrated that visual WM load can also increase the likelihood of detecting an unexpected stimulus, when the paradigm tests load effects on competition between a selective attention task and the unexpected stimulus.

The paradigms used by Lavie and colleagues typically test WM load effects on selection between relevant and irrelevant stimuli, hence these findings can only account for WM effects on selection in another task. However, evidence from other tasks that directly test the effects of WM load in a relevant task on the processing of task–irrelevant stimuli challenges the premise that WM load and perceptual load effects are diametrically opposed. These tasks typically involve participants engaging in an n-back task where WM load is increased by requiring the participant to match a target stimulus to another target presented n places back in the sequence while ignoring task-irrelevant stimuli. For example, Rose et al. (2005) have demonstrated that an increase in the level of WM load in an n-back task results in reduced processing of irrelevant background images. This effect has also been demonstrated cross-modally: for example, SanMiguel et al. (2008) and Klemen et al. (2010) both demonstrate that distraction from irrelevant auditory stimuli is reduced under high visual WM load. These results lead Klemen et al. (2010) to suggest a "generalised" theory of load, which suggests that an increase in WM load leads to reduced processing of task-irrelevant stimuli.

There is also evidence from various studies on visual search, IB (Todd et al., 2005; Fougnie and Marois, 2007) and AB (Akyürek et al., 2007; Colzato et al., 2007; Visser, 2010) which suggests that this generalised theory of load can also be applied to task-relevant stimuli. However, as outlined in section 2.2.5, there are limitations with regards to the conclusions that can be drawn from each of these studies in terms of how much they support the application of this generalised theory to task-relevant stimuli processing. Although it should be noted that although the surprise, retrospective recognition tests employed by Rose et al. and Klemen et al. do go some way towards providing a measure of the extent to which participants have become consciously aware of the task-irrelevant images under different levels of load, these measures are unexpected, indirect (there is no "online" behavioural measure of the extent to which the images are being processed), retrospective (the surprise recognition test happened at the end of the experiment, hence image recall required a memory component, and above all images are task-irrelevant (participants are instructed to ignore them). As it stands, no study has directly tested the effects of WM load on change detection using discrete WM and attention tasks and manipulating WM load demands without changing the nature of the task between conditions. Also, needless to say, no study has tested these effects across different modalities.

Accordingly, the aim of the studies presented in this chapter is to address the gaps in the literature outlined above. In Chapter 3 visual and auditory perceptual load tasks were presented concurrently with a change blindness task in order to measure perceptual load effects on change detection. Participants were able to cope remarkably well with performing the perceptual load tasks while simultaneously monitoring the background image for a change, and it appears that the flicker paradigm is a useful tool for measuring the effects of a visual or auditory task on another task that requires conscious visual processing. Accordingly, in the current chapter a novel set of experiments were designed to test the effects of WM load, rather than perceptual load, on change detection.

In keeping with previous studies (e.g. Rose et al., 2005; Klemen et al., 2010; Bingel et al., 2007; Gläscher et al., 2007) I decided to manipulate WM load both using visual and auditory n-back tasks - this allowed me to test WM load effects on change detection both within and between modalities. The n-back task was introduced in the late 1950s by (Kirchner, 1958; Mackworth, 1959). It is now considered to be the "gold standard" WM technique in cognitive neuroscience (Kane and Engle, 2002; Conway et al., 2005) and a meta-analysis by Owen et al. (2005) provides evidence that various versions of the n-back task consistently activate frontal and parietal regions of the cortex. It has also been demonstrated that systematic manipulation of WM processing load can be achieved by increasing n i.e. the number of places back in the sequence that a target has to be compared to (Jonides et al., 1997) . Both visual and auditory versions of the n-back WM task have already been demonstrated to be effective in terms of behavioural manipulation in studies by (Rose et al., 2005; Bingel et al., 2007; Gläscher et al., 2007; Klemen et al., 2010), so this seemed like the most appropriate form of WM manipulation to use. Furthermore, one can argue that the n-back task continuously taxes WM processes to a far greater extent than the

WM set/probe paradigm, which really tests storage and maintenance. Incoming stimuli have to be encoded and the new material has to be monitored and maintained in WM while also attempting to match new stimuli to stimuli presented n positions back in the sequence (Jaeggi et al., 2010). This is likely to be an important factor in determining whether or not WM load impacts on change detection, as research on the effects of WM on the AB has demonstrated that WM load only impacts on the AB if the WM load task requires active processing (Akyürek et al., 2007), rather than just storage, as in the set/probe paradigm (Akyürek and Hommel, 2005, 2006).

The following studies will effectively bridge the gap between research that has systematically manipulated WM processing load using n-back tasks to test load effects on task-irrelevant stimuli processing; and studies that have used a range of other WM load manipulations to test load effects on task-relevant stimuli. Study 4a tests auditory WM load effects on change detection, Study 4b improves on the paradigm used in study 4a, and finally study 4c tests the impact of visual WM load on change detection.

Study 4a - Auditory WM Load and Change Detection

4.2 Introduction

A novel experimental paradigm was constructed that incorporated elements of the change blindness “flicker” task (Rensink et al., 1997) and the auditory n-back task used by Klemen et al. (2010), to test the impact of auditory WM load on change detection. Participants performed an auditory 1-Back (low WM load) or 2-Back (high WM load) tone matching task, while simultaneously searching for a change between two images cycling on screen. Following the same logic as Klemen et al. (2010), the WM task was presented in the auditory modality in order to eliminate interference between the n-back stimuli and change-blindness stimuli at the perceptual level. This study is the first to investigate the effects of auditory WM load on task-relevant stimuli, and it is also the first to test whether the processes underlying change-blindness are directly affected by a manipulation of WM load.

Given that Klemen et al. have demonstrated that an increase in auditory WM load leads to reduced recognition of task-irrelevant images, Fougnie and Marois (2007) have demonstrated increased inattentional blindness under high WM load and (Han and Kim, 2004; Peterson et al., 2008) have demonstrated that visual search efficiency can be reduced under high auditory WM load, I predict that increasing auditory WM load in the current study will also lead to a decline in change detection performance in the flicker task, as indexed by reduced accuracy and increased RTs.

4.3 Methods

4.3.1 Participants

21 undergraduate students (7 males, mean age = 19 years, SD = 1.1 years).

4.3.2 Design

The study was a one-way design with a within subjects variable of n-back task difficulty [*1*-back, *2*-back].

4.3.2.1 Change-blindness Stimuli

Two sets of change-blindness image pairs were selected from the four sets that were put together in Study 2a. Sets A (mean acc = 87.78%, mean RT = 13.51s) and D (mean acc = 85.56%, mean RT = 13.70s) were selected, on the basis that these two sets were the most closely matched in terms of mean change-detection accuracy and reaction time. The images in each change-blindness image pair are referred to throughout this section as Image A (the original version of the image) and Image A' (the modified version in which an object has either been omitted or changed colour). Importantly, the two sets of images were counterbalanced between the different conditions of WM load in order to control for any differences in change detection difficultly between the sets. The change-blindness images were presented using the flicker procedure shown in Figure 4.1.

4.3.2.2 Auditory n-Back Task Stimuli

A set of 5 different tones were used to create the auditory n-back tasks. The tones (200, 400, 600, 800 and 1000 Hz) were identical in frequency and duration to those used by Klemen et al. (2010). These were created and matched for duration (500ms) and volume using “Audacity” sound editing software (http://audacity.sourceforge.net/). Pilot testing suggested that the lowest and highest tones (200 and 1000Hz) were considerably easier to identify as targets than the middle tones, therefore in order to control for this only the middle three tones (400, 600 and 800 Hz) were used as targets in the main study. The tones were presented via a pair of closed ear headphones using the procedure outlined in Figure 4.2.

4.3.3 Procedure

Participants were positioned 50cm from the screen and given a brief verbal overview of the two tasks and how the experiment would proceed over the next 45 minutes.

4.3.3.1 Breakdown of Trial Procedure

All participants were required to complete a block of low WM load trials (*1*-back task + change detection) and a block of high WM load trials (*2*-back task +change detection). The order that the blocks were presented in was counterbalanced between participants to avoid order effects. Each trial consisted of a maximum of 15 cycles – 3 *prep* cycles + 12 *main* cycles. The 3 initial *prep* cycles (consisting of 2 targets and 4 non-targets) were presented prior to the onset of the of the change-blindness image. The purpose of these trials was to fully engage the participant in the n-back WM load task and allow them to "settle into it" before introducing the change blindness task. The aim was to prevent participants from focussing all their attention on the change blindness task in the first few trials at the expense of the WM task, and possibly detecting the change while under no working memory load. Up to 12 *main* cycles (consisting of 10 targets and 14 non-targets) were then presented concurrently with the alternating change-blindness images. The onset of each tone coincided with the onset of each image (see Figure 4.1). The N-Back tasks were designed so that participants never encountered more than 2 consecutive targets and 3 consecutive non-targets per-trial, and also so that the number of "same" and "different" target responses remained consistent.

Each *prep* cycle: n-back tone > Blank > n-back tone > Blank
Each *main* cycle: n-back tone + Image A > Blank > n-back tone + Image A' > Blank

4.3.3.2 Breakdown of Experimental Procedure

Instruction screens were displayed at the beginning of the block with information designed to remind the participant about both tasks and the need for them to be as accurate as possible on the n-back task. Participants were instructed to position their left hand over the space-bar, and the index and middle fingers of their right hand over the first two buttons on the response box (labelled "same" and "different"). The experimenter ensured that the participant was positioned with their eyes approximately 50cm from the screen. The instructions then prompted the participant to press the spacebar in order to hear their target tone for the forthcoming trial (the target tone was varied randomly between trials). This was repeated in order to give the participant two chances to hear the target tone and reduce the likelihood of them forgetting the target while engaged in the trial itself.

The trial then began; participants were required to attend to the stream of tones and to only respond when they heard their target tone. WM load was manipulated by requiring participants to compare the target tone with a tone either n=1 or n=2 positions back in the sequence. Participants pressed the "same" key if their target matched the colour n positions back in the sequence, and the "different" key if their target was different to the colour n positions back in the sequence. They carried out this task using the index and middle fingers of the right hand. See figure 4.2.

Participants were also required to attend to the alternating change-blindness images and to press the space bar with their left hand as soon as they detected a change. Total trial length and number of cycles seen per trial were contingent on change detection speed and accuracy. If the participant failed to detect the change the trial ended on the 12th change cycle (40.3 seconds). However, if the participant detected the change, then pressing the spacebar immediately brought the trial to a halt. The image froze on screen and the participant used the mouse to indicate the change location. The next trial followed immediately, with an instruction screen requiring the participant to press the spacebar to hear the new target-tone for the next trial.

Participants received visual feedback on their N-Back performance after every two trials. Scoring over 75% resulted in the following message being displayed: "Well done, you are performing at XX% accuracy on the N-Back task, please keep this up"! If they were scoring at less than 75% this resulted in the following message: "You are performing at XX% accuracy on the N-Back task - please try to be more accurate"! Pilot testing (and prior experience working with the perceptual load task in Study 2b) indicated that instructions and feedback were highly important for ensuring participants fully engaged in the WM load task, in order to ensure successful WM load manipulation. The image sets and presentation order were fully counterbalanced so that during the experiment both image sets appeared in every load condition and presentation order.

All participants completed both different conditions of WM load (*1*-back and *2*-back). Order of presentation was counterbalanced between subjects.

4.3.3.3 Practice Trials

Participants were familiarised with the change detection task at the beginning of the experiment. They were given 4 example change-blindness image pairs taken from the set of images used by Rensink et al. (1997) and instructed to detect the changes as quickly and as accurately as possible. Then, prior to each of the main conditions they were given practice at performing the n-back task on its own (2 trials), and practice performing both the n-back task and change-detection task concurrently (3 trials).

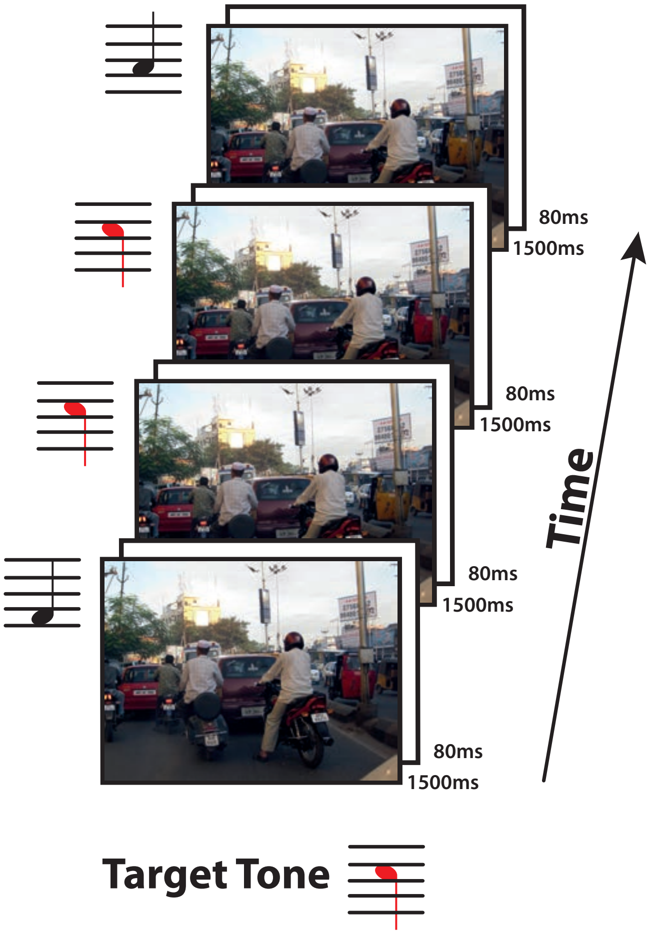

Figure 4.1: Example of concurrent *1*-back tone matching task and change detection "flicker" tasks. The target tone was presented to the participant at the start of the trial and then their task was to monitor the sequence and respond *only* when they hear the target tone. If the target was *different* to the tone one position back in the sequence they pressed the button labelled "different". If the target was the *same* as the tone one position back they pressed the button labelled "same". Participants were also required to look for a change between the two images and press the space bar as soon as they detected it.

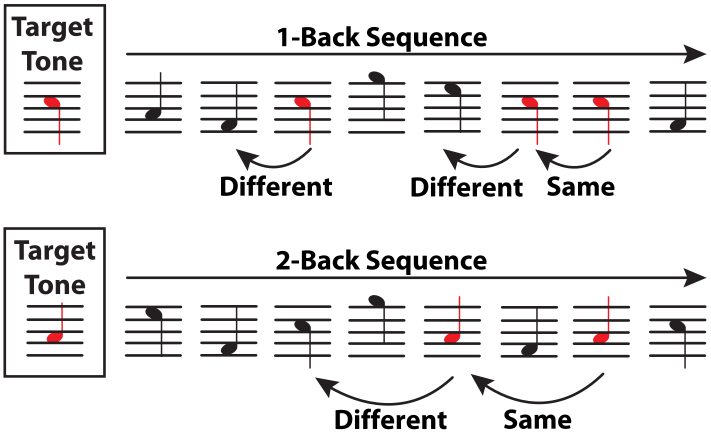

Figure 4.2: Examples of the auditory *1*-back (low load) and *2*-back (high load) procedures. Please note that the musical tones (D,F,A,C,E if one assumes treble clef notation) used in these diagrams are just for illustrative purposes only, these are not meant to represent the frequencies of the actual tones used in the study (200, 400, 600, 800 and 1000 Hz).

4.4 Results

Four participants were excluded from all further analysis due to exceptionally poor performance on the high load task (the reason for this and exclusion criteria for this are explained in the next section).

Throughout this section the *1*-back and *2*-back conditions are referred to as the low and high load conditions, respectively.

4.4.1 Load Task Performance Analysis

Responses to *n*-back targets in the *prep* cycles were not included in the analysis, as participants were not engaged in both the WM and change detection tasks during these cycles[1]. Paired samples t-tests on the *main* trial accuracy data revealed that participants were more accurate at the low load task than the high load task, t(16) = 5.68, $p < .001$, d=1.39. Responses were also more rapid on the low load task than the high load task, t(16) = 3.68, p=.002, d=.90 These results indicate that participants found the high load task more demanding, which confirms that WM load was successfully manipulated between conditions.

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[1] This rule was also applied to subsequent load task analyses in Studies 4b and 4c

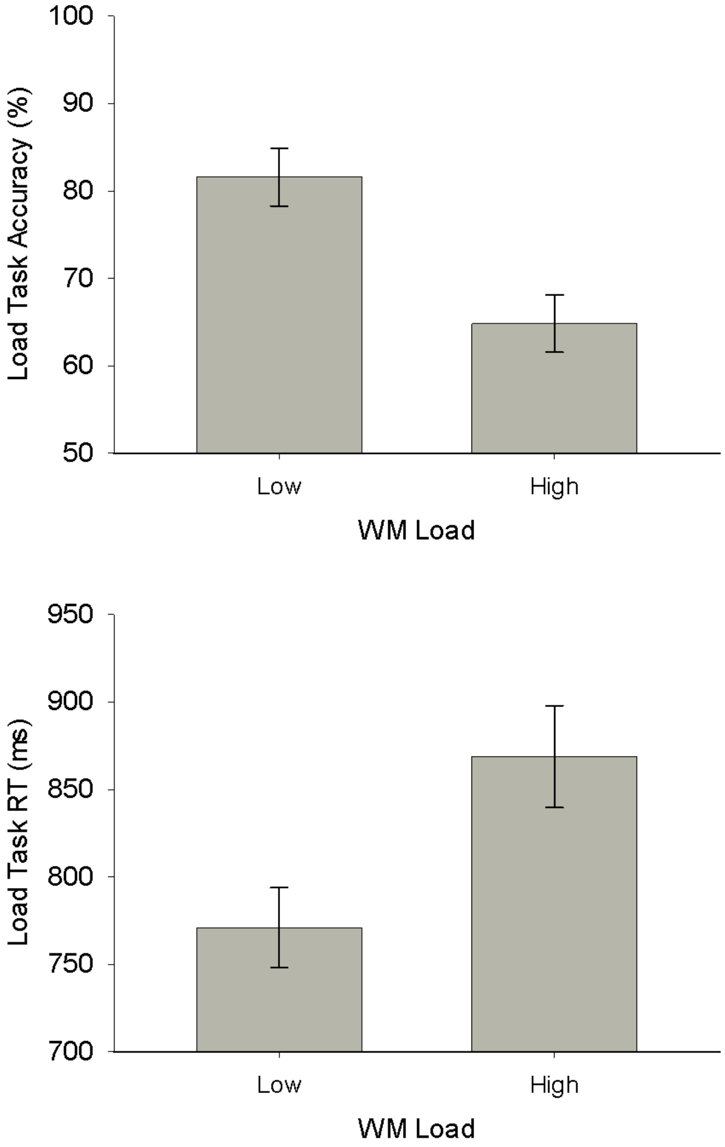

Figure 4.3: Mean accuracy and RT on auditory WM load tasks across low (*1*-back) and high (*2*-back) conditions.

Inspection of the data revealed that on some trials participants' load task accuracy was very poor, which suggested that they may not have engaged properly with the n-back task on certain trials and thus the WM load manipulation cannot be confirmed. It was necessary to exclude these trials from any further analysis. An inclusion criterion was applied to the dataset whereby a trial was only included in further analysis if the participant scored 67% accuracy or above on the n-back load task. This ensured that only trials in which participants were definitely subject to load demands were analysed. The criterion was set at 67% as this was the same load task accuracy criterion used by Cartwright-Finch and Lavie (2007) in their inattentional blindness & perceptual load paradigm. A score for proportion of trials that achieve 67% accuracy or greater was calculated for the low and high load conditions for each participant. The reason that four participants were excluded from this entire analysis was primarily due to exceptionally poor performance on the high load task (they achieved 67% accuracy in less than 3 out of 9 possible trials).

4.4.2 Change Detection Task Analysis

A score for *change detection accuracy* was calculated, based only on trials in which the 67% accuracy criterion had been achieved. In other words, if a change was detected on a particular trial, it only counted towards the change detection accuracy score if performance on the n-back task had reached the 67% accuracy criterion. This resulted in a score out of a possible maximum of 9 for each condition.

This score was then divided by the score for *number of trials that achieve the 67% accuracy criterion,* in order to obtain a figure to represent the proportion of changes detected in each condition while accurately performing the WM load task. Mean change detection RT was also calculated for each condition, based on RTs from trials where the change was successfully detected and the 67% *n*-back accuracy criterion was achieved.

Paired samples t-tests revealed that the level of WM load did not significantly impact on change detection accuracy, t(16) = .22, p=.83, *d*=.03, or reaction time, t(14) = .99, p=.34, *d*=.27.

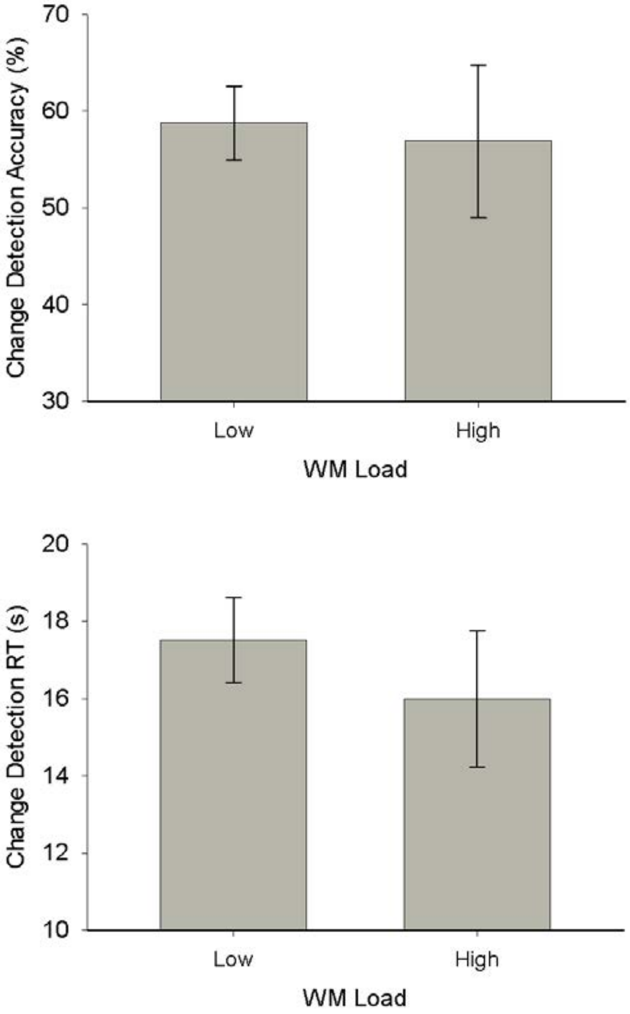

Figure 4.4: Mean change detection accuracy and RT across low and high auditory WM load conditions.

4.5 Discussion

The aim of the study was to test the effects of auditory WM load on visual change detection using 1-back (low load) or 2-back (high load) auditory tone matching tasks to manipulate WM load, and a change-blindness "flicker" paradigm as a measure of conscious attendance to relevant stimuli. WM task performance was measured in terms of correct target comparisons (accuracy) and speed of comparison (RT). Change-blindness performance was measured in terms of total changes detected (accuracy) and speed of change detection (RT). The results indicate that WM load was manipulated successfully between low and high load conditions; demonstrated by significantly reduced accuracy and increased RTs in the high load condition. This increased load had no impact on change detection accuracy or reaction time, suggesting that under these experimental conditions, change detection performance is not modulated by an increase in auditory WM load.

However, given that mean accuracy was 80% and 67% on both the low and high load tasks respectively, this suggests that participants actually found both tasks quite demanding i.e. both tasks actually imposed a relatively high level of WM load. Although the low and high load conditions were designed to be as identical as possible to the tasks used by Klemen et al. (2010) (they also used *1*-back and *2*-back tasks in their low and high load conditions), it is possible that participants may have found the tasks considerably easier in their study because as Klemen et al. only required participants to carry out the n-back task and ignore the images, whereas the current study also requires participants to attend to the images[2]. In the current study, the "low" load task may have been too demanding, and although the load manipulation was successful, the distinction between low and high load tasks may not have been great enough to have a significant impact on the number of image changes detected in each

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[2] Unfortunately Klemen et al. do not provide error rates in their article, so I am unable to compare performance between our studies.

condition. In order to address this concern, a less demanding "*0*-back" load condition will be incorporated into the design of a follow up study, where the only task requirement is to detect the target tone when it appears in the sequence (i.e. there is no matching of the target to a tone so many places back in the sequence).

Furthermore, in the current paradigm the length of each trial was contingent on how rapidly the participant detected the change, if they were able to detect the change at all. The issue with this aspect of the design was that participants who were faster and more accurate at the change detection task would have been subject to less overall cognitive load demands throughout the entire experiment. For example, if participant X detected 16 changes with a mean RT of 10 seconds and participant Y only detected 6 changes with a mean RT of 18 seconds, then participant X would be subject to significantly lower cognitive load demands over the course of the experiment than participant Y. This may have impacted on the outcome of the study. Accordingly, the paradigm will be modified for the follow-up study, so that when a change is detected, the n-back tone matching task will continue until the trial times out. This will mean that every participant will be subject to the same WM load demands over the course of the experiment, regardless of how they perform at the change-detection task.

In the current paradigm, the duration of the *main* part of each trial (not including the *prep* trials) was close to 40 seconds, as this was the timing originally used by Rensink et al. (1997). However, the average time taken to detect a change was 16.9 seconds, and it is clear from Figure 4.4 that most change detection responses are made well within 20 seconds. Therefore, in a the follow-up study the duration of each *main* trial will be reduced to 20 seconds. This will reduce the overall duration of each condition, which is important to minimise fatigue/boredom effects, especially considering that an extra *0*-back load condition will also be added.

Performance on the n-back task was quite poor throughout the study, which resulted in a lot of trials being eliminated from the final analysis as they were below the 67% accuracy criterion. This will be addressed in the follow-up study by increasing the total amount of practice each participant receives. Furthermore, in order to make the n-back task more manageable across all conditions, the duration of each tone will be increased from 500ms (the duration previously used by Klemen et al. (2010)) to 1500ms. This will mean that the duration and onset times of both the tone and image will be identical.

Study 4b - Improved Auditory WM Load and Change Detection Paradigm

4.6 Introduction

The main aim of study 4b was to address the theoretical and methodological flaws with this paradigm that are outlined in the discussion section of Study 4a. The predicted outcome was the same as before i.e. that increasing WM load would lead to a decline in change detection performance, as indexed by reduced accuracy and increased RT.

4.7 Methods

4.7.1 Participants

21 new undergraduate students (5 were male, mean age = 18.9 years, SD = 1.1 years).

4.7.2 Design

The study was a one-way design with the within subjects variable of n-back task difficulty [*0*-back, *1*-back, *2*-back].

4.7.2.1 Change Blindness Stimuli

3 new sets of 10 change blindness image pairs were assembled from the existing set of 36 images. This slightly increased the number of trials in each condition. The three sets of image-pairs were balanced for change detection difficulty (based on how difficult the changes in each image were to detect in the pilot study). As before, the image pairs are referred to throughout this section as Image A and Image A' ("A" is the original version of the image. "A'" is the modified version in which an object has either been omitted or changed colour). The three sets of images were counterbalanced between the different conditions of WM load in order to control for any differences in change detection difficultly between the sets. The change-blindness images were presented using the same procedure as in procedure shown in Figure 4.1

4.7.2.2 Auditory *n*-back stimuli

The 5 tones (200, 400, 600, 800, 1000 Hz) that were used in Study 4a were also used in the current study. The duration of the tone stimuli was increased to 1500ms (the same duration as the image was presented for) in order to give participants more time to listen to and process each tone. It was hoped that this would help improve accuracy on the *n*-back tasks, meaning that fewer trials would need to be discarded from the analysis as a result of poor performance. The serial response box used in the previous study was unavailable - instead responses were made using keys on the numberpad (“1” = Same, “2” = Different). Stimuli were presented via a pair of closed ear headphones

4.7.3 Procedure

4.7.3.1 Description of Trial Procedure

Each condition consisted of a block of 10 trials all at the same difficulty level (0-back, 1-back or 2-back).

Each trial consisted of 10 cycles – 3 *prep* cycles + 7 *main* cycles. The 3 initial *prep* cycles (consisting of 2 targets and 4 non-targets) were presented prior to the onset of the of the change-blindness image. 7 *main* cycles (consisting of 6 targets and 8 non-targets) were then presented concurrently with the alternating change-blindness images.

4.7.3.2 Description of Main Experimental Procedure

The experiment followed the same procedure as Study 4a (outlined in Section 4.3.3.2) for both the *1*-back and *2*-back conditions. In the new *0*-back condition participants were just required to press the "1" key in response to a target. This condition still invoked a WM component (participants had to memorise the target tone at the start of each trial and compare this to the tones presented in the sequence), but did not require a "same/different" judgement like in the *1*-back and *2*-back conditions. See Figure 4.5 for an example of the *0*-back task.

As before, participants were also required to attend to the alternating change-blindness images and to press the space bar with their left hand as soon as they detected a change. This response was logged, but unlike the previous study (where the trial ended after the change had been detected), in the current study the trial continued for the full 10 cycles and the participant continued to carry out the WM load task. The reason for this was to ensure that the total amount of cognitive load was consistent for all participants across all trials. After the trial timed out, participants were then presented with a new target, and the process was repeated. See figure 4.8

All participants completed the three different conditions of auditory WM load (*0*-back, *1*-back and *2*-back). Order of presentation was counterbalanced between subjects.

4.7.3.3 Practice Trials

As before, participants were familiarised with the change detection task at the beginning of the experiment. They were given example change-blindness image pairs taken from the set of images used by Rensink et al. (1997) and instructed to detect the changes as quickly and as accurately as possible. Then, prior to each of the main conditions they were given practice at performing the n-back task on its own (5 trials), and practice performing both the n-back task and change-detection task concurrently (3 trials). The number of practice trials was increased relative to Study 4a, in order to better ensure that participants were competent at the tasks before they completed the main trials.

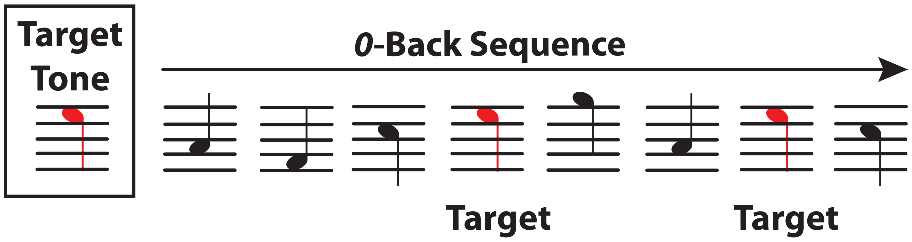

Figure 4.5: Example of the Auditory *0*-back task. Participants were just required to press the “1” key in response to a target.

4.8 Results

I realised after finishing data collection that left-handed participants may have been at an unfair disadvantage in this study as the keyboard response keys were specifically set up for right-handers (i.e. the continuous, demanding n-back task responses were made with the right hand, whereas the relatively simple change detection responses were made with the left hand). The decision was therefore made to exclude the one and only left handed participant from further analyses. One participant was excluded as they had previously taken part in a pilot study and had already seen the change-blindness image-pairs (hence they were not naive to the location of the changes). Another participant was excluded due to poor performance on the n-back task in the *1*-back condition relative to the rest of the sample (their score was over two standard deviations from the mean).

Load task accuracy in the medium load condition was negatively skewed, as was the measure of critical total possible trials, which was negatively skewed in the low load and medium load conditions due to a majority of participants scoring at or close to ceiling. However, the main data of interest (change detection accuracy and RT) were all normally distributed. ANOVA and t-tests are regarded to be robust to violations of normality, so these are the primary tests that are reported in the results sections of the current study and also study 4c. As a precaution, when a measure violated normality assumptions the non-parametric equivalent tests (Friedman's ANOVA and Wilcoxon Signed Ranks Test) were also used. In all tests the results of the non-parametric tests concurred with the results of the parametric tests.

For the remainder of this chapter (studies 4b and 4c) the 0-back, 1-back and 2-back conditions will be referred to as "low load", "medium load" and "high load", respectively. Note that this is different from the previous study, where "low load" refers to the 1*-back condition.*

4.8.1 Load Task Performance Analysis

Following the same procedure as Study 4a, responses to *n*-back targets in the *prep* trials were not included in the analysis, as participants are not under dual-task load while engaged in these trials. A one-way repeated-measures ANOVA on the *main* trial load task accuracy data revealed a main effect of load task difficulty, F(2,34) = 14.21, p<.001, $\eta_p{}^2$=.46. Paired samples t-tests confirmed that responses to the load task were more accurate under low load than high load, t(17) = 4.23, p=.001, *d*=1.04 , and more accurate under medium load than high load, t(17) = 4.26, p=.001, *d*=1.07. Accuracy did not differ between the low load and medium load tasks, t(17) = -.23, p=.82, *d*=.12.

A one-way repeated-measures ANOVA on the *n*-back RT data also revealed a main effect of load task difficulty , F(2,34) = 11.16, p<.001, $\eta_p{}^2$=.40. Paired-samples t-tests confirmed that RTs on the load task were more rapid under low load than under medium load, t(17) = 4.81, p<.001, *d*=1.14 and more rapid under low load than high load, t(17) = 2.78, p=.01, *d*=.65. RT did not differ between medium and high load conditions, t(17) = 1.76, p=.10, *d*=.42.

The data suggest that the *overall* WM load manipulation was a success, in that participants were more accurate and faster to respond under low WM load (*0*-back) than high WM load (*2*-back). The introduction of the *0*-back task appears to have had the desired effect, in the sense that it is easier than the *1*-back task (i.e. responses to *0*-back target tones were significantly faster than to *1*-back target tones). However, accuracy did not differ between the *0*-back and *1*-back conditions, and RT did not differ between the *1*-back and *2*-back conditions, meaning that the intended low > medium > high graduated load increase did not work out exactly as expected. The implications of this are discussed at the end of this chapter.

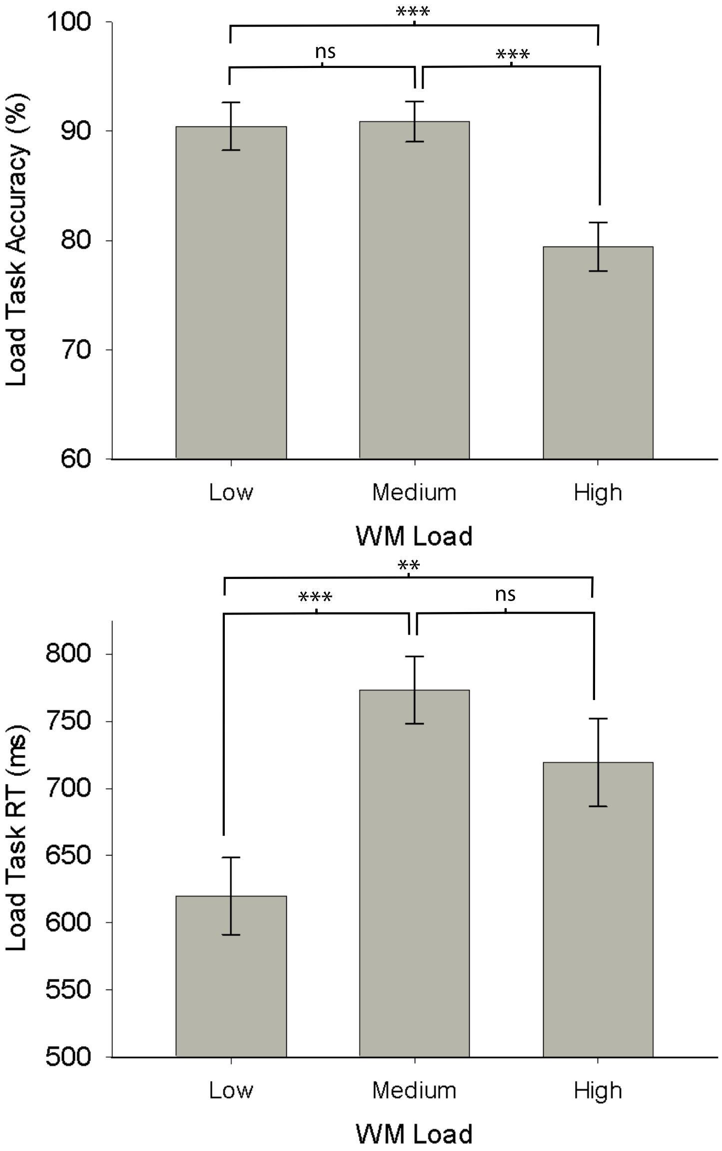

Figure 4.6: Mean accuracy and RT on auditory WM load tasks across low (*0*-back), medium (*1*-back) and high (*2*-back) conditions. ***p<.001, **p<.01

Following the same procedure as in Study 4a, an inclusion criterion was applied to the dataset whereby a trial was only included in further analysis if the participant scored 67% accuracy on the n-back load task. This ensured that only trials in which participants were definitely subject to load demands were analysed. A score for number of trials that achieve 67% accuracy or greater was calculated for the low, medium and high load conditions for each participant. It was not necessary to exclude any participants this time, which suggests that the n-back tasks were generally more manageable than in Study 4a i.e. the length of the n-back tones was increased and participants were given more practice trials prior to the main study.

4.8.2 Change Detection Task Analysis

Following the same procedure as in Study 4a, a score for *change detection accuracy* was calculated, based only on trials in which the 67% accuracy criterion had been achieved. In other words, if a change was detected on a particular trial, it only counted towards the change detection accuracy score if performance on the n-back task had reached the 67% accuracy criterion. This resulted in a score out of a possible maximum of 10 for each condition.

The change detection accuracy score was then divided by the score for *number of trials that achieve the 67% accuracy criterion,* in order to obtain a figure to represent the proportion of changes detected in each condition while accurately performing the WM load task. Mean change detection RT was also calculated for each condition, based on RTs from trials where the change was successfully detected and the 67% n-back accuracy criterion was achieved.

One-way ANOVAs on change detection Accuracy and RT revealed that the level of WM load did not significantly impact on accuracy, F(2,34) = 1.93, p=.16, $\eta_p{}^2$=.10, or RT, F(2,34) = 2.52, p=.12, $\eta_p{}^2$=.12.

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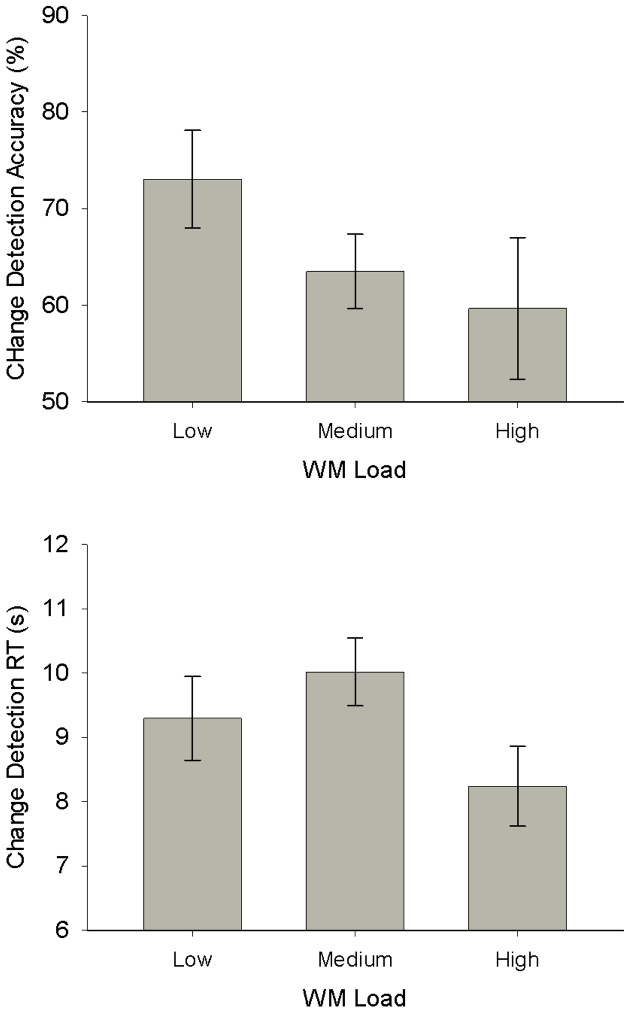

Figure 4.7: Mean change detection accuracy and RT across low, medium and high auditory WM load conditions.

4.9 Discussion

The aim of the current study was to improve the paradigm developed in the previous study (4.1) and further test the effects of auditory WM load on change detection. A *0*-back condition was added to the experiment, the duration of the n-back tone stimuli was increased from 500 to 1500ms, the overall length of the experiment was reduced (to help reduce fatigue/boredom effects) and participants were given more practice trials before beginning the main task. WM load task accuracy was generally higher and RTs were faster, so evidently participants found the current WM task more manageable than the task in Study 4a.

The drop in load task performance between low and high WM load conditions confirms that the *overall* WM load manipulation was effective. Although load task accuracy did differ between medium (*1*-back) and high (*2*-back) load conditions, the non significant difference between low (*0*-back) and medium (*1*-back) load conditions calls into question the effectiveness of introducing the new *0*-back low load task, as ideally accuracy on this task would have been higher than on the *1*-back task. Coupled with the fact that performance across both tasks was quite high (90% accuracy), this suggests that my assertions in the previous section that the *1*-back task is too challenging may have been unfounded. However, given that responses to the *0*-back task were more rapid than responses to the *1*-back task, this does demonstrate that the *0*-back task was easier. In fact, RT may be the more sensitive measure here, especially considering that both the *0*-back and *1*-back tasks were quite easy to perform, as indexed by subjects scoring around 90% accuracy on average across both tasks. Furthermore, performance in the high load task was still at 79%, which indicates that participants didn't really find this task very challenging either.

Despite these changes made to the current paradigm, it appears that the present findings concur with those of Study 4.1 and confirm that increasing auditory WM load does not significantly impact on change detection. These findings are discussed in greater detail in the general discussion section at the end of this chapter.

Study 4c - Visual Working Memory Load and Change-Blindness

4.10 Introduction

The results of studies 4a and 4b suggest that increasing the WM load of an auditory task does not impact on change detection. These studies are the first to test the effects of auditory WM load on visual change detection, and the results contradict findings from previous studies that have tested auditory WM load effects on both task-relevant and task-irrelevant stimuli (see Section 4 for examples). One possible reason that auditory WM load does not impact on visual change detection is because the two tasks are presented in different modalities and thus place demands on different processing resources. Under the framework of the Baddeley and Hitch (1974) WM model, change detection in a flicker task places demands on the visuo-spatial sketch pad, as change blindness is thought to represent both a failure to represent information about the changing object, and a failure to compare changing information across views Varakin et al. (2007). Conversely, memory for tones is assumed to take place in the phonological loop (PL). Schulze and Koelsch (2012) highlight that Baddeley and Hitch do not specify whether the PL deals the processing of non-verbal sound information, and that it is possible that either a separate “tonal loop” exists alongside the PL specifically for the processing of tonal information, or that there is a common acoustic store where both verbal and non-verbal auditory information is stored and rehearsed (Pechmann and Mohr, 1992). Either way, the two tasks in 4.1 and 4.5 place demands on separate visual and auditory WM systems.

In order to explore this, I decided to carry out a further study to test whether presenting the WM task in the visual modality would impact on change detection, as theoretically, both the n-back task and change detection task would be in competition for the same visual WM resources. Accordingly, the paradigm used in the previous two studies was adapted to allow visual, rather than auditory presentation of the WM task. In order to minimise visual interference between the WM task and change detection task, the n-back stimuli (different colours) were presented in a frame completely surrounding the images. The frame meant that there was no visual overlap between the n-back stimuli and images, unlike versions of this task used by in previous studies (e.g. Rose et al., 2005; Gläscher et al., 2007), where the n-back task required participants to attend to digits that were presented at fixation and superimposed over the images.

A number of other studies suggest that increasing the level of WM load in a visually presented n-back task leads to reduced processing of task-irrelevant visual stimuli (e.g. Bingel et al., 2007; Gläscher et al., 2007; Rose et al., 2005) and also unexpected stimuli Todd et al. (2005). This effect is also predicted for the current study. Detecting changes in a flicker-paradigm relies on visual WM resources, hence any increase in the visual WM load of a concurrent task will reduce the WM resources available for processing the changing scenes in the flicker paradigm, resulting in a decline in change detection performance (as indexed by reduced accuracy and increased RT).

4.11 Methods

4.11.1 Participants

18 new undergraduate students (2 were male, mean age = 19 years, SD = 1.9 years) who received course credit for their participation. All had normal hearing and vision, and were non-dyslexic, native English speakers.

4.11.2 Design

The study was a one-way design with the within subjects variable of visual n-back task difficulty [*0*-back, *1*-back, *2*-back].

4.11.2.1 Change Blindness Stimuli

The 3 sets of 10 change-blindness image-pairs from Study 4b were used in the current study. As before, the three sets of images were counterbalanced between the different conditions of WM load in order to control for any differences in change detection difficultly between the sets. The images were presented using the procedure shown in Figure 4.8

4.11.2.2 Visual n-back stimuli

Five colours (red, green, blue, yellow and brown) were used as n-back stimuli in the visual paradigm, but only three colours (red, green and blue) were used as targets. This was so that the total number of possible targets was the same in both the visual and auditory versions of the experiment. See Figure 4.9 for examples of the n=0, 1 and 2 back tasks. The visual n-back stimuli were presented in a rectangular frame around the change-blindness image (see Figure 4.8). The change-blindness image subtended 35.1° x 28.5° visual angle and the frame uniformly subtended 2.39° of visual angle. Onset and duration (1500ms) of the n-back stimuli was the same as for the images.

4.11.3 Procedure

The procedure for the main and practice trials was exactly the same as for Study 4b, except that the auditory n-back stimuli were replaced with visual n-back stimuli (see Figure 4.8). At the start of each trial a target n-back colour was presented on screen. The trail then began - for each cycle participants were required to press a key if they detected the n-back target colour in the frame surrounding the image. In the *0*-back condition they just pressed the “1” key on cycles where the target was present. In the *1*-back and *2*-back conditions they pressed the “1” key if the target colour was different to the colour n positions back in the sequence and “2” if the target was the same as the colour n positions back in the sequence.

As before, participants were also required to attend to the alternating change-blindness images and to press the space bar with their left hand if/when they detected the change. As in the previous study, the change detection response was logged, but the trial continued for the full 10 cycles and the participant was required to continue carrying out the WM load task. This ensured that the amount of overall WM load was as consistent as possible for all participants across trials.

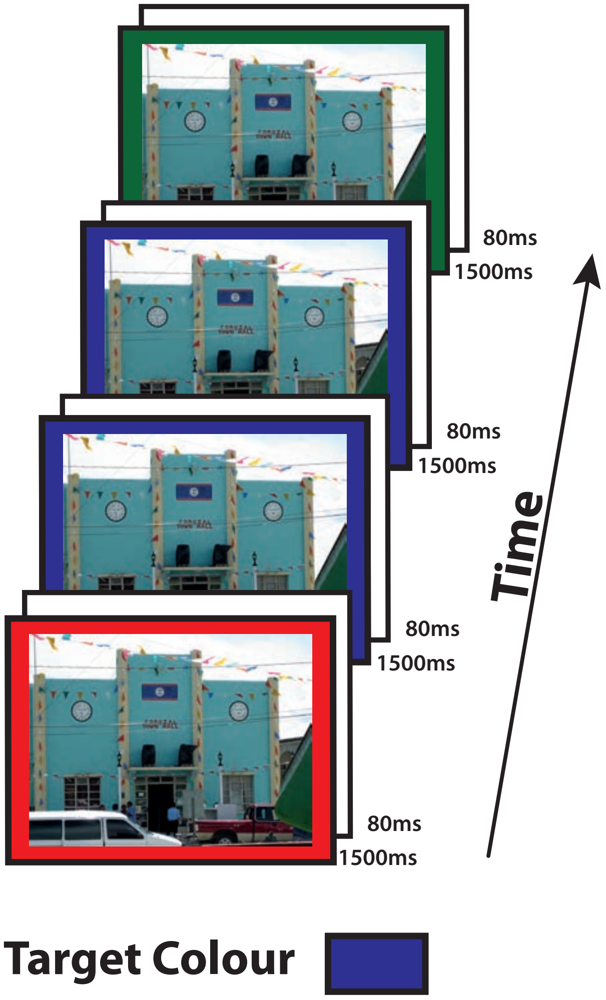

Figure 4.8: Example of concurrent *1*-back colour matching task and change detection “flicker” task. The target colour was presented to the participant at the start of the trial and their task was to monitor the sequence and respond *only* when they see the target colour. If the target was different to the colour one position back in the sequence the correct response is “1”, whereas if the target was the same as the colour one position back then the correct response was “2”. The participant pressed the space bar to indicate that they had seen the change, and they were then required to use the mouse cursor to confirm the location of the change.

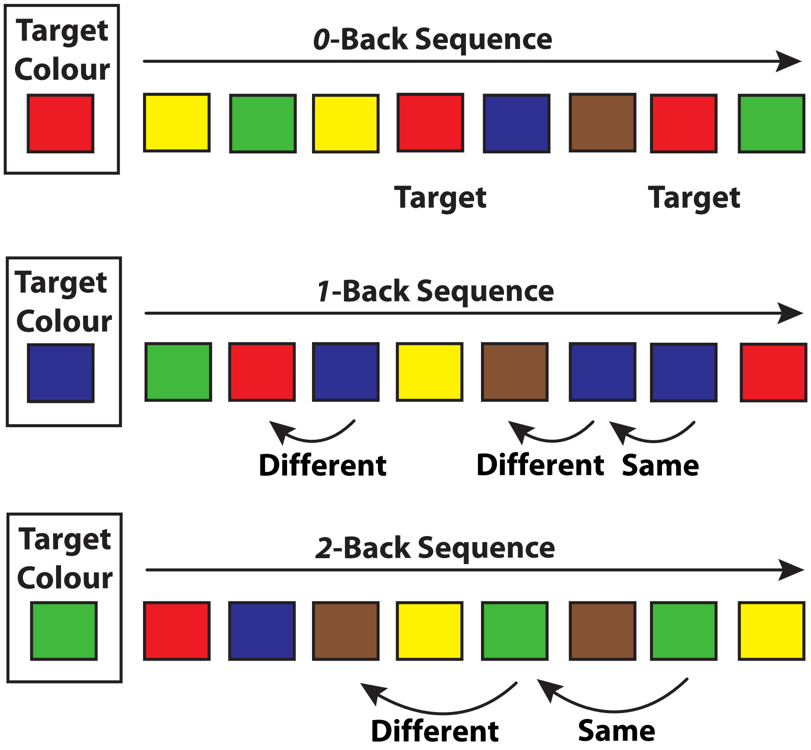

Figure 4.9: Examples of the visual *0*-back (low load), *1*-back (medium load) and *2*-back (high load) procedures.

4.12 Results

The response keys for the load task and change detection task were set up in the same way as for Study 4b, therefore one left-handed participant was also excluded from further analysis in the current study (see section 4.8 for more details). Load task accuracy in the low load (*0*-back) condition was negatively skewed, due to a majority of participants performing at or close to ceiling in this condition. Critical total possible trials were also negatively skewed in all three conditions due to participants performing at or close to ceiling. The data for change detection accuracy were normally distributed. Change detection RT was positively skewed in the medium load condition.

4.12.1 Load Task Performance Analysis

Following the same procedure as in Studies 4a & 4b, responses to *n*-back targets in the *prep* trials were not included in the analysis, as participants are not under dual-task load while engaged in these trials. A one-way repeated measures ANOVA on the load task accuracy data revealed a main effect of load task difficulty, $F(2,32) = 13.32$, $p<.001$, $\eta_p{}^2=.45$. Bonferroni corrected paired samples t-tests (adjusted alpha criterion of $p<.017$) confirmed that participants were more accurate at the low load task than the medium load task, $t(16) = 4.81$, $p<.001$, $d=1.25$, and more accurate at the low load task than the high load task, $t(16) =3.44$, $p=.003$, $d=.78$. Performance was marginally different between the medium and high load tasks, $t(16) = 2.29$, $p=.04$, $d=.62$.

A one-way repeated measures ANOVA on the load task RT data revealed a main effect of load task difficulty, $F(2, 32) = 14.10$, $p<.001$, $\eta_p{}^2=.47$. Paired samples t-tests confirmed that participants made more rapid responses to the load task under low load than medium load, $t(16) = 5.37$, $p<.001$, $d=1.45$. However, responses were more rapid under high load than medium load, $t(16) = 3.60$, $p=.002$, $d=.87$, and there were no significant differences between low load when compared to high load, $t(16) = 1.5$, $p=.15$, $d=.43$.

These data suggest that the intended WM load manipulation was a partial success. Participants were more rapid and accurate at the load task under low load when compared to medium load, and more accurate under low load compared to high load. However, the medium to high load manipulation was ineffective, as participants were marginally more accurate and faster to respond to target under high load than medium load - the opposite direction to what was expected.

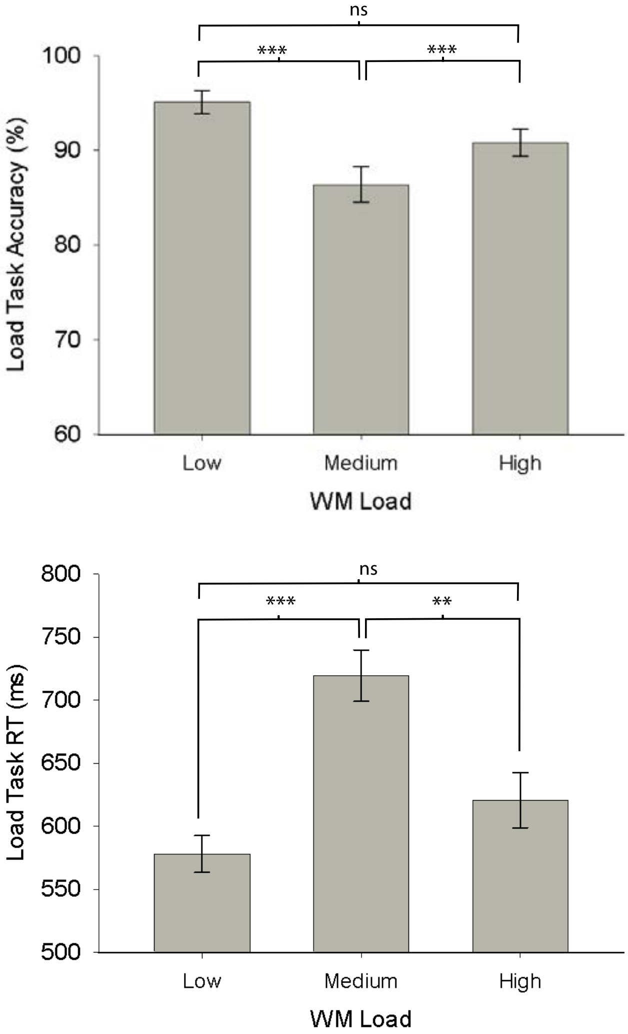

Figure 4.10: Mean accuracy and RT on auditory WM load tasks across low (*0*-back), medium (*1*-back) and high (*2*-back) conditions. ***p<.001, **p<.01

Following the same procedure as in the previous two studies, an inclusion criterion was applied to the dataset whereby a trial was only included in further analysis if the participant scored 67% accuracy on the n-back load task. This ensured that only trials in which participants were definitely subject to load demands were analysed.

4.12.2 Change Detection Task Analysis

Following the same procedure as in Study 4b, a score for *change detection accuracy* was calculated, based only on trials in which the 67% accuracy criterion had been achieved (see Section 4.8.2 for more details).

A one-way ANOVA on the change detection accuracy data revealed a main effect of load, F(2,32) = 5.02, p=.01, $\eta_p{}^2$=.24. Post-hoc analysis was carried out in order to explore this effect further. Given that the load manipulation in the *2*-back condition was unsuccessful, it did not make sense to compare change detection in this condition to any of the other conditions. Accordingly, this condition was removed from any further analysis, and a single paired-samples t-test was carried out to test for a difference between performance in the low and medium load conditions. The test confirmed that fewer changes were detected under medium load than low load, t(16) = 3.24, p<.05, *d*=.80.

A one-way ANOVA on the change detection RT data revealed no main effect of load, F(2, 32) = .87, p=.43, $\eta_p{}^2$=.05.

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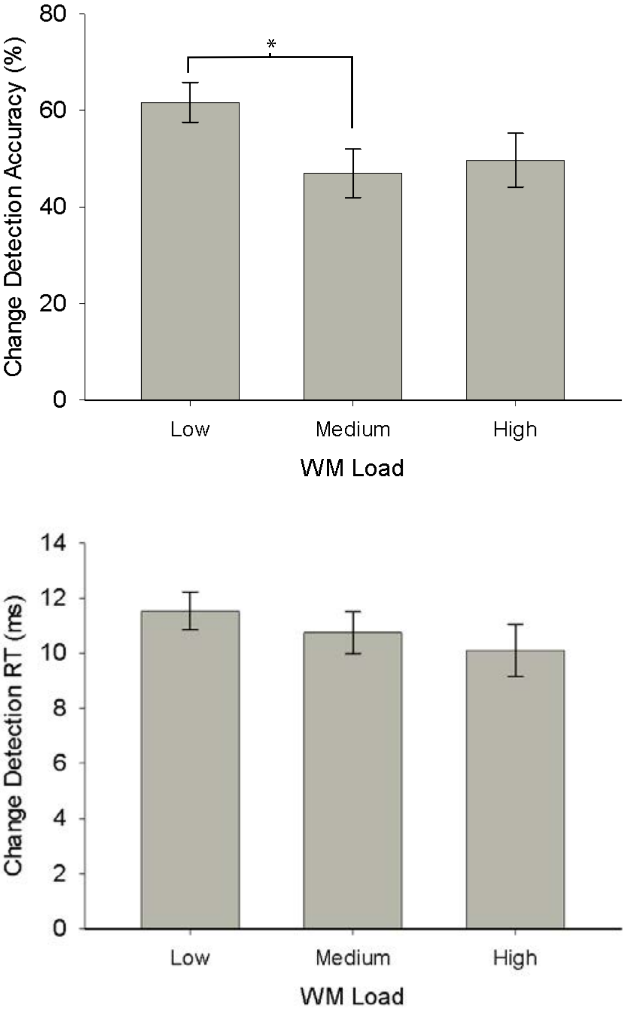

Figure 4.11: Mean change detection accuracy and RT across low (*0*-back), medium (*1*-back) and high (*2*-back) conditions. *p<.05

4.13 Discussion

This study aimed to expand on studies 4a and 4b by testing visual WM load effects on change detection.

WM load was successfully manipulated between the low and medium load conditions (responses were more accurate and rapid in the *0*-back task than in the *1*-back task). The manipulation between the supposed medium and high load conditions was less successful, however, as participants actually performed better at the *2*-back task than the *1*-back task, indicating that they found the "high" load task easier than the "medium" load task. Given these issues with the *2*-back task, the decision was made to only compare change detection performance between the low and medium load conditions. Fewer changes were detected under medium load when compared to low load; however there were no effects of WM load on change detection RT. These findings can be cautiously interpreted as supporting the predictions made at the start of this section, in that they suggest the visual n-back task competes for visual WM processing resources with the change detection task. These findings are discussed in more detail alongside the findings from studies 4a and 4b in the next section.

It is difficult to pinpoint why performance in the *2*-back task was higher than in the *1*-back task, as this is certainly not typical of n-back tasks. This may have been due to the fact that the *2*-back task did not require participants to respond to two targets in a row, whereas the *1*-back task did. Participants may have struggled to respond to two targets in sequence while also trying to spot the change between the two cycling images.

Chapter 4 Discussion

The studies presented in this chapter aimed to test the effects of WM load on change detection performance. WM load was manipulated by increasing the difficulty of either visual or auditory WM n-back tasks while participants engaged in a concurrent change detection task. Change detection performance was measured as both the number of changes detected (accuracy) and change detection speed (RT). In study 4a manipulating WM by increasing the level of load from *1*-back to *2*-back in an auditory WM task did not impact on change detection. In Study 4b the paradigm developed in Study 4a was improved to address a number of concerns. WM was manipulated by increasing the level of load between three levels; *0*-back, *1*-back and *2*-back. Despite addressing the concerns with the previous study, change detection remained unaffected by the level of load, providing further evidence that auditory WM load does impact on change detection. Study 4c investigated whether manipulating WM load in the visual modality instead of the auditory modality would impact on change detection. Despite the issues with the unsuccessful manipulation of WM load between medium and high load condition, WM load was successfully manipulated between low and medium load conditions, and change detection was demonstrably reduced under medium load compared to low load. These findings are discussed in relation to existing literature that documents WM load effects in similar cognitive paradigms.

4.13.1 Relationship to existing literature on task-irrelevant image processing

Klemen and colleagues (e.g. Rose et al., 2005; Klemen et al., 2010) demonstrated using both neuroimaging and behavioural measures that increasing WM load in visual n-back task (Rose et al., 2005; Gläscher et al., 2007; Bingel et al., 2007) or auditory n-back task (Klemen et al., 2010) can lead to reduced processing of task-irrelevant visual stimuli. The studies outlined in this chapter also manipulated the level of WM load in visual and auditory n-back tasks, but with the goal of testing WM effects on the processing of task-relevant, rather than task-irrelevant, stimuli.

Although it was difficult to make any firm predictions; given the similarities between auditory n-back Studies (4a & 4b) and the Klemen et al. study, increasing auditory n-back task load was predicted to impact on image processing, and thus reduce the likelihood of change detection. However, in Studies 4a and 4b this was demonstrated not to be the case - both studies show that increasing auditory n-back task load does not significantly impact on change detection accuracy or RT.

There are a number of possible reasons for these contrasting findings: first, it is possible that simply attending to the images in the present studies allowed the effects of the WM load manipulation to be overcome. Allocating focused attention to the images, rather than ignoring them as in previous n-back studies, may have meant that the images received much more extensive, prioritised processing, which was unaffected by increasing n-back demands. Second, in the previous n-back studies (e.g. Rose et al., 2005; Klemen et al., 2010) the behavioural measure of image processing was a surprise retrospective two alternative forced choice (2AFC) task that tested image recognition accuracy for ignored stimuli. Not only was it likely that stimuli received less processing than in the current study, the behavioural measures are completely different, in that retrospective image recognition and change detection are entirely different tasks. Furthermore, whereas the behavioural measures in the change detection paradigm are immediate and on-line, retrospective recognition in the previous studies will have involved a memory component i.e. it could be that task-irrelevant images processed under high WM load fade from memory at a more rapid rate. Third, it is important to note that Klemen et al. demonstrated that an increase in auditory WM load leads to reduced recognition for task-irrelevant images in a surprise recognition test. This drop in performance was attributed to reduced activity in the LOC, an area that has been linked to visual object recognition (e.g. Malach et al., 1995; Grill-Spector et al., 2001). Although imaging data were not collected in the current study, it is plausible that activity in the LOC will have also been reduced under high auditory WM load in the current study. While reduced activity in the LOC may impact on object recognition capacity, there is no evidence that LOC activation is implicated in change blindness, as it is not mentioned in previous studies that have investigated the neural correlates of change blindness (Beck et al., 2001; Pessoa and Ungerleider, 2004). Furthermore, reduced activity in the LOC is not associated with visual attention (Grill-Spector et al., 2000).

It was also difficult to make any firm predictions regarding whether increasing the level of WM load in the visually presented n-back task (Study 4c) would impact on change detection, but given the similarities between this paradigm and (Rose et al., 2005) it was predicted that change detection performance would be reduced under high WM load. Change detection accuracy did indeed decrease as WM load increased from low (*0*-back) to medium (*1*-back) condition - a result that is in-line with predictions - although the unsuccessful manipulation of WM load between medium (*1*-back) and high (*2*-back) conditions does mean that the results of this study are not as robust as they ideally would be. The decline in change detection accuracy as visual WM load increased from low to medium load may have been due to increased interference between the load task and change detection task in visual WM. Both the n-back task and change detection task require information to be stored and constantly updated in visual WM; but visual WM has limited storage and processing capacity, hence it follows that an increase in task demands in one task will restrict the amount of resources available for the other task. As discussed in Section 3.7.1, one of the key factors thought to contribute towards CB is failure to compare representations of scenes across brief delays (Angelone et al., 2003; Varakin and Levin, 2006; Varakin et al., 2007); so it is possible that in the current dual-task paradigm, increasing n-back WM load could reduce the amount of spare capacity available to process and compare the representations of the two versions of the image cycling in the flicker task. This result supports the generalised theory of load proposed by Klemen et al., and also suggest that it may be possible to expand this theory to account for the effects of WM load on task-relevant stimuli. It should also be noted that the overall pattern of results across Studies 4a, 4b and 4c concur with evidence from the *perceptual load* literature, which demonstrates that increasing visual perceptual load can lead to reduced processing of an irrelevant motion stimulus (Rees et al., 1997), whereas increasing auditory perceptual load does not (Rees et al., 2001). This adds further support to Klemen et al. (2010)'s generalised theory of load effects.

However, the effects of the visual n-back task on change detection in Study 4c are at odds with the null effects of the auditory n-back task in Studies 4a & 4b. There are several reasons that may account for why increasing the visual n-back task load impacted on change detection, whereas increasing auditory n-back talk load did not. First, as both the n-back and change detection tasks were presented in the visual modality, there may have been some perceptual interference between the two tasks which could have interfered with the actual effect of increased WM load. However, this is unlikely, as all the features of the visual n-back task remained the same between different conditions (same number of targets, same colours) and only the task instructions changed with regards to the number of places back in the sequence (“n”) the participant had to match the target to. Second, participants would have used different strategies in performing the different visual and auditory n-back tasks, and this could have possibly impacted differentially on change detection. In a sense the auditory task is more “pure” as tones are presented in the auditory modality and it would have been more difficult for participants to verbalise the tones (although it is possible they could have given the tones arbitrary labels e.g. low, low medium etc). In contrast, despite being presented in the visual modality, the colours in the visual n-back task would have been much more easy to internally verbalise [3], which may be part of the reason that participants responded more rapidly overall to visual n-back targets than auditory n-back targets. Importantly, given the verbalisation, this also meant that the task was not a particularly “pure” measure of visual WM. Without further testing it is difficult to say what the effects of different strategy were, but, given that verbalisation would have probably been more difficult in the auditory condition, one might speculate that if strategy really was an issue then the effect of WM load on change detection would have been seen in the auditory conditions in addition to, or instead of, the visual paradigm.

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[3] Although participants were not asked about strategy in the present studies, there is evidence that the majority of participants do verbalise in n-back based tasks that use colour stimuli (Vuontela et al., 1999).

4.13.2 Relationship to existing literature on task-relevant stimuli processing

WM load has been demonstrated to impact on task-relevant stimuli processing in a range of different cognitive tasks. Han and Kim (2004) have demonstrated that although visual search can remain efficient when a concurrent WM task just requires storage, search efficiency was reduced when the WM task required information to be manipulated. Furthermore, although Akyürek and Hommel (2005, 2006) have demonstrated that WM load has no impact on the magnitude of the AB when a typical AB task is interleaved with a standard WM set/probe task, Akyürek et al. (2007) have shown that when participants have to process and manipulate the information held in WM during the AB task then WM load does impact on the AB magnitude. Also, Fougnie and Marois (2007) presented participants with unexpected visual stimulus while engaged in a WM task that either required them to simply maintain a set of verbal information in WM *or* rearrange the information into alphabetical order (high load). The authors discovered that when participants were required to engage executive processes and manipulate the information in WM, the likelihood of detection was reduced compared to conditions where the verbal information was just maintained in WM. Importantly, these examples demonstrate that WM load *can* impact on the processing of task-relevant stimuli, even if there is no perceptual interference between the WM task and the task-relevant stimuli. They also demonstrate that WM load can only impact on the processing of task-relevant stimuli *if* the information held in WM has to be processed concurrently with the task-relevant stimuli.

Surprisingly, there are no studies to my knowledge that directly correlate performance on the change blindness flicker task with performance on AB, IB or visual search tasks[4]. The findings from Studies 4a & 4b are at odds with findings from the visual search, IB and AB literature, as they suggest that increasing the level of WM load in a task that requires manipulation of the information in WM leads does not impact on change detection. Given that there is no perceptual interference between the WM stimuli and change detection stimuli in any of the tasks mentioned in this section, and there is no perceptual interference between the *n*-back task and stimuli in the current paradigm, this suggests that change-blindness is not necessarily susceptible to WM demands in the same way that IB, AB and visual search are. However, the findings from Study 4c *do* suggest that change blindness is susceptible to WM demands, but given the potential for perceptual interference between WM and change detection tasks, this data may be considered less conclusive. Further testing needs to be carried out in order to elucidate the relationship between change detection and WM demands - what really needs to happen is for WM to be manipulated in a wide range of tasks that require both storage and/or manipulation, and the effects of these tasks to be tested on CB.

4.13.3 Methods Critique

One issue with Study 4c is that the verbal encoding of the colour stimuli means that the task cannot be treated as a true test of visual WM. Given that the aim of Study 4c was to present stimuli in an analogous manner to Studies 4a

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[4] The only paper I could find that looked at the relationship between any of these different tasks was a paper by Beanland and Pammer (2012) which demonstrates a relationship between the magnitude of the AB and likelihood of failing to detect a critical stimulus in an IB task.

& 4b, it was very difficult to get around this problem. In a pilot study I did try presenting participants with varying shades of grey, rather than colours, with the assumption that it would be more difficult for them to verbalise shades than colours - however participants just found this task far too difficult. I also considered the possibility of using a visuo-spatial version of the n-back task, such as the task used by (Jaeggi et al., 2010) where the target was a white cube in a particular location on-screen and this location had to be matched to locations n targets back in the sequence. However, this would have introduced an unwanted spatial element to the task, and would have meant the n-back stimuli precluding the CB images and also diverting attention towards particular parts of the screen, and participants still potentially could have verbalised locations. The only way to truly prevent participants verbalising during either the visual or auditory n-back tasks would have been to require them to perform an articulatory suppression task throughout each trial. Given that participants already had demanding n-back task and change detection tasks to perform, the additional challenge of performing an articulatory suppression task would have been very difficult to cope with, and it would have obstructed the tone delivery in Studies 4a & 4b.

Another potential issue is that the n-back tasks in 4b and 4c may been too easy. Mean accuracy in the hardest auditory n-back condition (*2*-back) was 79% and mean accuracy in the hardest visual n-back condition (*1*-back) was 86%, meaning that even when the WM manipulation *did* work and there was a significant drop in performance, the fact that performance was still reasonably high under WM meant that the manipulation perhaps was not very effective. One of the problems with the current methodology was how difficult it was to set appropriate difficulty levels for the n-back tasks. If the n-back task was too difficult, participants were liable to give up on the task and instead focus their attention on the change detection task. This meant that they were not subject to load demands and their data had to be excluded from further analysis (as was the case in Study 4a). It is possible that if the n-back tasks were made more difficult in Studies 4a & 4b, then there may have been an effect upon CB performance.

It was also quite difficult to match n-back task difficulty across different presentation modalities. The visual n-back task in 4c appeared to be significantly easier overall than the auditory n-back task in 4b, in that participants were faster to respond to the colours than the tones across all conditions. This may reflect the relative difficulty of holding an arbitrary target tone in memory in the auditory n-back tasks, compared to holding a colour in memory in the visual conditions.

4.13.4 Conclusion

The load theory of cognitive control proposed by Lavie et al. (2004b) demonstrates that increased WM load can lead to increased interference from distractors. However, the paradigms used to demonstrate this effect typically use a set/probe paradigm to test WM effects on another task that requires selection between task relevant stimuli and irrelevant distractors. In contrast, the n-back based paradigms discussed in the previous section directly test WM effects on task-irrelevant image processing and demonstrate that increasing WM load leads to reduced processing of task-irrelevant images. Furthermore, studies testing WM effects on the AB, IB and visual search paradigms have all demonstrated a decline in performance under increasing WM demands. The current findings also suggest that under certain conditions high WM load can reduce change detection in a CB flicker task, although this appears to depend largely on whether the WM task is presented in the visual or auditory modality. The current findings do not contradict the load theory of cognitive control, as it is fair to say that the paradigms that support this theory are measuring WM on selective attention, rather than directly measuring WM effects on the processing of task-relevant or task-irrelevant stimuli. Instead they offer some mixed support for the "generalised" theory of load suggested by Klemen et al. (2010).

Chapter 5

Perceptual Load and Affective Images

5.1 Chapter Introduction

The role of perceptual load in the processing of highly salient emotional stimuli is currently under debate (see Section 2.3 for a more in-depth discussion). Although there are numerous studies that test whether emotional stimuli processing is modulated by whether the stimuli are task-relevant or task-irrelevant, (e.g. Vuilleumier et al., 2001; Pessoa et al., 2002b; Holmes et al., 2003), relatively few studies have directly tested perceptual load effects on the processing of task-irrelevant stimuli. On one hand, there is evidence that under certain conditions, high perceptual load does not modulate distraction from task-irrelevant emotional stimuli (Sand and Wiens, 2011; Norberg et al., 2010), but this contrasts with evidence that high perceptual load can eliminate distraction from emotional stimuli (Pessoa, 2005; Erthal et al., 2005). The type and potency of the emotional stimuli, and the nature of the tasks are likely to be key factors in determining whether emotional stimuli are able to modulate the effects of perceptual load or not.

There are a number of other important questions regarding load effects on the processing of affective images that remain unanswered and it appears to be the case that the gaps in this area of literature are very similar to those already highlighted in the perceptual and cognitive load literature. First, in the studies mentioned about that do test low and high perceptual load effects on emotional stimuli, participants are required to attend the a load task (either bar discrimination or visual letter search) while attempting to ignore a task-irrelevant emotional or neutral stimulus. There are no studies that test load effects on task-relevant emotional stimuli, and none that provide a behavioural measure of the extent to which stimuli are processed to the level of conscious awareness under different conditions of perceptual load. Second, no behavioural studies have addressed whether emotional visual stimuli can impact on the processing of information in another sensory modality, namely audition. Results of research on cross-modal load effects are inconsistent. Although Rees et al. (2001) have demonstrated that auditory load has no impact on the processing task-irrelevant motion stimuli, Yucel et al. (2005) have shown that activation in the temporal auditory cortex from task-irrelevant deviant tones can be reduced under high visual perceptual load, and in Study 2b I demonstrated that auditory perceptual load can impact on visual change detection. It is therefore possible that auditory perceptual load could also have a modulatory effect on the processing of emotional stimuli.

The main aim of the studies outlined in this chapter was to test whether the processing of task-relevant emotional visual stimuli is modulated by either visual or auditory perceptual load. The paradigm used by Pessoa et al. and Erthal et al. was replicated and then modified for the purposes of the current study. Originally, each trial consisted of a fixation point, an image presented at fixation flanked by two bars and then a checkerboard mask. In order to ensure that the images were task-relevant, a categorisation task was added to each trial, in which participants were required to categorise the image as either "negative" or "neutral" at the end of each trial. In order to succeed at this task, the images would have to be consciously attended to in addition to the bar discrimination task. Participants were required to respond to the categorisation task directly after the bar/tone discrimination task; this ensured that the image was task-relevant, but also that there was no response competition between the load and categorisation tasks. In order to test auditory perceptual load effects, an analogous auditory paradigm was created, in which the visual bar discrimination load task was replaced with an auditory tone discrimination task. Visual and auditory perceptual load were manipulated by varying the discriminability between the bars or tones. The categorisation task also served the additional function of ensuring that participants actually looked at the screen during the auditory load conditions.

There is a key difference between this new task and the change detection based tasks that I developed earlier in the thesis. In Chapters 2 & 3 the paradigms allowed task-relevant perceptual and cognitive load effects, respectively, to be tested on task-relevant change detection. These studies were concerned with testing the extent to which task-relevant load impacted on the likelihood of detecting a change between the images cycling on screen, and change detection was the dependent variable. In the current paradigm, to an extent, the images also served as a measure of how much the stimuli had been processed - however, the main purpose of this task was really to confirm that the categorisation judgement was made on the images and thus ensure that they were "task-relevant". Furthermore, any trials where an incorrect categorisation judgement was made (suggesting that the subject was not paying attention to the image) could be discarded, thus ensuring that only trials where load effects on task-relevant stimuli were included in the final analysis. In other words, whereas the tasks in Chapters 2 & 3 investigated the extent to which load can modulate participants' ability to detect a change in a task-relevant scene, the current task investigates the extent to which load can modulate distraction by task-relevant emotional stimuli.

The bars/image paradigm was chosen as the basis for the current study as its effectiveness has already been demonstrated; it allows the level of perceptual load to be directly manipulated without changing the type of task; it could be adapted across different modalities relatively easily i.e. the bars could be replaced with simple tones in an auditory manipulation; and the image categorisation task could be added to the paradigm without causing interference/response conflict with the perceptual load task. From the literature, it appears that two critical factors in determining whether perceptual load impacts on emotional processing are task difficulty and the potency of the emotional images(Pessoa et al., 2002a; Pessoa, 2005; Erthal et al., 2005). First, the emotional images needed to be highly negative and arousing. Accordingly, I decided to use images that depicted accidents, gunshots, surgery and mutilation, as these are consistently rated as being the most highly negative and arousing images (e.g. Lang et al., 1999; Lasaitis et al., 2008). Second, the high visual and auditory perceptual load tasks needed to be very demanding, in order to exhaust participants' attentional resources. Performance needed to be close to chance, but not *at* chance, as I would need confirmation that participants were capable of performing the task properly.

It was necessary to carry out several studies prior to the "main" study. For various reasons, an entirely new set of images had to be sourced and rated (Study 5a), and then task difficulty levels had to be determined for the visual perceptual load paradigm (Studies 5b, 5c and 5d) and the auditory perceptual load paradigm (Study 5e). It was important to get this right, as ensuring that the set of images were highly emotionally potent, and that the high visual and auditory perceptual load tasks were as challenging as possible means that the findings cannot be criticised for not using potent enough emotional stimuli, or a demanding enough perceptual load task. Study 5f was the main experiment that tests visual and auditory perceptual load effects on *task-relevant* emotional stimuli processing. A further study (5g) was also run at the end of the chapter to test the effects of visual perceptual load on *task-irrelevant* stimuli. This study addressed an important question with regards to task-irrelevant emotional stimuli processing, and the accompanying rationale is discussed in more depth in section 5.25.

Erthal et al. demonstrated that task-irrelevant emotional images slowed reaction times in a visual bar discrimination task under conditions of low, but not high visual perceptual load. A similar modulatory effect of visual perceptual load on task-relevant emotional stimuli processing may also be expected in the current study; a result that would provide additional support for load theory. However, it is difficult to make any firm predictions about the modulatory effects of visual perceptual load on task-relevant emotional stimuli, as this effect has not been directly tested before. It is also possible that requiring participants to attend to the emotional stimuli may mean that the typically modulatory effects of load may be overcome, meaning that load and valence will not interact. It is even more difficult to predict a possible pattern of results for the data in the auditory perceptual load task. As discussed earlier, there is evidence from neuroimaging studies that high visual perceptual load can inhibit the processing of task-irrelevant auditory distractors (Yucel et al., 2005), and also that emotional images can increase processing of distracting auditory stimuli (Domínguez-Borràs et al., 2009; Lv et al., 2011); hence it is also possible that the emotional visual stimuli will impact on the processing of the auditory stimuli in the current study.

Study 5a - Creating a Standardised Set of Emotive Stimuli

5.2 Introduction

Mirtes Pereira kindly sent me through the set of images that were used used in the original Erthal et al. study. They had obtained 14 neutral and 28 highly negative and arousing images from the IAPS and supplemented these with images obtained from an internet search, as there was not a sufficient number of highly emotionally potent images available from the IAPS. All the images had then been rated in terms of valence (from *negative* to *positive*) and arousal (from *low* to *high*)by a group of students from the Federal Fluminense University, Brazil, using the ratings protocol developed by Lang et al. (1999) for creating the IAPS.

Rather than reusing the entire Erthal et al. set, a new set of images were collated and standardised for the purposes of the current set of studies. There were two reasons for this. First, the original set consisted of a majority of images that contained faces somewhere in the scene. The set of 152 images that I received from the authors contained 53 negative face-present images, 64 neutral face-present images, 20 negative face-absent images and 15 neutral face-absent images. There is a large body of evidence to suggest that the processing of faces by the brain is "special" (for a review see Farah et al., 1998), Facial expressions are highly socially and biologically meaningful (Öhman and Mineka, 2001) and evidence from neuroimaging demonstrates increased activation in the fusiform face area (FFA) and amygdala in response to fearful faces, even when they are presented at task-irrelevant locations (Vuilleumier et al., 2001), or outside of conscious awareness (for reviews, see Vuilleumier and Pourtois, 2007; Whalen et al., 2004). However, despite the fact that brain responses to fearful facial expressions are typically of a larger magnitude than responses to other facial expressions, there is little evidence to suggest that the fearful faces are processed any more rapidly (Batty and Taylor, 2003). Although the facial expressions in the Erthal et al. image set were not always explicitly fearful, it is possible that highly affective images of this nature that contain a human face may be processed differently to images that do not contain a face, and it is also possible that load might impact differently on highly negative images that either do or do not contain faces. In order to control for this (and also to test whether load modulates face-present and face-absent images differently), the new stimuli set comprised equal number of face-present and face-absent negative and neutral images. Throughout the remainder of the chapter the face-present images are referred to as "face" images, and the face-absent images are referred to as "body" images.

The second reason for developing a new image set was that the image ratings protocol was carried out by a group of Brazilian students, and there is the possibility that their valence and arousal ratings may have differed from a group of English students[1], meaning that the ratings would be non-transferable between our two studies. Accordingly, the current image set was rated by a group of native English undergraduates who were of a similar age to the participants who would take place in the main study.

5.3 Method

5.3.1 Participants

16 undergraduate students (7 were male, mean age = 20.2 years, SD = 2.2 years) who received five pounds each for their participation..

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[1] Cultural differences in IAPS ratings do exist, as demonstrated in a study by Lasaitis et al. (2008) where, on average, Brazilian students rated the IAPS images as higher in arousal compared to North American students.

5.3.2 Design

One hundred and sixty negative and neutral images were divided into four sets of forty. Each set contained ten negative face images, ten neutral face images, ten negative body images and ten neutral body images. “Face” images contained a recognisable human face somewhere in the scene, whereas “body” images did not. Allocation of images to sets was random, and the images in each set were presented in a randomised order using Microsoft PowerPoint. Participants were given printed booklets with sets of Self Assessment Manikin (SAM) Lang (1980) ratings scales for valence and arousal that corresponded to each of the images. SAM scales were used as part of the original IAPS protocol (Lang et al., 1999).[2]

5.3.3 Procedure

Participants were seated approximately 57 cm from the computer screen. They each received a booklet which contained an informed consent form, three sets of practice image ratings scales and one hundred and sixty sets of test image ratings scales. For each image there was two SAM ratings scales, one for valence and one for arousal (these were presented in a random order). After participants had given informed consent they were given a series of on-screen instructions to clarify the meanings of the two SAM scales. The valence scale was referred to as the “happy-unhappy” scale, and was said to vary from “happy, pleased, satisfied, contented, hopeful”, at one extreme (represented by a smiling face), to

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[2] In the original IAPS procedure (Lang et al., 1999), participants were also asked to rate the image for *dominance* (ranging from feeling completely controlled, awed, submissive to completely controlling, influential and in control). Erthal et al. (2005) did not ask their participants to rate their images for dominance, so I also decided to omit this rating, as it appeared to be less important for the purposes of my research than the ratings for valence and arousal.

"unhappy, annoyed, unsatisfied, melancholic, despaired, bored" at the other extreme (represented by a frowning face). The arousal scale was referred to as the "excited-calm" scale, and was said to vary from "stimulated, excited, frenzied, jittery, wide-awake, aroused" at one extreme (represented by wide-eyed figure), to "relaxed, calm, sluggish, dull, sleepy, unaroused" at the other extreme (represented by a closed-eyed figure). Participants were instructed to watch each image and mark on each of the SAM scales *how they actually felt* while they viewed each picture. They then viewed and rated three practice images: a neutral image (man with neutral expression), a highly positive image (puppies peering over a wall), and a highly negative image (a mutilated body). The practice allowed them to become familiar with the rating procedure. Furthermore, the images were specifically chosen to provide examples of the full range of responses, so they would serve as anchors on the emotional ratings scale.

Participants then viewed the four sets of 40 images. Each trial consisted of the following procedure: a screen instructing participants to "Rate the next picture on Scale _ _" (5s), then the image (6s), and finally the instruction to "Please rate the following picture on both dimensions" (10s). The order of presentation of the four sets of images was counterbalanced between participants. The opportunity to take a break was provided every 20 trials.

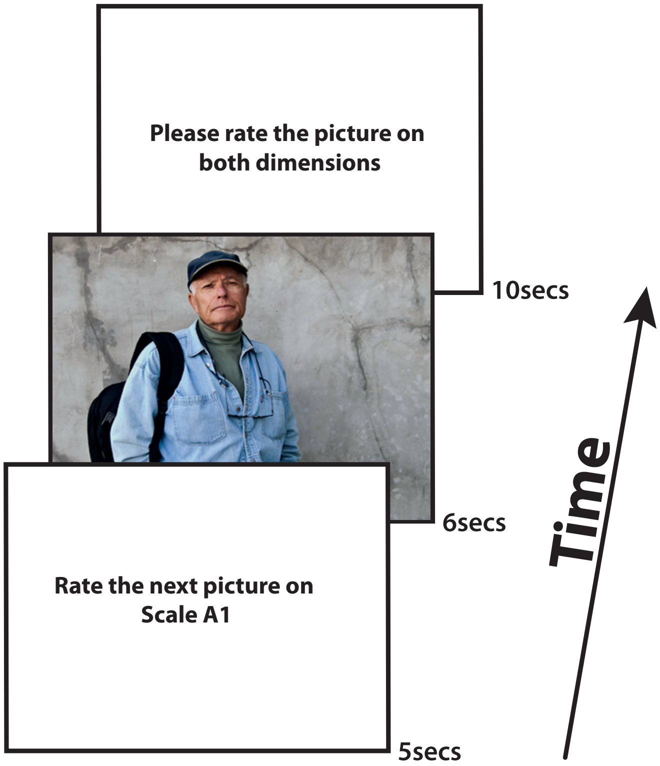

Figure 5.1: IAPS Ratings Procedure (based onLang et al. 1999)

5.4 Results

5.4.1 Ratings of Valence and Arousal

Please see appendix A for the mean valence and arousal ratings for each image and their standard deviations. The marks on the SAM sheets were converted into numerical ratings for valence (1 = highly negative, 9 = highly positive) and arousal (1 = very calm, 9 = very excited). The mean valence and arousal ratings for images in the negative category (mutilated bodies and faces) and images in the neutral category (regular pictures of bodies and faces) are displayed in Table

5.1. The mean ratings for negative images (valence = 2.83, arousal = 6.04) and neutral images (valence = 5.38, arousal = 2.61) in the current study were similar to the mean ratings for negative images (valence = 2.2, arousal = 6.4) and neutral images (valence = 5.0, arousal = 3.3) in the Erthal et al. (2005) study. Critically, images in the negative category were rated significantly more negative and arousing than images in the neutral category, t(15) = 11.76, 8.48, $p<.001$, *d= 3.67, 2.13,* respectively.

In addition to the overall ratings for the negative and neutral images, the ratings are also broken down further into separate scores for face and body images (see Table 5.1). Faces in the negative category were rated more negative and arousing than bodies in the negative category, t(15) = 9.25, 5.62, $p<.001$, *d=3.24,1.43.* Faces in the neutral category were rated more negative than bodies in the neutral category, t(15) = 4.45, $p<.001$, *d*=1.17, but the arousal ratings did not significantly differ, t(15) = .99, p=.34, *d*= .33.

	Negative			Neutral		
	Face	Body	Overall	Face	Body	Overall
Valence	2.38*(.78)*	3.27*(.50)*	2.83*(.63)*	5.58*(.55)*	5.17*(.46)*	5.38*(.48)*
Arousal	6.56*(1.65)*	5.52*(1.60)*	6.04*(1.58)*	2.67*(1.61)*	2.55*(1.33)*	2.61*(1.46)*

Table 5.1: Mean Valence and Arousal Ratings for each Image Category

The one hundred and sixty images were divided into four balanced sets (A, B, C and D) for use in the forthcoming studies. Each set contained forty images (ten negative faces, ten negative bodies, ten neutral faces, ten neutral bodies). Care was taken to ensure that valence and arousal ratings were balanced between sets. Mean valence and arousal ratings for each set are displayed in Table 5.2.

	Set A	Set B	Set C	Set D
Valence	4.10(1.37)	4.10(1.37)	4.10(1.38)	4.09(1.37)
Arousal	4.32(1.86)	4.27(1.77)	4.36(1.88)	4.33(1.83)

Table 5.2: Mean Valence and Arousal Ratings for each Image Set

5.5 Discussion

The aim of this preliminary study was to create a large standardised set of negative and neutral images for use in the studies that form the remainder of this chapter. The data confirm that images in the negative category were rated as very unpleasant, and that they are distinctly more negative and arousing than images in the neutral category. The data also confirm that within this image set the negative images of faces are rated as significantly more negative and arousing than negative images of bodies. The mean ratings attributed to the current image set are very similar to those given by participants in the Erthal et al. study, although it is worth noting that their negative images were rated as slightly more negative and arousing than the present set of images. This may be because participants appear to rate negative faces as more negative and arousing than negative bodies, and the Erthal et al. image set contained a much higher ratio of face images to body images than the current image set, which contained equal numbers of both.

Throughout the remainder of this thesis the term "negative" will be used to refer to the highly affective arousing images and the term "neutral" to refer to the neutral non-arousing images.

Study 5b - Visual Paradigm Development - Testing Effects of Categorisation and Stimulus Duration

5.6 Introduction

To recap, the main aim of the studies outlined in this chapter is to test whether the processing of task-relevant emotional stimuli is modulated by either visual or auditory attentional load. Having developed a new set of images in Study 5a, the purpose of the next preliminary studies was to replicate and modify the paradigm originally used by Erthal et al. (2005), in which a negative or neutral image was presented simultaneously with a flanking bar discrimination task (see Figure 2.8). Studies 5.5, 5.9, and 5.13 describe the development and piloting of the visual perceptual load paradigm.

In the original version of the task, participants were instructed to attend to the bars and try to ignore the centrally presented images, thus allowing the effects of high and low perceptual load on irrelevant image processing to be tested. This version of the task is depicted in 5.2a, and is referred to throughout this section as the *task-irrelevant images* condition. However, in the current study the aim was to test the effects of perceptual load on task-relevant image processing, so it was necessary to introduce a measure to check that the images were task-relevant. Accordingly, an image categorisation task was added to the experiment. At the end of each trial, after the participant had responded to the bar discrimination task, they were then required to categorise the image as either “negative” or “neutral” (see Figure 5.2b). In order to succeed at the categorisation task the images would need to be attended to, rather than ignored. This version of the paradigm is referred to as the *task-relevant* images condition. It was anticipated that requiring participants to perform the categorisation task *in addition* to the bar discrimination task would lead to increased error rates and RTs in the bar discrimination task. The primary aim of this preliminary study was therefore to compare performance on the task-irrelevant and task-relevant conditions, in order to determine the extent of the categorisation task interference.

A further aim of this study was to test whether there was any effect of different stimulus presentation duration. Erthal et al. presented their visual perceptual load task stimuli and image for 200ms, presumably to prevent participants from moving their eyes between flanking bars and image. It can be argued that 200ms presentations are not rapid enough to completely rule out the effects of eye movements, as eye meaningful eye movements can occur as rapidly as 100ms after stimulus onset. This has been demonstrated through forced-choice saccade tasks, where subjects are presented with two images side by side from different categories and required to move their eyes as quickly as possible to the image corresponding to a pre-designated category. Kirchner and Thorpe (2006) show that participants can reliably saccade towards the image containing an animal in as little as 120ms, and Crouzet et al. (2010) demonstrate that reliable saccades to human faces can occur in just 100-110ms. One might speculate that if the bars and image are presented for 200ms, eye movements could be made between the bars and image. Furthermore, this would be more likely to occur under low perceptual load, as the participant is not required to pay as much attention to the bars task so they might be more likely to try and fixate on the image, especially if the image is highly emotionally salient. Accordingly, this study tested whether reducing the stimulus presentation to 100ms (which should be fast enough to completely eliminate the possibility of any eye movements) would impact on the results. It was predicted that reducing stimulus presentation from 200ms to 100ms would lead to increased errors rates and RTs, as perceiving the bars and making the orientation judgement would become increasingly challenging.

Finally, although this study was intended as a preliminary study (with a low sample size and relatively few trials in each condition), it would also give an early indication of whether image valence and perceptual load interact or not, under varying conditions of task-relevant and task-irrelevant image processing.

5.7 Method

5.7.1 Participants

Nine postgraduate students (5 were male, mean age = 24.8 years, SD = 3.30 years) volunteered to participate in the study.

5.7.2 Design

The study was a 2x2x2x2 mixed measures design, with three within-subjects factors of load [low, high], valence [negative, neutral], duration [100ms, 200ms] and one between-subjects factor of image relevance [task-irrelevant, task-relevant]. The stimuli were presented in a block design. Load was manipulated between each block by making the difference in orientation between the two bars either easy (90° difference) or hard (6° difference) to discriminate (these two conditions will be referred to throughout the study as low load and high load, respectively). Bar discriminability in the low and high load conditions were designed to be identical to bar discriminability in the low and high load conditions used by Erthal et al. in their second experiment. Stimulus duration was also manipulated between each block by varying the bars/image presentation time between 100ms and 200ms. Image valence was manipulated within each block by either presenting a negative or neutral image with each trial. Four blocks of trials were created: low load 100ms duration, high load 100ms duration, low load 200ms duration, high load 200ms duration. Each block consisted of forty trials, in which twenty negative and twenty neutral images were presented in a randomised order. Finally, image relevance was manipulated between participants by either assigning them to the "task-irrelevant images" condition, where they were instructed to ignore the centrally presented image, or the "task-relevant images" condition, where they were required to attend to the centrally presented image and categorise it as either "negative" or "neutral".

5.7.3 Standard Procedure for the Visual Perceptual Load Tasks

The procedure for both the task-irrelevant and task-relevant versions of the visual perceptual load task are outlined below. With the exception of those aspects of the task that are manipulated for the purposes of this study, the spatial and temporal properties of the task are set to up to be identical to those used by Erthal et al. Please note that the spatial properties of the stimuli described in this section are consistent for all studies subsequently described in this chapter.

5.7.3.1 task-irrelevant Images Condition

Participants completed all four blocks of trials. Each trial began with a “Get Ready” warning slide (1500ms) and then a fixation cross (1500ms, jittered by ± 200ms). A negative or neutral image was then presented (9° X 12°) flanked on either side by a white bar (0.3° X 3.0°). Each bar was presented at 9° from the centre of the image. The duration was either 100ms or 200ms, depending on the block. A checkerboard mask was then presented - this filled the whole screen and remained until a response was detected *or* 1500ms had elapsed. In the this version of the task participants were required to *ignore* the centrally presented image and respond as quickly and as accurately as possible to the bar discimination task, either by pressing “Z” to indicate that the bars were at different orientations, or “M” to indicate that they were at the same orientation. There was an equal number of “same” and “different” responses in each block, and the order of presentation was randomised. The order that the four testing blocks were completed in was counterbalanced between participants. See Figure 5.2a for an example of this task. Equal numbers of “face” and “body” images were presented per block/condition - this was just to ensure consistency among sets - the additional face present/absent variable is not analysed in this study, but it is in Studies 5f and 5g.

5.7.3.2 task-relevant Images Condition

The procedure was identical to that listed above, except that in this version of the task participants were instructed to *attend* to the centrally presented image in addition to the bars. Immediately after responding to the bar discrimination task a screen appeared with the question “Was the image negative or neutral?”. Participants pressed “T” to categorise the image as negative, or “G” to categorise the image as neutral. The trial ended as soon as response was made[3]. See Figure 5.2b for an example of this task.

5.7.3.3 Practice Trials

Prior to the main trial, participants completed two blocks of twenty practice trials: one block in the low load condition and one block in the high load condition. In the practice trials participants were presented with images of arbitrary neutral objects (cars and motorbikes) instead of negative and neutral images, in order to prevent them potentially becoming acclimatised to the negative images prior to the main trials. If a participant had been assigned to the task-irrelevant image condition they were told to ignore the images, whereas if a participant had been assigned to the task-relevant image condition, they were require to categorise the images as either “motorbike” or “car”, using the “T” key to represent “Motorbike”, and the “G” key to represent “Car”.

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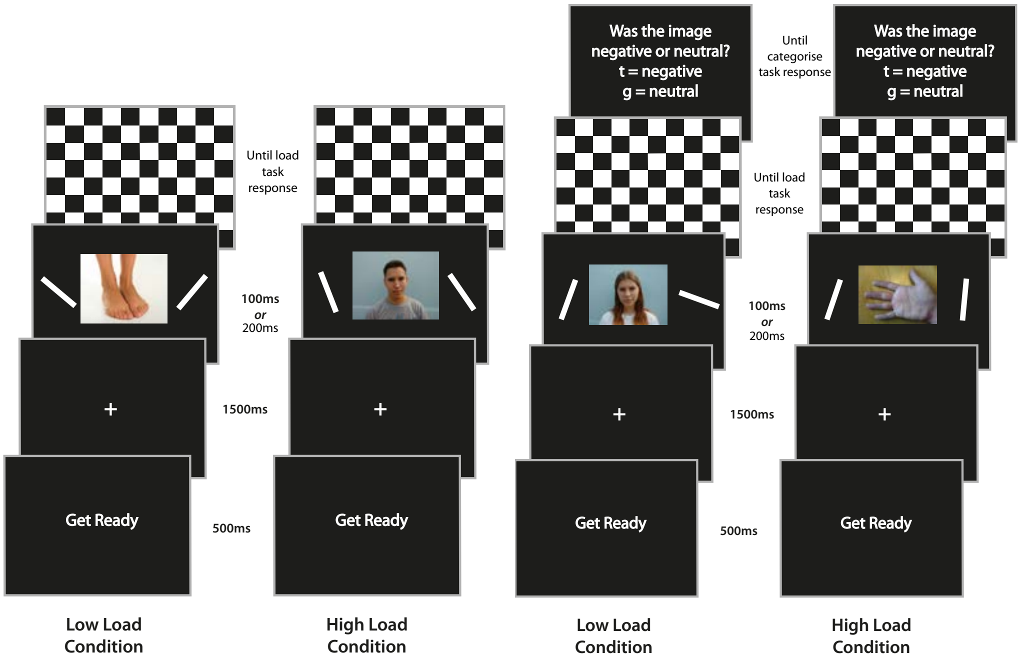
[3] Please note that the “Get Ready” warning slide at the start of each trial was introduced to give participants adequate time to replace their fingers on the “M” and “Z” keys in preparation for the load task, after pressing “T” or “G” to respond to the categorisation task. For consistency, this slide was present in both versions of the task, even though it was only really necessary in the “categorise” task.



(a) task-irrelevant Images Condition (b) Task-Relevant Images Condition

Figure 5.2: Examples of low and high visual perceptual load trials in the task-irrelevant and task-relevant images versions of the task. In the task-irrelevant images condition participants' sole task was to indicate whether the bars were the "same" or "different" orientation, by pressing the Z and M keys, respectively. In the task-relevant images condition participants responded to the bars task and then immediately after were required to indicate whether the image was negative or neutral, by pressing the T and G keys, respectively. Perceptual load was manipulated in both versions of the task by making the bar orientation easy or hard.

5.8 Results

5.8.1 Load Task Accuracy

Mean accuracy in the task-irrelevant image condition was solely based on the proportion of correct responses to the bar discrimination task. However, the addition of the categorisation task in the task-relevant image condition meant that two separate sets of accuracy scores were obtained for this condition: a score for bar discrimination accuracy and a score for image categorisation accuracy. The primary aim of the image categorisation task was to ensure that the image had been attended - therefore, only trials where the image was correctly categorised were included in further analysis. Load task performance on the task-relevant images and task-irrelevant images versions of the task could then be compared[4]. The load task accuracy data were then analysed with a 2x2x2x2 mixed measures ANOVA, with the within subjects factors of load [low, high], valence [negative, neutral], duration [100ms, 200ms] and the between subjects factor of image relevance [task-irrelevant, task-relevant].

There was a main effect of load, $F(1,8) = 461.08$, $p<.001$, $\eta_p{}^2=.98$, which indicated that accuracy on the bar discrimination task was reduced under high load. This confirmed that the load manipulation was a success. There was a marginally significant main effect of image relevance, $F(1,8) = 3.69$, $p=.091$, $\eta_p{}^2=.32$. However, a significant interaction of load by image relevance, $F(1,8) = 6.66$, $p=.033$, $\eta_p{}^2=.45$, suggested that this main effect was being driven by poor

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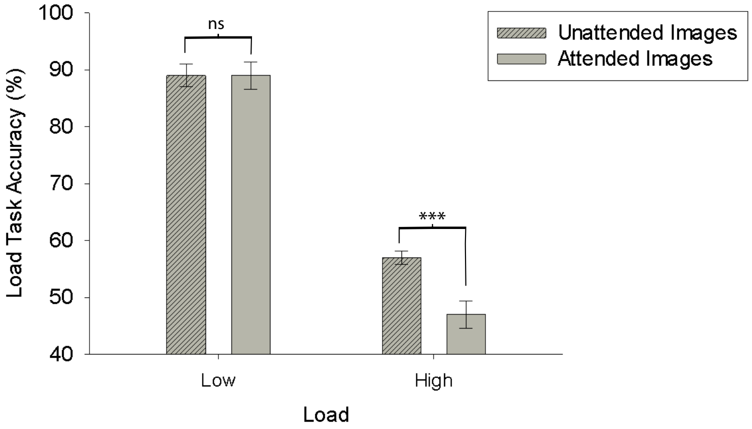
[4] However, one caveat of this analysis is that unless the score on the categorisation task is 100%, there are typically fewer trials in the load task analysis in the categorisation condition than the non categorisation condition.

performance in the task-relevant image condition under high load only. Post hoc independent-samples t-tests confirm that accuracy was significantly reduced in the task-relevant image condition when compared to the task-irrelevant image condition when the bar discrimination task was high load, t(8) = -3.33, p=.01, *d*=.33, but not when the bar discrimination task was low load, t(8) = -.047, p= .97, *d*=.04. However, single sample t-tests confirmed that although performance was above chance in the high load task-irrelevant image condition, t(4) =5.10,p=.007, performance did not significantly differ to chance in the high load task-relevant image condition, t(4) = -1.08, p= .34. These results suggest that under the current high load conditions the task-irrelevant images condition was too difficult to be performed successfully (see Figure 5.3a).

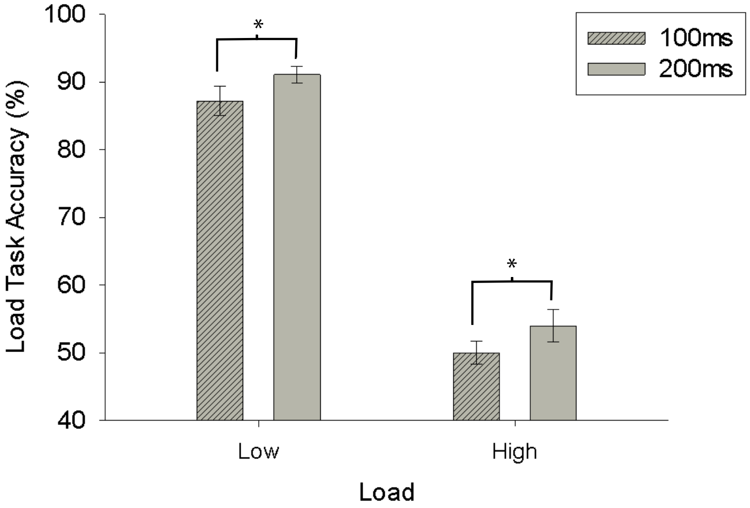
There was also a main effect of duration, F(1,8) = 5.48, p=.047, $\eta_p{}^2$=.41, implying that more rapid stimuli presentation leads to a significant drop in accuracy across all conditions. Once again, single samples t-tests revealed that when collapsed over image relevance and valence, performance in both the high load conditions is not significantly above chance, t(9) = .02, 1.6, p=.99, .15 (see Figure 5.3b).

There was a marginally significant main effect of valence, F(1,8) = 3.85,p=.085, $\eta_p{}^2$=.32, and a significant load*valence interaction, F(1,8) = 11.27, p=.01, $\eta_p{}^2$=.59. Post-hoc paired-samples t-tests confirm that participants were significantly more accurate in the high load negative condition than the high load neutral condition, t(9) = 2.37, p=.04, *d*=1.00, and that valence had no effect in the low load condition, t(9) = -1.1, p=.30, *d*=.38). This suggests that the marginal main effect of valence was driven by participants attaining *higher accuracy* in the negative high load condition than the neutral high load condition. However, single samples t-tests revealed that performance did not significantly differ from chance in either of the high load negative or high load neutral conditions, t(9) = 1.88, -1.18, p=.09, .27, hence this result is not really meaningful.

There was also a significant interaction between image relevance and image valence, F(1,8) = 6.82, p=.031, $\eta_p{}^2$=.46. Post-hoc independent-samples t-tests confirmed that in the task-relevant images condition participants were more more accurate on negative image trials than neutral trials, t(8) = -3.12, p=.01, *d*= 2.0, whereas in the task-irrelevant images condition image valence did not significantly differ, t(8) = .07, p=.95, *d*=.04.



(a) Image Relevance and Load



(b) Load and Duration

Figure 5.3: Mean load task accuracy data representing the relationship between perceptual load, image relevance and stimulus duration.***p<.001, *p<.05

5.8.2 Load Task RT

A 2x2x2x2 ANOVA (as described in the previous section) on the RT data only revealed a significant main effect of image relevance, F(1,8) = 8.40,p=.02, $\eta_p{}^2$=.51, suggesting that participants generally took longer to respond to the bar discrimination task in the relevant images condition than the irrelevant images condition.

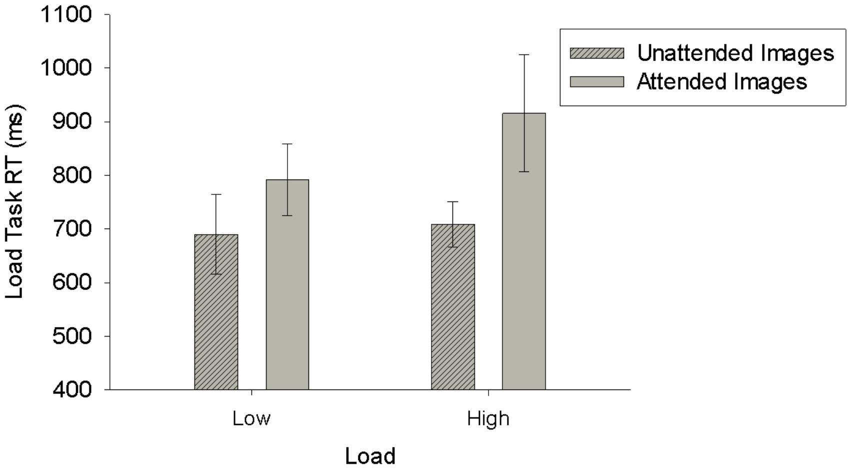


Figure 5.4: Mean load task RT data representing the relationship between perceptual load and task type.

5.8.3 Categorisation Task Accuracy

The image categorisation task accuracy data were also analysed, in order to determine whether participants had been performing this task correctly, and also to check whether performance on the categorisation task was impacted by any of the IVs[5]. Given the non-normality of the data, a Friedman's ANOVA

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[5] Since the categorisation response was not speeded, there were no RT data to analyse for this task.

was calculated, and this confirmed that there were no significant differences between categorisation accuracy in any of the conditions X^2=7.71, df =7, p=.36. Importantly, the results indicated that image categorisation accuracy was high across all conditions(mean accuracy = 90.9% across all conditions), meaning that participants were able to accurately categorise the images regardless of perceptual load, stimulus duration and image valence.

5.9 Discussion

The aims of preliminary study 5b were: 1) to test whether requiring participants to attend to the centrally presented images would impact on performance in the bar discrimination task, 2) to test whether reducing the duration of the stimuli presentation to 100ms led to reduced performance in the bar discrimination task, and 3) to provide an early indication of whether image valence and perceptual load interact or do not interact under conditions of task-relevant image processing when compared with conditions of task-irrelevant image processing.

As expected, the load manipulation was successful - bar discrimination task accuracy was dramatically reduced under high load compared to low load. Bar task accuracy was also reduced in the task-relevant image condition when compared to the task-irrelevant image condition (see Figure 5.3a), but only when the perceptual load of the bar discimination task was high. Under high perceptual load participants can perform just above chance when the images are task-irrelevant, but performance drops to chance when they are required to attend to the images in addition to the bar discrimination task. Under low perceptual load manipulating image relevance has no effect on bar discrimination performance, which suggests that under low load attentional capacity is not exhausted by the bar discrimination task to the extent that it impacts on the processing of the images. Bar discrimination task RTs also significantly increased in the task-relevant images condition, but unlike accuracy this occurred across both low and high load conditions. According to the results obtained by Pessoa et al. and Erthal et al., task-irrelevant emotional image processing is only modulated under very high perceptual load. In order to test whether the same applies to task-relevant emotional images, the level of perceptual load in the final task will need to be very high. However, the results of this preliminary study suggest that if I use the same task-difficulty level as in Erthal et al. (6° bar orientation difference) but *also* require participants to attend to the images, then accuracy is likely to drop to chance levels. Accordingly, the bar discrimination task will need to be made easier (i.e. the orientation difference between the bars will need to be increased), in order to compensate for the additional demands of having to attend to the images, and to allow participants to perform at above chance. The aim of the next pilot study will be to determine an appropriate difficulty level for the task-relevant images task.

As predicted, the data also suggest that faster stimuli presentations lead to reduced accuracy across all conditions. The fact that duration did not significantly interact with any of the variables is also important, as this suggests that speeding up stimulus presentation time does not selectively impact on any of the image relevance, valence or load conditions. This has important implications for the final version of the study, as it suggests that faster stimulus presentations (100ms) can be used without worrying about this changing the nature of the study. The bars and images will therefore be presented for 100ms in all the remaining studies.

As predicted, there was a main effect of image valence on bar task accuracy, which confirms that the negative images were distracting regardless of whether or not they were task-relevant. A main effect of image valence on RT would have also been expected, but this was not the case. Finally, there was an interaction between load task accuracy and image valence. Under high load participants were more accurate at the bar discimination task when the image was negative rather than neutral, although, whereas under low load bar discrimination accuracy did not differ. The direction of the effect is in the opposite direction to what was predicted i.e. negative images would be expected to distract attention away from the bar discrimination task more than neutral images. However, paired-samples t-tests revealed that performance did not significantly differ from chance in either the negative high load or neutral high load conditions, and with this being a preliminary study the sample size is quite low, meaning that this finding is not necessarily valid. The main experiment will provide an opportunity to investigate this effect further.

Study 5c - Visual Paradigm Development - Determining Load Task Difficulty Level

5.10 Introduction

Preliminary Study 5b demonstrated that modifying the original Erthal et al. (2005) “task-irrelevant images” paradigm so that participants were required to attend to the images *and* reducing the stimulus presentation time from 200ms to 100ms resulted in participants performing at chance on the bar discrimination task in the high load conditions. Therefore the first aim of Study 5c was to establish a more suitable task difficulty level for the bar discrimination task in the high load condition. It was critical that participants still find the task very demanding, as task difficulty appears to be crucial in determining whether emotional image processing is modulated by load, but it was equally important that participants did not find the task so challenging that they were unable to perform above chance, as this would effectively result in meaningless data. The second aim of Study 5c was to test the impact of modifying the task so that the two flanking bars would onset consecutively in the new version of the task, rather than simultaneously as in previous versions of the task. It was absolutely necessary to make these changes so that the visual perceptual load version of the task was directly comparable with the auditory perceptual load version of the task described in Study 5e. In the current task the image appeared for 100ms while a bar appeared on each side for 50ms. The rapid presentation of the bars ensured that no eye movements could take place between the offset of the first bar and the onset of the second, and this also meant that any possible visual WM involvement was reduced to a minimum. Consecutive presentation of stimuli is not very common in visual perceptual load tasks, but a consecutive visual presentation task was used in a load manipulation by Doallo et al. (2006), and serial presentation is much more common in auditory load tasks Dalton and Lavie (2004, 2007), primarily due to issues with consecutive presentation of auditory stimuli (please see Section 5.17 for further discussion on this topic). Given that one of the main aims of this set of studies is to compare visual and auditory perceptual load performance this justifies consecutive presentation of the visual perceptual load stimuli.

In the current study participants just performed the *task-relevant* images version of the task i.e. they were required to categorise the image at the end of each trial. Both load task difficulty level and bar stimuli presentation type were manipulated between blocks of trials.. Load task difficulty was manipulated by varying the number of degrees difference between the orientation of the two bars, and bar stimuli presentation type was manipulated by either having the bars appear simultaneously *or* consecutively. Reducing the difference in bar orientation was expected to result in a drop in accuracy. The potential effects of manipulating bar presentation type were more difficult to predict; however, it was conceivable that consecutive presentation might make the bar task harder, as it is not possible to compare both bars on screen at precisely the same time. Critically, if bar presentation type interacted with load or valence this would mean that consecutive stimuli presentation changes the nature of the task and is therefore unsuitable.

5.11 Method

5.11.1 Participants

Nine new postgraduate students (4 were male, mean age = 24.2 years, SD = 2.8) volunteered for the study.

5.11.2 Design

The study was a 4x2x2 design with the within-subjects factors of load [ten degrees, twelve degrees, fourteen degrees, ninety degrees], presentation type [simultaneous, consecutive] and image valence [negative, neutral]. The stimuli were presented in a block design. Load was manipulated between blocks by varying the difference in bar orientation between three levels of high load (ten, twelve and fourteen degrees) and one level of low load (ninety degrees). Although a certain amount of guesswork was involved, pilot testing suggested that the optimal high load difficulty level would be between ten and fourteen degrees. Ninety degrees was chosen for the low load condition as this is furthest apart the two bar orientations can be, and also because this was previously used by Erthal et al. (2005). Stimulus presentation type was also manipulated between blocks - the two bars were either presented simultaneously on either side of the central image, or consecutively i.e. one on either side. Image valence was manipulated within each block by either presenting a negative or neutral image with each trial. Eight blocks of trials were created: simultaneous [10 degrees, 12 degrees, 14 degrees, 90 degrees] and consecutive [10 degrees, 12 degrees, 14 degrees, 90 degrees]. Each block consisted of twenty trials, in which ten negative and ten neutral images were presented in a randomised order.

5.11.3 Procedure

The procedure was identical to that outlined for the "task-relevant images condition" in Study 5b, except for the manipulation of bar stimuli presentation. In the "synchronised bars" condition the procedure was exactly as shown in 5.2b - the image and flanking bars were all presented for 100ms. In the "consecutive bars" condition the image was presented for 100ms and the first bar was presented for 50ms on one side of the image, followed by the second bar for 50ms on the other side of the image. The order of presentation was randomised so that in half the trials the bars appeared on the left and then the right of the image, and in half the trials the bars appeared on the right and then the left. Throughout the entire experiment participants were required to attend to the images and categorise them as either negative or neutral. Participants initially completed two blocks of twenty practice trials - these were as described in Study 5b, except that in the first block the bars were presented simultaneously, and in the second block they were presented consecutively. The practice trials were then followed by the eight blocks of twenty main trials. The order that the 8 blocks were completed in was counterbalanced between participants.

5.12 Results

5.12.1 Load Task Accuracy

Following the same procedure as in Study 5b, only trials where the image was correctly categorised were included in any further analysis. This ensured that only trials where the participant had paid attention to the image were analysed. A preliminary check revealed that one participant had performed exceptionally poorly on the low load task, suggesting that they may have misinterpreted the nature of the task. This participant's data were removed from further analysis. A 4x2x2 ANOVA was computed for the bar discrimination task accuracy data, with the within-subjects factors of load [ten degrees, twelve degrees, fourteen degrees, ninety degrees], presentation type [simultaneous, consecutive] and image valence [negative, neutral]. There was a main effect of load, $F(3,21)=43.83$, $p<.001$, ${\eta_p}^2=.86$, which was largely driven by the low load condition (ninety degrees bar orientation difference) being considerably easier than the other three relatively high load conditions (ten, twelve and fourteen degrees bar orientation difference). There were no other main or interaction effects of any of the other variables. One-sample t-tests were also computed to check whether or not accuracy was above chance in all conditions. Performance in three of the simultaneous bar presentation conditions (12 degrees negative, 12 degrees neutral, 14 degrees negative) and one of the consecutive bar presentation conditions (12 degrees neutral) did not differ significantly from chance, $t(8) = 1.20, 1.50, 1.0, 1.38$, $p>.05$.

In order to test whether the low load conditions [90 degrees negative and 90 degrees neutral] were solely responsible for the main effect of load, a further 3x2x2 ANOVA was computed with the low load conditions omitted from the analysis. The factors were load[10 degrees, 12 degrees, 14 degrees], presentation type [simultaneous, consecutive] and image valence [negative, neutral]. With the low load condition removed, there were no main or interaction effects of any variables, which indicates that the low load condition significantly contributed towards the main effects of valence and presentation type.

5.12.2 Load Task RT

A 4x2x2 ANOVA (factors as described above) was computed for the bar discrimination task RT data. There were significant main effects of load, F(3, 6) = 6.31, p=.03, $\eta_p{}^2$=.76, image valence, F(1, 8) = 16.64, p=.004, $\eta_p{}^2$= .68, and presentation type, F(1, 8) = 10.35, p=.01, $\eta_p{}^2$=.56. RTs were significantly increased under high load compared to low load, on trials where there was a negative image present compared to a neutral image, and also when bar presentation was simultaneous rather than consecutive. Again, it appeared that the low load [90 degrees] conditions were responsible for the main effect of load.

As in the previous section, in order to test whether the low load was solely responsible for the main effect of load, a further 3x2x2 ANOVA was computed with the low load conditions omitted from the analysis. The factors were load[10 degrees, 12 degrees, 14 degrees], presentation type [simultaneous, consecutive] and image valence [negative, neutral]. With the low load condition excluded from the analysis, there was no main effect of load. However, there were still main effects of valence, F(1,8) = 7.36, p=.03, and presentation type, F(1,8) =

9.30, p=.02.

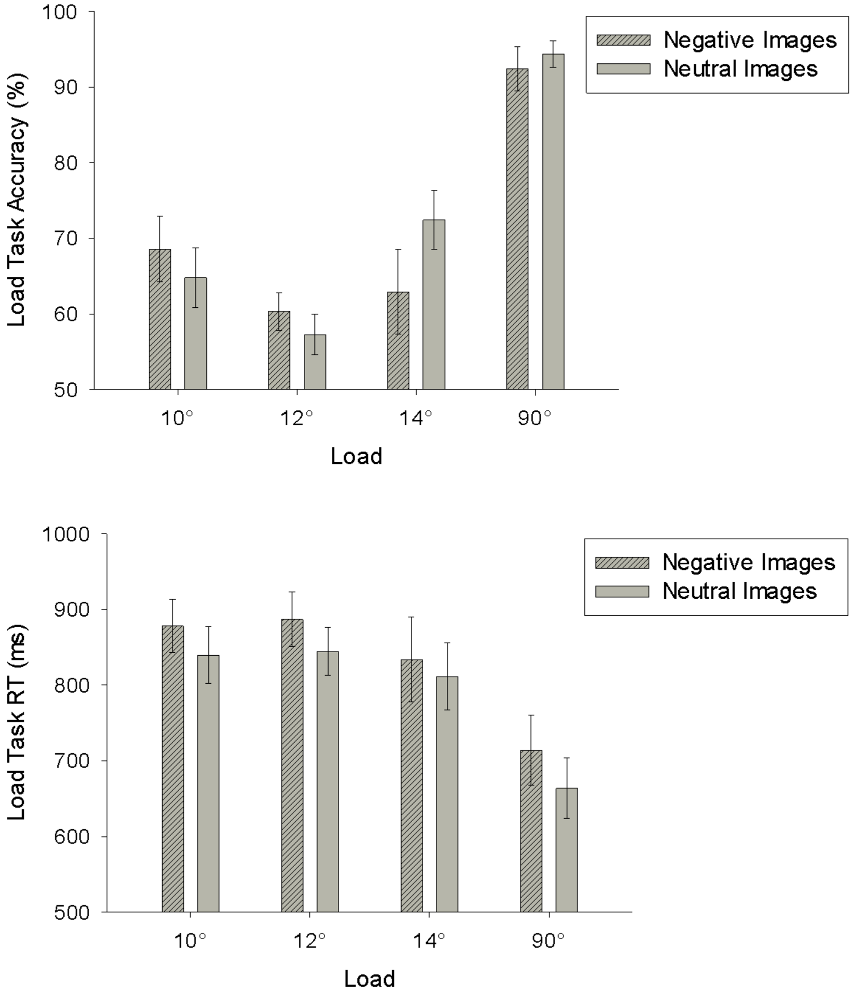

Figure 5.5: Mean load task accuracy and RT data representing the relationship between image valence and perceptual load [10, 12, 14 and 90 degrees bar orientation difference].

5.12.3 Categorisation Task Accuracy

The image categorisation accuracy data were analysed in order to check that participants had performed the categorisation task properly. Image categorisation accuracy was consistently high across all conditions (mean accuracy = 90.1%, SE = 4.5%). Given the non-normality of the data, a Friedman's test was applied to the data - this confirmed that there were no significant differences between any of the conditions, X^2=14.8, df = 9, p=.47.

5.13 Discussion

The two main aims of this study were to establish an appropriate level for the high load task whereby mean accuracy performance was around 60-65%, and to test whether performance was affected by presenting the bars consecutively compared to simultaneously. The data confirm that the low load task (90 degrees bar orientation difference) was suitable for use in the main experiment, as mean accuracy was high (suggesting that participants found the task easy), but not at ceiling. The high load task data were less conclusive; although performance in the ten degrees condition was circa 65% accuracy, mean accuracy in the 12 degrees condition was lower, and performance did not differ significantly from chance in some of the 12 degrees and 14 degrees conditions. This is a surprising result, as 10 degrees would be expected to be more challenging than 12 or 14 degrees, and it suggests that this may have been a fluke. Furthermore, the ANOVA on the high load accuracy data (excluding the low load condition) revealed that accuracy did not significantly differ between 10, 12 and 14 degrees, which indicates that participants found all three conditions very challenging and there was very little difference between them.

A similar pattern of results were observed with the RT data. Although the initial ANOVA revealed main effects of load, image valence and presentation type; a further ANOVA with the low load condition excluded revealed that RT did not significantly differ as a result of the load manipulation between 10, 12 and 14 degrees, which again suggests that there was very little difference between performance on these conditions. The main effect of image valence was as expected, and crucially, presentation type did not interact with any other variables.

As none of the high load conditions were suitable for use in the main study, it was necessary to repeat the study but with a set of slightly easier high load conditions (Study 5d).

Study 5d - Further Visual Paradigm Development - Determining Load Task Difficulty Level

5.14 Introduction

The previous study established that participants found all three prospective high load conditions (10, 12 and 14 degrees bar orientation difference) too challenging to perform at above chance. The aim of this study was to further reduce the difficulty of the bar discrimination task (by increasing the magnitude of the bar orientation difference), in order to try and determine a level at which participants found the task very challenging, but were still able to perform at consistently above chance.

5.15 Method

5.15.1 Participants

Nine new postgraduate students (3 were male, mean age = 25.4 years, SD = 2.5 years) volunteered for the study.

5.15.2 Design and Procedure

The study was a 3x2x2 design with the within-subjects factors of load [14, 18 and 22 degrees], presentation type [simultaneous, consecutive] and image valence [negative, neutral]. The design and procedure were identical to Study 5c, except that the levels of difficulty of the high load bar discrimination task were changed to 14. 18 and 22 degrees. Study 5c had already established that 90 degrees was a suitable level for the low load condition, so it was not necessary to test this again. As before, presentation type was manipulated to test whether presenting bars consecutively rather than simultaneously interacted with any of the other variables.

5.16 Results

5.16.1 Load Task Accuracy

Following the same procedure as in the previous studies, only trials where the image was correctly categorised were included in any further analysis. This ensured that only trials where the participant had paid some attention to the image were analysed. A 3x2x2 repeated-measures ANOVA with the within-subject factors of load [14, 18, 22 degrees], presentation type [simultaneous, consecutive] and image valence [negative, neutral] was computed for the bar discrimination task accuracy data. Again, there was no main effect of load, but a significant interaction between load and valence was revealed, F(2,16) = 9.82, p=.002, $\eta_p{}^2$=.55. Bonferroni corrected paired-samples t-tests (reduced alpha criterion p<.017) suggested that this interaction was due to participants performing marginally more accurately on negative trials than neutral trials in the 14 degrees condition, t(8) = -2.38, p=.046, but marginally more accurately on neutral trials in than negative trials in the 18 degrees condition, t(8) = 2.22, p=.05. There was no difference between performance on negative and neutral trials in the 22 degrees condition, t(8) = 1.04, p=.33. The opposing patterns of data in the 14 and 18 degrees conditions are unexpected - however, given the relatively small sample size, not too much should be read into these preliminary results. Paired samples t-tests were also carried out to test whether the data in all conditions were above chance - this was the case in all conditions except for both the consecutive and simultaneous neutral 14 degrees conditions, t(8) = 1.75, 1.60, p=.12, .15, respectively.

5.16.2 Load Task RT

A 3x2x2 ANOVA (as described above) was computed on the bar discrimination RT data. There was a main effect of bar presentation type, F(1,8) = 44.05, $p<.001$, $\eta_p{}^2$=.85. RTs were significantly higher when the bars were presented simultaneously, compared to when they were presented consecutively, but no main or interaction effects of either load or valence.

5.16.3 Categorisation Task Accuracy

The image categorisation accuracy data were analysed in order to check that participants had performed the categorisation task properly. Image categorisation accuracy was consistently high across all conditions (mean accuracy = 90.1%, SE = 4.5%). Given the non-normality of the data, a Friedman's test was applied to the data - this confirmed that there were no significant differences between any of the conditions, X^2=12.45, df = 11, p=.33.

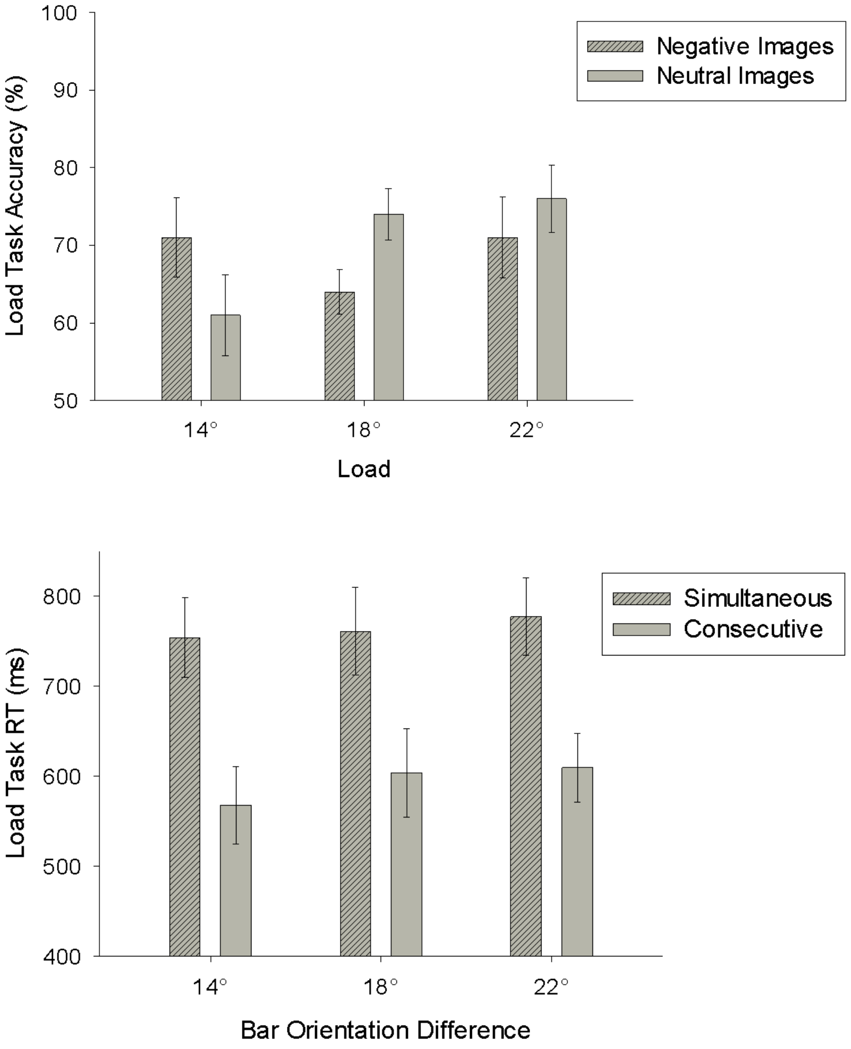

Figure 5.6: Mean load task accuracy and RT data representing the relationship between image valence, presentation type and perceptual load [14, 18 and 22 degrees bar orientation difference], image valence and presentation type.

5.17 Discussion

The aim was to discover a bar discrimination level that participants found very challenging, but at which they were still able to perform above chance. Once again, there was no main effect of perceptual load observed across the high perceptual load conditions, which suggested that increasing bar discrimination difference from 14 - 22 degrees does not impact on performance. However, accuracy in all the 18 and 22 degrees conditions was consistently above chance (mean accuracy was circa 65%) whereas in the 14 degrees condition there was still chance performance in some conditions, which suggests some participants were still unable to do the task properly. On this basis, either 18 or 22 degrees orientation difference should be a suitable level for a high load task in the forthcoming main experiment.

As before, RTs were higher when the bars were simultaneous, compared to when they were consecutive, which just suggests that simultaneous presentation increases overall task difficulty. There was no main effect of load, which ties in with the accuracy data. Surprisingly there was also no main effect of image valence on load task RT - a result that is inconsistent with the previous study (5.13) which did demonstrate a main effect of image valence on load task RT. One possible explanation for this inconsistency is that in the previous study the difficulty level of the load task was so high that participants were unable to engage in the task properly (as indicated by chance performance across multiple conditions), meaning that they focused more attention on the image and their load task “guesses” were affected more by the negative images than the neutral images. In the current study, participants were able to correctly engage in the load task across more of the conditions, meaning that they were actually subject to the effects of high perceptual load as intended. If high perceptual load really does modulate the effects of emotional stimuli, then the non-significant main effect of image valence demonstrated in the current study is to be expected.

Finally, accuracy at the image categorisation task was very high across all conditions, which suggests that participants were able to perform this task fairly easily despite the level of perceptual load they were subjected to with the bars task.

Study 5e - Auditory Paradigm Development - Determining Load Task Difficulty

5.18 Introduction

As stated in the main introduction, the overall goal of this chapter was to test whether visual *and* auditory load can modulate the processing of emotional images. The "task-relevant images" visual perceptual load paradigm used in Studies 5b-5e was therefore modified to allow the effects of auditory load on emotional image processing to be assessed. In the new auditory version of the task, participants were presented with an image on screen accompanied by a tone discrimination load task. The new auditory task was designed to be analogous to the visual task i.e. participants were presented with two auditory stimuli and were required to make a "same/different" judgement. This task was loosely based on the auditory search tasks used by Dalton and Lavie (2004, 2007), where the task was to monitor a sequence of five tones for a target tone that differed in frequency to the non-targets. However, given that the image and tone presentation needed to be very rapid (100ms) in order to eliminate the effects of eye movements, the number of tones in the sequence was reduced to two (50ms each), and rather than monitoring the sequence of tones for the “odd one out”, the task was just to indicate whether the two tones were the same or different frequency.

Ideally, the two tones in the auditory load task would have been presented simultaneously in a similar manner as the two bars in visual load task. I originally pilot tested a tone discrimination task where two tones were presented simultaneously; one tone in one ear, and tone of the same or different frequency in the other each. It quickly became apparent that participants found it extremely difficult to make accurate same/different judgements unless the two tones were of dramatically different frequencies. The data suggested that performance was either at ceiling, or at chance, meaning that identifying a “high load” condition where accuracy was consistently around 65% would have been very difficult indeed. Accordingly, I adapted the task so that the tones were presented consecutively, rather than simultaneously. Participants found this task considerably easier to deal with, so I decided to go ahead and run a full scale pilot with the consecutive presentation version of the task.

One of the main criticisms of the auditory and visual perceptual load tasks in my perceptual load/change-blindness study was that the nature of the tasks was quite different i.e. in the visual perceptual load task targets and non-targets were all presented simultaneously, whereas in the auditory perceptual load task targets and non-targets were presented sequentially. It was therefore very important that the visual and auditory tasks were as identical is possible in the current study. Simultaneous presentation did not appear to be viable in the auditory task, so this meant it was necessary to adapt the visual perceptual load task so that it was as similar as possible to the auditory task. This explains why the effects of simultaneous Vs consecutive bar task presentation were tested in studies 5.9 and 5.13. Furthermore, given that that the bars in the visual tasks were presented consecutively to the left visual field then right visual field (or vice-versa), an analogous method of presentation was incorporated into the design of the auditory tasks, so that the tones were presented consecutively to the left ear then right ear (or vice-versa).

The aim of Study 5e was to test the novel auditory paradigm and try to determine an optimal difficulty level at which to set both the low and high auditory load tasks. In order for valid comparisons to be drawn between the visual and auditory data, performance in the high and low auditory load conditions would need to be roughly similar to performance in the high and low visual conditions (approximately 95% and 65% accuracy, respectively).

5.19 Method

5.19.1 Participants

10 undergraduate students (3 were male, mean age = 19.5 years, SD = 1.1 years) who participated in the study in exchange for course credits.

5.19.2 Design

The study was a 4x2 design with the within-subjects factors of load [40Hz, 60Hz, 120Hz, 150Hz] and image valence [negative, neutral]. The values given for load represent the difference between the two tones in each of the conditions e.g. "40Hz" represents a 40Hz difference. Some preliminary testing suggested that people generally found a 120-150Hz tone discrepancy relatively easy to detect, and a 40-60 Hz discrepancy much more challenging, hence these were the values that were chosen for this pilot study. The tones were created using audacity sound editing software (http://audacity.sourceforge.net/). The tones ranged from 700Hz to 1200Hz, in 5Hz increments, and each tone was 50ms in duration.

5.19.3 Procedure

The procedure was the same as for the visual perceptual load task-relevant images condition detailed in Section 5.2b, except that the two bars presented consecutively on the left and right sides of the image were replaced with two tones presented consecutively to each ear (via headphones). [6] Load was manipulated between each block by varying the difference between the two tones

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[6] The original plan had been to present the two tones simultaneously (one in each ear), akin to the manner of bar presentation in the "simultaneous presentation" version of the visual perceptual load task. However, initial pilot testing suggested that participants found it very challenging to discriminate tones that were presented in this manner, and that it would have extremely difficult to develop high and low load versions of a "simultaneous tones" task. The necessity for consecutive presentation of the auditory stimuli was the primary reason for adapting the original version of the bars task from simultaneous to consecutive presentation, and for testing the two different versions of the task in an attempt to determine what the effects of these changes were.

- as the difference between the two tones decreased the task became more demanding. Participants pressed “Z” to indicate that the tones were different, or “M” to indicate that they were the same. There were the same number of “same” and “different” responses in each block. To prevent participants becoming accustomed to a particular tone and order of delivery, the frequencies of both tones were randomised between trials as well as the order of delivery to each ear. For example, trial one: 800Hz Right Ear → 840Hz Left Ear, trial two: 950Hz Left Ear → 910Hz Right Ear, trial three: 1000Hz Left Ear, 1000Hz Right Ear etc. Participants completed two blocks of 20 practice trials [150Hz and 40Hz], then four blocks of 40 main trials at varying difficulty levels [40Hz, 60Hz, 120Hz and 150Hz]. The order of presentation was counterbalanced.

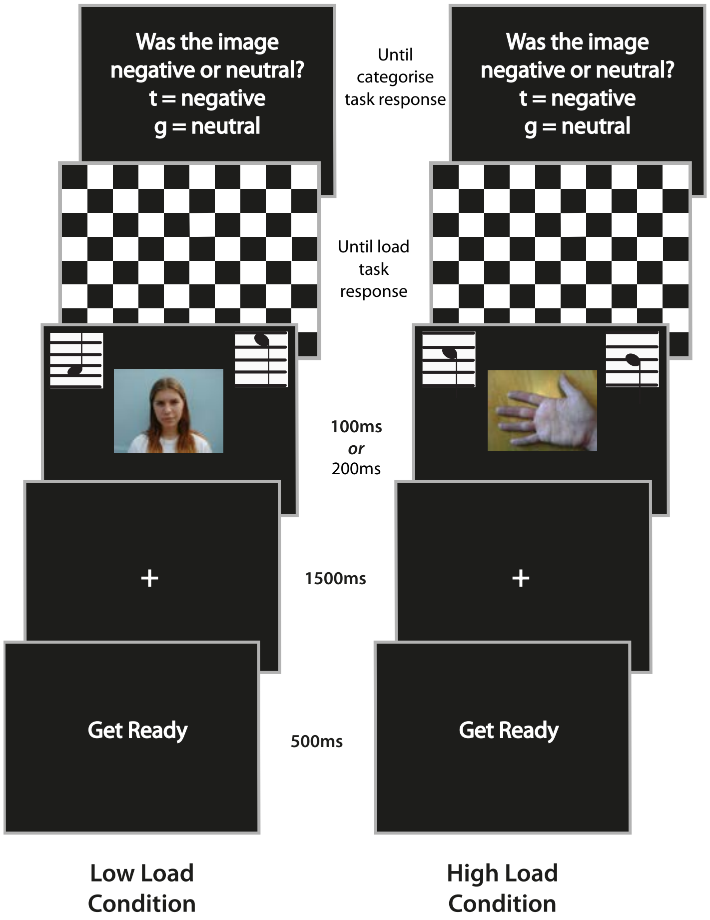

Figure 5.7: Examples of low and high auditory perceptual load trials. Participants were required to first make a speeded response to indicate whether the two tones presented concurrently with the image were the same or different, and then to indicate whether the image was negative or neutral. Load was manipulated by decreasing the difference in frequency between the two tones.

5.20 Results

Two participants were excluded from further analysis as they demonstrated poor performance at the image categorisation task (two standard deviations below the mean of the other participants in several conditions), suggesting that they had either misinterpreted the nature of the task, or that they had not been attending to the images presented on screen.

5.20.1 Load Task Accuracy

A 4x2 repeated measures ANOVA was computed for the load task accuracy data, with the within subjects factors of load [40Hz, 60Hz, 120Hz, 150Hz] and valence [negative, neutral]. There was only a significant main effect of load, F(3, 21) = 3.43, p=.04, $\eta_p{}^2$=.33. As the level of auditory load was decreased (by progressively increasing the difference between the two tones), accuracy at the tone discrimination task increased. However, single sample t-tests revealed that accuracy in each of the high load conditions (40Hz negative, 40Hz neutral, 60Hz negative, 60Hz neutral) was very variable, and did not in fact differ significantly from chance, t(7) = .56, 1.72, 1.02, 1.57, p>.05, respectively. Critically, there was an enormous amount of variability between participants in all conditions of this task, even in the supposedly low load conditions. For example, in the 150Hz neutral condition (where participants would be expected to perform well), accuracy rates (%) per participant were: 100, 85, 80, 80, 62, 59, 50, 27. In the 60Hz neutral condition (which participants were expected to find challenging), accuracy rates (%) per participant were: 90, 90, 83, 60, 58, 55, 42, 26. Similar variability was observed across all 8 conditions.

5.20.2 Load Task RT

A 4x2 repeated measures ANOVA (factors as described above) was also computed for the RT data - this revealed a significant main effect of valence, F(1, 7) = 5.59, p=.05, $\eta_p{}^2$=.33. It appears that, with the exception of the 40Hz load condition, RTs were generally higher on negative trials compared to neutral trials.

5.20.3 Categorisation Accuracy

The image categorisation accuracy data were analysed in order to check that participants had performed the categorisation task properly. Image categorisation accuracy was consistently high across all conditions (mean accuracy = 90.1%, SE = 4.5%). Given the non-normality of the data, a Friedman's test was applied to the data - this confirmed that there were no significant differences between any of the conditions, X^2= 6.68, df = 7 , p= . 46.

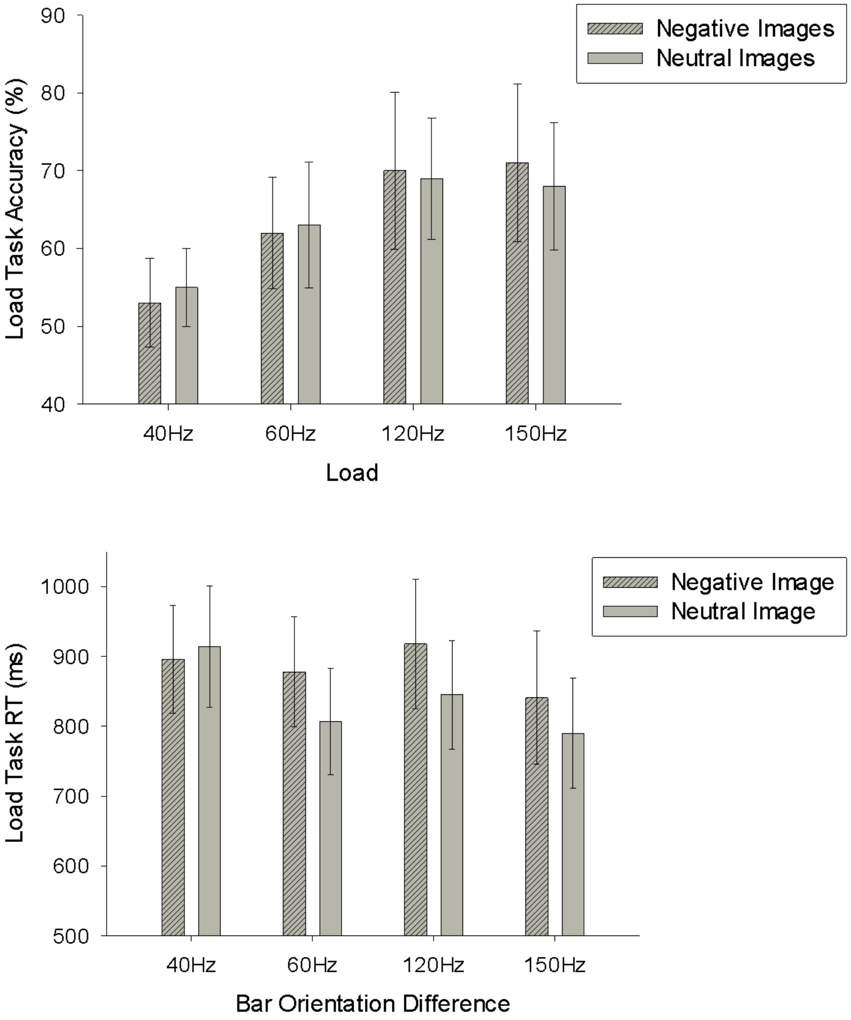

Figure 5.8: Mean load task accuracy and RT data representing the relationship between image valence and auditory perceptual load [40, 60, 120 and 150 Hz].

5.21 Discussion

The primary aim was to determine optimal tone discrimination difficulty levels to use in the high and low auditory perceptual load conditions. The accuracy data suggest that the 40Hz and 60Hz conditions were too demanding to be used in the high load condition of the main experiment, and that the 120Hz and 150Hz conditions were also too demanding to be used in the low load condition of the main experiment. Although the primary aim of the study was not achieved, the main effect of image valence on the auditory load task RT data is an important finding, as it indicates that the emotional images lead to increased tone discrimination RTs when compared with neutral images. Furthermore, image categorisation accuracy was consistently high across all conditions, although accuracy was not quite as close to ceiling as it was in the two preceding visual perceptual load studies, which suggests that participants find it more difficult to perform this cross-modal adaptation of the task-relevant images paradigm.

One option at this stage would have been to re-run the study with a slightly easier set of conditions, which would have hopefully lead to improved tone discrimination accuracy across all conditions. However, this would not have addressed the issue of extensive tone discrimination variability between participants. For example, in the 60Hz condition, which was expected to be challenging; three participants found the task relatively easy (scoring 90, 90 and 83% accuracy), whereas the other five participants found it significantly more challenging (scoring 60, 58, 55, 42 and 26% accuracy). This suggests that the task was actually “low” load for the high scoring participants, and “high” load for the low scoring participants. Similar patterns of variability were present in all conditions, which indicated that regardless of the task difficultly level that was set, some participants would be able carry out the task successfully, whereas others would not. Ultimately, this indicated that it was probably not plausible to determine fixed load task difficulty levels for the auditory perceptual load task.

The second option was to accept that large individual differences in tone discrimination ability mean that it was just not plausible to determine fixed load task difficulty levels for the auditory perceptual load task, and instead adopt a different approach whereby task difficulty in the main study would be calibrated to each individual participant's ability. Differences in pitch discrimination thresholds have been demonstrated in classically trained musicians versus non-musicians - Micheyl et al. (2006) found that non-musicians' mean thresholds for the discrimination of tones were more than six times larger than the thresholds of classically trained musicians; and even after 2 hours of training the non-musicians' thresholds were still four times that of the musicians, and other studies that have compared the two groups found similar, but smaller, effects (Spiegel, 1984; Kishon-Rabin et al., 2001). Given that such differences can exist in pitch discrimination between those with musical experience and those without, it is not too surprising that pitch discrimination thresholds varied substantially between randomly selected participants in my sample. I therefore decided to go with the calibration approach, as I believed it would result in a more robust experiment and cleaner dataset. The development and application of the calibration procedure are described in the next section.

Study 5f - Main Experiment - The Effects of Auditory and Visual Perceptual Load on Task-relevant Image Processing

5.22 Introduction

5.22.1 Recap results from preliminary studies 5a - 5e

The aim of this study was to test whether visual and auditory perceptual load modulates the processing of task-relevant emotional images. In order to design a fully within subjects study with analogous visual and auditory conditions and a well balanced set of neutral and emotive images it was necessary to carry out a number of pilot studies to develop and refine the paradigm. To summarise:

- In study 5a, a set of 80 neutral and 80 emotive images were rated using the IAPS rating procedure developed by Lang et al. (1999).
- Study 5b demonstrated that the addition of a categorisation task to the original bar discrimination paradigm made the visual bar discrimination task significantly more challenging. It also confirmed that reducing the duration from 200ms to 100ms had the general effect of making the bar discrimination task harder, but that reducing the duration did not interact with any of the other variables. These results suggested that the difficulty level of the bar discrimination task needed to be reduced, and that, aside from making the bar discrimination task slightly more challenging, re-

ducing the duration of the stimulus presentation would not significantly impact on the outcome of the study, in its own right.

- Overall, studies 5c and 5d suggested that either 18 or 22 degrees difference would be suitable for use in the high visual perceptual load condition. However, within each condition bar discrimination accuracy varied considerably between participants, suggesting that the level of perceptual load experienced in any "low" or "high" task, is strongly influenced by each individual's perceptual discrimination abilities. These studies also confirmed that altering the method of bar presentation from simultaneous to consecutive did not selectively impact on the outcome of the study, but that this just had the effect of making RTs to the task slightly faster overall.
- Study 5e confirmed that there was even more variability in the auditory tone discrimination task data than the visual bar discrimination task data, and indicated that setting fixed levels for the high high and low auditory load tasks would most likely result in very messy data and either chance or ceiling performance in many participants.

5.22.2 Using the Method of Constant Stimuli

Given the extensive variability in the visual and auditory perceptual load tasks, the decision was made to calibrate the difficulty level of both the visual and auditory perceptual load tasks according to each participant's bar and tone discrimination abilities. Calibration ensured that participants were engaging in tasks that were of high or low perceptual load relative to them, rather than relative to group means, and in theory this would result in cleaner, less variable data, and less likelihood of chance/ceiling performance. In order to determine what calibration method to use it was first necessary to weigh up the pros and cons of two different calibration methods commonly used in psychophysics.

One common problem in psychophysics is determining the strength of a signal required for a subject to be able to perform a perceptual task. One of several solutions to this problem is the method of constant stimuli (MCS) (e.g. Simpson, 1988; Gescheider, 1997), where stimuli are presented at multiple different strength levels, ranging from weak to strong. If the task is 2AFC, then performance across the range of stimuli will vary from 50% (chance) to 100% (ceiling). Performance can then be plotted against stimulus strength and a curve fitted to the data, allowing the threshold strength to be calculated for any probability level. An alternative solution to determining threshold strength is to use an "adaptive staircase" method, whereby signal strength in the first trial is very strong and easy to detect, but on subsequent trials intensity is reduced until the participant is unable to respond, at which point the staircase "reverses" and intensity is increased until the participant begins to respond correctly again, at which point another "reversal" is triggered (e.g. Kaernbach, 1991). There is evidence that adaptive staircase methods are just as accurate when it comes to estimating thresholds values, but more efficient because the staircase cuts out all the trials that are well above or below the threshold of interest far more quickly (Emerson, 1984; Watson and Fitzhugh, 1990; Dai, 1995). However, staircase methods can be problematic, and there are a myriad of different factors that need to be taken into account when designing the task, such as the size of the steps, the ratio of the up-down rule and whether step size is kept consistent or reduced over trials(García-Pérez, 1998, 2011). Considering that in the current study I was applying a calibration procedure to a novel task, I decided to stick to the more straightforward (albeit slightly less efficient) MCS procedure.

The MCS procedure enabled participants' bar and tone discrimination thresholds to be assessed prior to the main experiment. Varying levels of the bar and tone discrimination tasks were presented, with discrimination difficulty ranging from easy to difficult. Difficulty levels were varied randomly between trials, so the participant had no insight into the difficulty level of each forthcoming trial. The MCS procedure was completed in the first testing session and a curve was fitted to the data to determine optimal thresholds for low and high visual and auditory perceptual load task performance. Task difficulty levels in the main experiment were then modified according to each individual's thresholds and the main experiment was run in a second testing sessions approximately 1 week after the first session.

5.22.3 Predictions

Erthal et al. demonstrated that task-irrelevant emotional images slowed reaction times in a relevant visual bar discrimination task under conditions of low, but not high visual load. In the current study a similar modulatory effect of visual load on task-relevant emotional stimuli may also be expected; a result that would provide additional support for load theory. Alternatively, it is possible that by attending to and consciously processing the emotional stimuli, the modulatory effects of visual load may be overcome; meaning load and valence may not interact. It is even more difficult to predict a possible pattern of results for the data in the auditory perceptual load task. Although evidence has suggested that auditory load does not impact on task-irrelevant motion processing (Rees et al., 2001), Study 3b suggests that auditory perceptual load can impact on change detection, and other studies have demonstrated that affective visual stimuli can impact on the processing of task-irrelevant auditory information. Therefore it is also possible that there will be an interaction between auditory perceptual load and affective image processing in their current study.

5.23 Method

5.23.1 Participants

24 undergraduate and postgraduate students (8 were male, mean age = 20 years, SD = 2.3 years) were each paid 15 pounds for their participation. The study took place over two sessions: a calibration session and a main experimental session. In the first session participants completed both the visual and auditory load task calibration procedures. Six participants were excluded from further testing at this stage as a result of poor performance in the auditory calibration procedure i.e. their accuracy in all conditions was so low that it was impossible to fit a Wiebull curve to their data and calibrate the main experiment according to their tone discrimination abilities. This meant that 18 participants in total went on to complete the second, main experimental session. However, a further four participants were also excluded from this session due to a change that had to be made to the experiment (this is discussed in Section 5.23.2.4). This meant that a total of 14 participant's data (7 were male, mean age = 20 years, SD = 2.1 years) were subject to further analysis. All participants were paid 15 pounds

regardless of whether they took part in one or both sessions.

5.23.2 Pre-experiment Calibration using Method of Constant Stimuli

5.23.2.1 Design

The visual and auditory calibration procedures were both one-way repeated measures designs. The visual procedure had a within subjects factor of load [the difference between the two bars ranged from four to forty degrees, in increments of four degrees]. The auditory procedure also had a within subjects factor of load [the difference between the two tones ranged from twenty to two hundred hertz]. Pilot testing indicated that participants would perform close to ceiling in the forty degrees visual condition and two hundred hertz auditory condition, and as the bars or tones become harder to discriminate, performance would drop to around chance levels.

Bar stimuli were presented at all possible angles with the *exception* of the cardinal orientations (0, 90, 180 and 270 degrees). These angles were omitted due to known asymmetries in visual search performance for target lines presented at horizontal or vertical orientations relative to tilted non-targets. For example, visual search for a target line segment tilted off vertical by 15° among non-target horizontal lines is more efficient than search for a vertical target line segment among non-targets tilted at 15° (e.g. Foster and Ward, 1991b,a; Foster and Westland, 1995; Treisman and Gormican, 1988). According to Treisman and Gormican (1988) this search asymmetry is because the vertical and horizontal axes provide a “frame” for the coding of orientation, so any non-horizontal or non-vertical orientations pop out, such as when search is for a tilted target among vertical non-targets; whereas the cardinal orientations themselves do not pop out, hence why search for a vertical line among tilted targets is inefficient. Although the bar discrimination task in the current study wasn’t strictly a visual search task, presenting the cardinal orientations during the experiment *may* mean that bar discrimination on trials where one or both bars were exactly vertical or horizontal may be enhanced relative to trials where neither bar was horizontal or vertical. As a further precaution to reduce any possible discrimination enhancement by bars that were just off vertical or horizontal, no bar orientations within 10 degrees of the vertical or horizontal orientations were used.

Tone stimuli ranged from 700Hz to 1200Hz. The entire frequency range was used. It was not deemed necessary to expose participants to negative or neutral images as part of the calibration procedure - instead, the images of cars and motorbikes that were used in the practice trials were used. This was also to avoid potentially desensitising participants to highly emotional images prior to the main study.

5.23.2.2 Visual Calibration Procedure

The Method of Constant Stimuli (MCS) required that a two alternative forced choice (2AFC) judgement is made for each trial. In its current form the task-relevant images version of the paradigm was not suitable for use in the MCS because a) the current task requires a speeded judgement (so “no response” is possible), and b) the level of load is defined on a "per block" basis [7]. The MCS task required a "same" or "different" judgement to be made for each trial, so the task was adapted accordingly (See Figure 5.9). The spatial configuration of the stimuli was as described in Section 5.7.3. Each trial began with a "Get Ready" warning slide (1500ms) and then a fixation cross (1500ms, jittered by ± 200ms). An image of a bar or motorbike was then presented, flanked either side by a white bar. The image appeared for 100ms, and the bars appeared consecutively on each side of the image for 50ms each. A checkerboard mask was then presented - this filled the whole screen and remained for 1500ms. This entire process was then immediately repeated. After the second checkerboard mask a screen appeared asking the participant to indicate which of the two *sets* of bars was different in orientation. Participants either pressed "1" to "2" to indicate that the first or second set of bars were different. This instruction remained until a response had been made. This was followed by a screen instructing the participant to indicate whether the two images were the "same" (both cars or both motorbikes) or "different" (one car, one motorbike). Participants responded "T" for "same", and "G" for "different". This instruction also remained until a response had been made. The next trial then followed immediately. The different difficulty levels were presented in a randomised order to prevent habituation at each level (this is standard procedure for the MCS). There were ten levels of stimuli (ranging from

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[7] For example, in a block of high visual load trials, participants are aware that there will not be much difference between the orientation of the two bars in "same" and "different" trials, and will thus be looking for the smallest discrepancy in bar orientation. In contrast, in a block of low load trials, participants are aware that the difference between the orientation of the two bars in "same" and "different" trials will be very different, and will thus not be looking for subtle orientation discrepancies in the same way. This block design works fine for the main study, in which participants are required to make a speeded 2AFC response for each trial, but it is unsuitable for use in the Method of Constant Stimuli, as the levels of the stimuli are presented randomly, not in blocks.

four to forty degrees difference) with twenty trials at each level. Participants completed 200 trials in total. They were able to take a break every 20 trials.

Although the calibration task was procedurally different from the standard version of the "task-relevant" task which will be used in the main study, it essentially required participants to do the same tasks i.e. discriminate between two bars while attending to the central image. However, the differences between the MCS and main study are discussed later.

5.23.2.3 Auditory Calibration Procedure

The procedure was exactly the same as for the visual calibration procedure, except that for each trial the pairs of flanking bars were replaced with pairs of tones. The tones were identical to those used in Study 5e i.e. they ranged in frequency from 700Hz to 1200Hz, in 5Hz increments, and each tone was 50ms in duration.

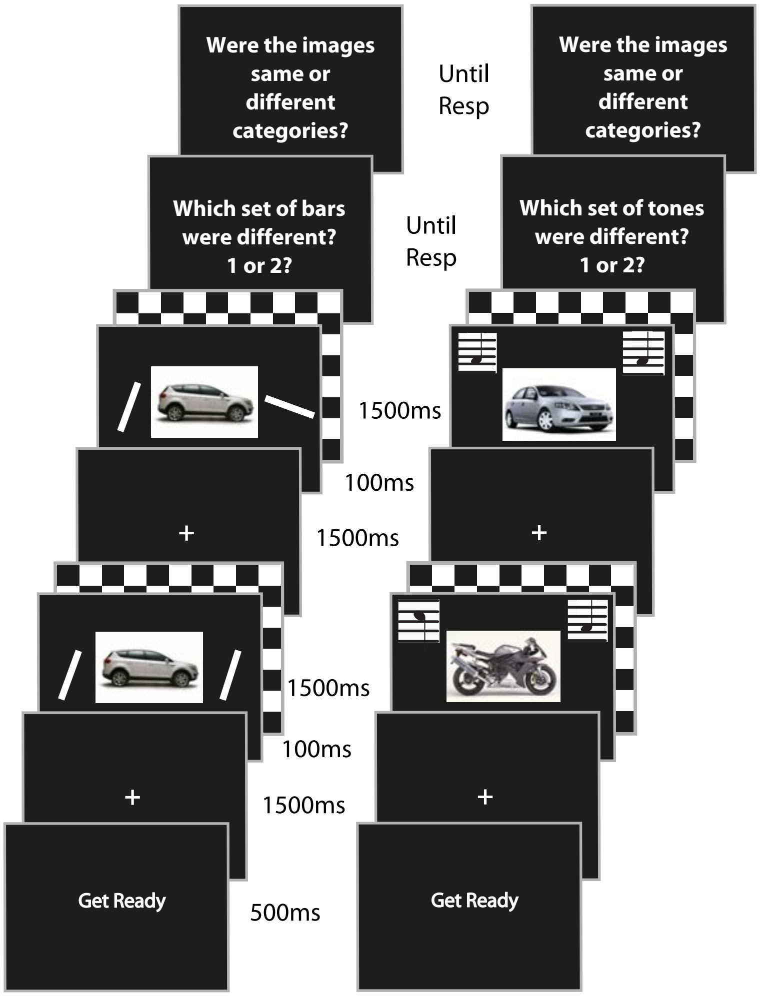
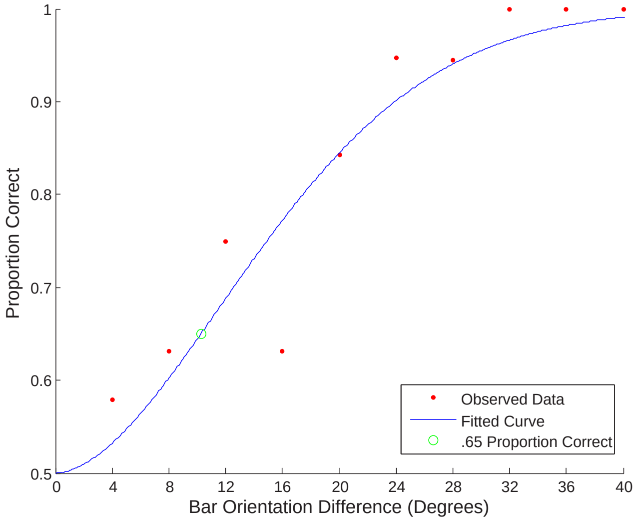


Figure 5.9: Examples of Trials in the Visual and Auditory MCS tasks. Participants viewed the trial sequence and were then asked to indicate which of the pairs of bars/tones were the same or different, and whether the two images belonged to the same category (both bikes/cars) or different categories (one bike/one car). In the visual task shown, the second pair of bars are different, and the images are the same category. In the Auditory task the first pair of tones are different, and the images are from different categories.

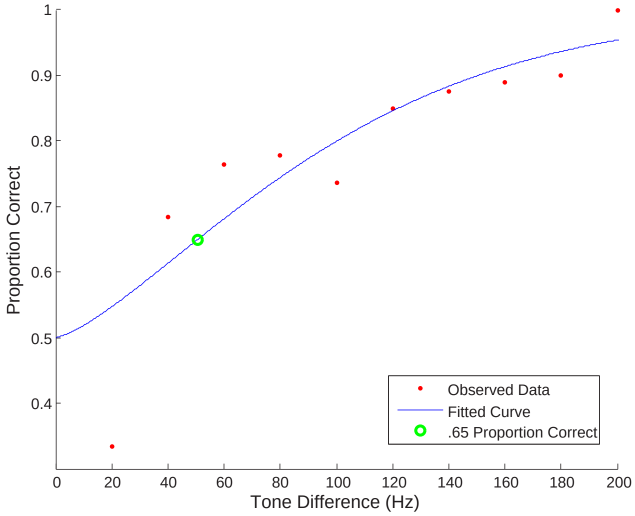
5.23.2.4 MCS Data Analysis

Bar discrimination accuracy data were extracted for both the visual and auditory calibration tasks. Trials in which participants did not correctly categorise the motorbike/car images were excluded from analysis. All data were processed off-line - MATLAB (2010) was used to fit a Wiebull curve to each participant's visual and auditory accuracy data. The curve was used to estimate the level at which each participant achieved 65% accuracy on the bar or tone discrimination task, as this is the level at which the high load task would be set at in the main experiment. The 65% accuracy scores for the visual and auditory tasks are displayed for each participant in Table 1 in the appendix.

The original plan had also been to use each participant's calibration data to calculate a 95% accuracy level, which could be used for the low load task in the main experiment. This was the case for the first four participants - however, a preliminary analysis of the data revealed that setting the low load visual and auditory tasks in this manner seemed to result in *relatively* poor performance (mean accuracy in the low visual and auditory conditions was 77.8% and 85.4%, s.d. = 10.8%, 12.8%, respectively), which suggested that participants were finding the low load tasks more challenging than intended. Performance under low load was expected to be close to ceiling, and the concern was that if the "low" load task was too demanding, then any contrasting effects between this and the high load conditions, might be lost. Rather than risk this, I decided to set the low visual and auditory load task levels to fixed values that all participants should (in theory) find very easy to discriminate, in order to ensure that the contrast between high and low load task difficulty levels was preserved. Ninety degrees bar orientation difference was used for the low visual load task, and six-hundred Hertz tone difference was used for the low auditory load task.



(a) Visual Calibration Data (Example)



(b) Auditory Calibration Data (Example)

Figure 5.10: Examples of Fitting Wiebull Curves to a Single Participant's Visual and Auditory Calibration Task Data. In this example, the participant attained 65% accuracy at approximately the "10 degrees" difficulty level in the visual bar discrimination task, and approximately the "50 Hz" difficulty level in the auditory tone discrimination task. These values would then be used in the high visual and auditory perceptual load conditions.

5.23.3 Main Experimental Method

5.23.3.1 Design

The experiment was a 2x2x2x2 repeated measures design, with the within-subjects factors of modality [visual, auditory], load [low, high], valence [negative, neutral] and image type [face, body]. The bar and tone stimuli were identical to those used in Studies 5.13and 5.17, respectively. Following the same procedure as before, no bars were presented at any of the cardinal angles, plus or minus 10 degrees, in order to prevent pop out effects of any stimuli presented at or near the horizontal/vertical axes. Tones from 700 - 1200 Hz were used. The stimuli were presented in a block design. Load was manipulated between each block in the visual conditions by making the the difference between the orientation of the two bars either easy (90° difference) or hard (as determined on a per-participant basis by the outcome of the visual calibration procedure). Load was manipulated between each block in the auditory conditions by making the difference the two tones either easy (600Hz difference) or hard (as determined on a per-participant basis by the outcome of the auditory calibration procedure). Image valence was manipulated within each block by either presenting a negative or neutral image with each trial. Four blocks of trials were created: visual low load, visual high load, auditory low load, auditory high load. Each block consisted of forty trials, in which twenty negative and twenty neutral images were presented in a randomised order.

5.23.3.2 Main Trials Procedure

Participants completed all four blocks of trials (visual low load, visual high load, auditory low load, auditory high load). Each trial began with a “Get Ready” warning slide (1500ms) and then a fixation cross (1500ms, jittered by ± 200ms). A negative or neutral image was then presented in the centre of the display for 100ms, accompanied by two flanking bars in the visual load conditions (50ms per bar), or two tones in the auditory load conditions (50ms per tone). A checkerboard mask was then presented - this filled the whole screen and remained until a response was detected *or* 1500ms had elapsed. Participants were required to respond as quickly to the bar or tone discrimination task, either by pressing “Z” to indicate that the bars/tones were different, or “M” to indicate that they were the same. There were an equal number of “same” and “different” responses in each block, and the order of presentation was fully randomised. Immediately after this response had been made, a screen appeared with the question “Was the image negative or neutral?”. Participants pressed “T” to categorise the image as negative, or “G” to categorise the image as neutral. The trial ended as soon as response was made. The order that the four testing blocks were completed in was counterbalanced between participants. Please see Figure 5.2b (task-relevant images condition) for examples of the low and high visual perceptual load conditions, and Figure 5.7 for examples of the low and high auditory perceptual load conditions.

5.23.3.3 Practice Trials Procedure

Prior to the main blocks participants were given blocks of practice trials. Two blocks of 20 visual practice trials (one low load, one high load) were presented prior to the main visual trials, and two blocks of 20 auditory practice trials (one low load, one high load) were presented prior to the main auditory trials. Practice trials were identical to main trials, except that participants were required to categorise images of cars and motorbikes rather than negative and neutral images, in order to prevent possible acclimatisation to the negative images prior to the main trials. Participants pressed “T” to categorise an image as a motorbike, and “G” to categorise an image as a car.

5.24 Results

5.24.1 Load Task Accuracy

The accuracy data were all normally distributed. A 2x2x2x2 repeated measures ANOVA with the within-subjects factors of modality [visual, auditory], load [low, high], valence [negative, neutral] and image type [face, body] revealed a main effect of load, $F(1,13) = 173.12$, $p<.001$, $\eta_p{}^2=.93$. Participants were significantly more accurate in the low load conditions than the high load conditions. There were no other significant main or interaction effects of any other variables.

Bonferroni corrected single-samples t-tests were carried out for all the high visual and auditory perceptual load accuracy data, in order to determine whether performance was significantly greater than chance. Disappointingly, given that the adjusted alpha criterion is $p<.006$, the results of the tests indicated that high load performance did not significantly differ from chance in any of the four visual load conditions (high negative body, high negative face, high neutral body), t(13) = 2.97, 1.83, .73, 1.91, p= .01, .09, .48, .08. Furthermore, inspection of the high auditory load data revealed that performance did not differ significantly from chance in any of the four auditory conditions (high auditory negative body, high auditory negative face, high auditory neutral body, high auditory neutral face), t(13) = 1.98, 1.58, 1.91, 1.12, p= .07, .13, .08, .28, respectively. Chance performance under high task load implies that participants were unable to carry out the tasks properly, which clearly has important implications for the validity of these data.

5.24.2 Load Task RT

The RT data were also all normally distributed. A 2x2x2x2 repeated measures ANOVA [same factors as described above] revealed main effects of load, F(1,13) = 13.86, p=.003, $\eta_p{}^2$=.52, modality, F(1,13) = 10.20, p=.007, $\eta_p{}^2$= .44, and image valence, F(1,13) = 4.59, p=.05, $\eta_p{}^2$=.26. Responses were more rapid under low load than under high load and more rapid in the visual conditions when compared to the auditory conditions. Responses were also more rapid to neutral trials when compared to negative trials - however image valence did not interact with any of the other variables.

5.24.3 Categorisation Accuracy

The image categorisation accuracy data were mostly at, or close to, ceiling (mean performance across all conditions = 98.2%, S.D. = 4.3%). Given the non-normality of the data, a Friedman's test was applied to the data - this confirmed that there were no significant differences between any of the conditions, X^2=13.94, df = 14, p=.53.

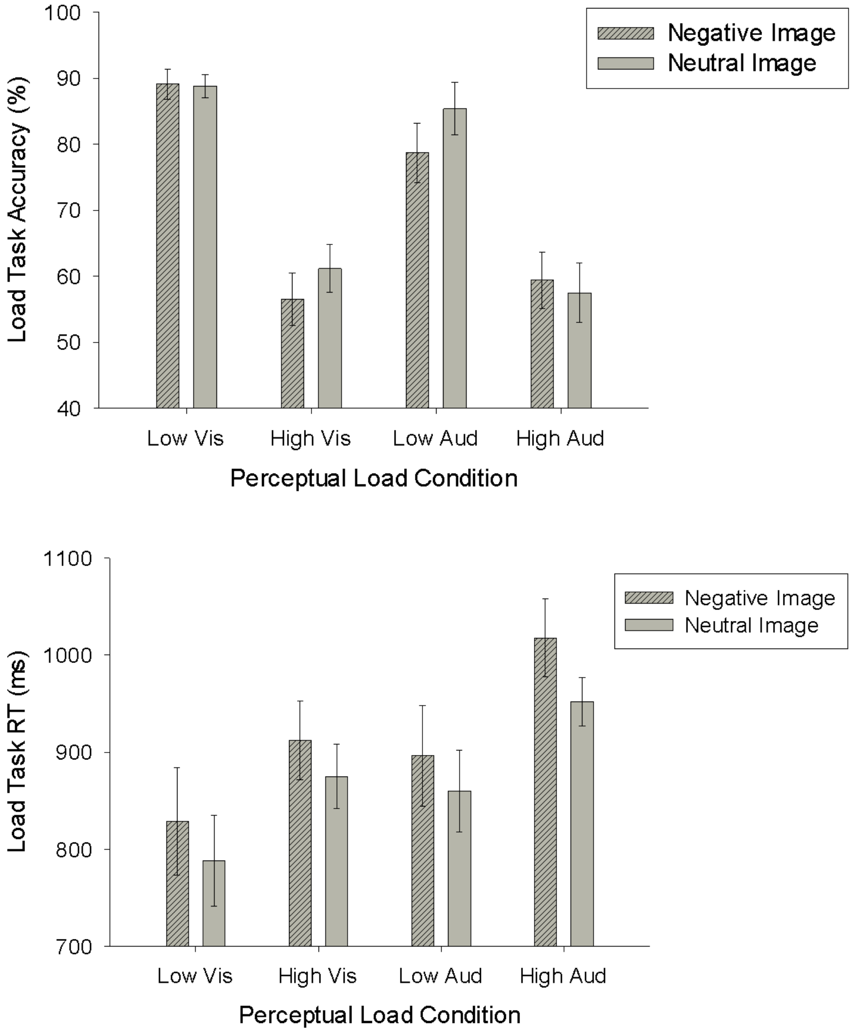


Figure 5.11: Mean image valence accuracy and RT data representing the relationship between image valence and high/low visual and auditory perceptual load conditions.

5.24.3.1 Comparing Calibration Task and Main Task Accuracy Performance

The high visual and auditory load tasks in the main experiment were set for each individual participant based on their performance on the calibration task. The purpose of the visual and auditory calibration tasks was supposed to be to determine appropriate levels for the high load task in the main experiment on a per-participant basis i.e. if a participant achieved 65% at 6° bar difference in the visual calibration task and 50Hz tone difference in the auditory calibration task, they were expected to perform at around 65% accuracy at these difficulty levels in the main experiment. However, overall performance in the main task was lower than expected (mean accuracy under high visual load = 58.7%, SD = 10.5%; mean accuracy under high auditory load = 58.4%, SD = 13.7%), and the large standard deviations imply that the data were still highly variable. Figure 5.12 illustrates the discrepancy between calibration task and main task accuracy under high load for each participant.

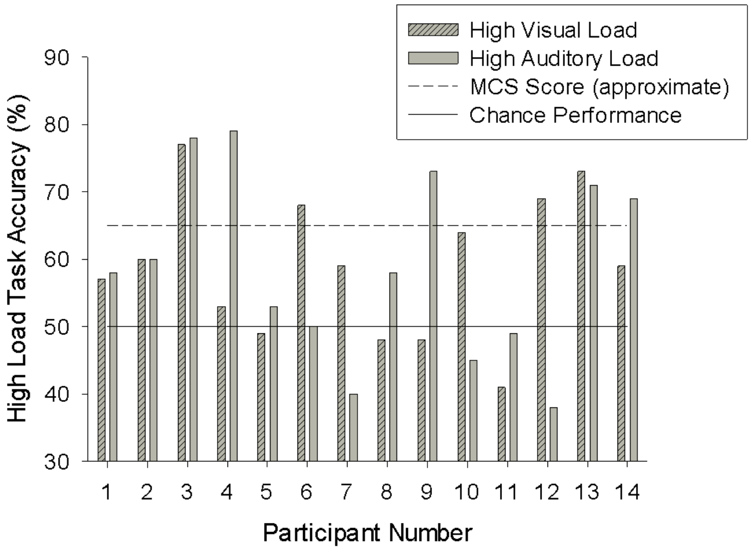


Figure 5.12: Graph comparing mean performance across the high visual and auditory perceptual load conditions in the main task on a per-participant basis. Task difficulty in both high load conditions was set according to individual performance at the MCS calibration task. The dotted line at 65% accuracy represents the mean level at which participants were expected to perform in the main task. The bars represent actual performance per-participant at the main low and high load conditions.

5.25 Discussion

The aim of the study was to test whether visual and/or auditory perceptual load are able to modulate the processing of task-relevant emotional images. Due to highly variable performance between participants in the high visual and auditory load tasks in previous pilot studies(5b - 5e) the decision was made to to calibrate the high visual and auditory load tasks to each participant's ability by testing them with the MCS prior to the main study. This procedure was *supposed* to ensure that participants found the high load tasks very challenging, but were still able to perform at above chance levels of accuracy. Unfortunately, despite these precautions, the majority of participants did not attain MCS levels of performance in the main task (Figure 5.12 suggests that only participants one , two, three, thirteen and fourteen performed at above chance on both the visual and auditory high load tasks). Given that overall performance did not significantly differ from chance, this suggests that the majority of participants were unable to do the high load task properly, and means that it is not possible to draw any firm conclusions from this data set.

In one sense, it was very unlucky that participants one, two and three all performed at above chance in the high load conditions, as this gave an early indication that the MCS had been effective, and that performance on the task was as expected. This lulled me into a false sense of security as I assumed that everything was working out as planned, and it was only later when I checked the data for 14 participants that I realised that this wasn't actually the case. At this point I had already tested 24 participants, at a cost of 15 pounds each, and was basically running low on time and available research funds. Ideally I would have started again and maybe tried to address the issues outlined with the MCS below, or perhaps tried again with a modified/improved version of the paradigm. But given the difficulties already encountered, especially with the auditory load task, I decided to discontinue this line of work and instead use my remaining time and resources to address another important and related question pertaining to visual perceptual load and task-irrelevant image processing (see Study 5.25).

One possible explanation for the discrepancy between calibration and main task performance in the current study is that the two tasks were actually quite dissimilar in nature. To recap, in the calibration procedure participants were presented with two *pairs* of bar or tone stimuli, and were required to indicate which pair were different in orientation. It was necessary to adapt the task in this manner in order to allow the method of constant stimuli to be used. However, in the main experimental procedure participants were presented with one pair of bar or tone stimuli and were required to indicate (as quickly and as accurately as possible) whether they were the same or different. The two tasks differed in a number of ways. In the calibration procedure participants were given an unlimited amount of time to respond, whereas in the main procedure the response was speeded, which may have lead to reduced accuracy. Furthermore, in the main procedure responses to the bar/tone stimuli were not logged after 1500ms had elapsed, so participants may have actually made a greater number of correct responses, but these simply were not logged. The duration of the checkerboard mask and data logging were set to 1500ms as this was the duration used by Erthal et al. (2005) in their study testing the effects of load on the processing of task-irrelevant images, but, given that in the current version of the study the task was to perform the load task *and* attend to the images, perhaps participants should have been given longer to respond. Another subtle difference between the calibration and main tasks was that in each calibration trial participants knew that one pair of bars would always be different and one would always be the same - this would have allowed them to make within-trial comparisons of the two pairs of bars and may have aided their responses. In the main experiment with a single pair of bars per trial there was no such opportunity to make within-trial comparisons.

It should also be noted that in the MCS task participants were only exposed to neutral images (cars and motorbikes), whereas the main task obviously featured negative and neutral images. Another contributing factor towards the poor performance across all conditions in the main task compared to the MCS task may have been a general performance reducing effect of the negative stimuli. One participant reported that the presence of the negative images in the study induced a “general feeling of unease”, and that she was “put off” the bar discrimination task even on neutral image trials, because there was the possibility that a negative image might appear. Context may have also played a role in determining the extent of the impact by emotional images. It was assumed that participants would think that the images depicted real negative events (which they did do), but a a number of participants did ask during the debriefing whether the negative images had been photoshopped or not. Mocaiber et al. (2010) showed participants negative and neutral IAPS images and manipulated a prior description which stated either that the images were fictitious (from movie scenes) or real scenes. They demonstrated attenuated RT and LPP amplitude to the negative images in the fictitious context when compared to the real context, which suggests that participants in the current study who maybe believed that the images were fictitious, would have been distracted less by them. Furthermore, elevated stress levels have been shown to have the same effect as high perceptual load in reducing distraction (Sato et al., 2012), so individual state anxiety levels induced by viewing the negative images may have also interacted with load.

Another possible explanation for chance performance in the visual *task-relevant images* version of the task (Study 5f), compared to performance in the *task-irrelevant images* version (Study 5g), is that requiring participants to attend to the centrally presented images in addition to the flanking bars may have interfered with attentional focus. Müller and Hübner (2002) have demonstrated that the attentional spotlight can effectively be shaped by a doughnut i.e.

information presented at fixation can be processed differently depending on whether the information is task-relevant or task-irrelevant. Attention can also be split across noncontigious locations (Hahn and Kramer, 1998; Awh and Pashler, 2000; Müller et al., 2003) and one of the ways in which this is achieved is by suppression of stimuli at unattended locations Awh and Pashler (2000), hence the spatial arrangement of stimuli is very important when testing the effects of competing stimuli. In my task-relevant images task, participants were effectively required to attend to three noncontigious locations at once (the central image and two flanking bars), so it is not really surprising that this made the difficult bar discrimination task very challenging to perform accurately. Furthermore, the 100ms stimuli presentation duration in the current study would have precluded any meaningful attentional switching, given the general consensus is that it takes a minimum of 200 - 500 ms to switch attention from target identification at one location to target identification at another location (e.g. Moore et al., 1996; Peterson and Juola, 2000; Duncan et al., 1994; Müller et al., 2003). An alternative method would have been to superimpose the perceptual load task over the images - a technique used in Müller et al. (2008), Wiens et al. (2012) and my studies in Chapters 2 and 3. Perhaps this would have made the bar discrimination task more manageable, as the image would be in the background and attention would not need to be shifted from one set of fixed locations (the bars) to another (the image).

A further issue is that presenting the bars/tones consecutively in the current study *may* have required a degree of WM involvement, although this would have most likely have been minimal, due to the very rapid presentation of the two bars. Although consecutive presentation is not particularly common in perceptual load tasks, there are previous examples of its use in both visual and auditory tasks (e.g. Doallo et al., 2006; Dalton and Lavie, 2004, 2007), which suggests that it is a valid from of load manipulation. The original paradigm, in which the bars were presented simultaneously, was more of a "pure" perceptual task, but it was necessary to adapt this to consecutive presentation in order to accommodate for the inclusion of the auditory load paradigm. Furthermore, the image categorisation task would have also placed demands on WM, as participants viewed the image at the same time as they viewed/heard the load task, but had to hold their response in WM while they first made their speeded response to the load task. These additional demands on WM, coupled with the further demands of having to focus on the bar/tone discimination task while also attending to the images, may go some way towards explaining why participants performed so poorly in the main experiment. Finally, the fact that I removed the cardinal angles may have made the task more difficult too. It does not appear that Erthal et al. (2005) and Pessoa et al. (2005) did this, hence participants may have had a small advantage on trials where one of the pair of bars was presented on the horizontal or vertical axis.

In conclusion, this study was unsuccessful primarily due to participants' performance at the calibration tasks not accurately predicting performance in the main tasks. This resulted in highly variable performance in the main tasks which largely did not differ from chance. It is possible that the role of visual and auditory perceptual load in the processing of task-relevant affective stimuli could be addressed in an improved follow-up study by making use of a more accurate/realistic calibration task to determine visual and auditory discrimination thresholds prior to the main experiment, thus ensuring high enough levels of performance.

Study 5g - Testing the Effects of Visual Perceptual Load on Task-Irrelevant Image Processing

5.26 Introduction

The previous study (5f) marks the end of the line investigation in the effects of visual and auditory perceptual load on task-relevant image processing (or at least for the purposes of this thesis). However, a number of important questions arose with regards to the original Erthal et al. (2005) study on the modulatory effects of attentional load on *task-irrelevant* affective image processing. These questions could be addressed using the new stimuli that were developed in Study 5a, therefore one final experiment was justified. To clarify, the purpose of this study was to attempt to replicate, examine and build upon Erthal et al.'s original findings, *not* to further the line of inquiry that has been the subject of studies 5b- 5f. The specific aims are outlined in the following sections:

5.26.1 Using a more "simple" set of negative/neutral stimuli

Erthal et al. did not observe a statistically significant interaction between image valence and attentional load in their paper, and their conclusion that attentional load can modulate task-irrelevant emotional image processing is based on post-hoc paired-samples t-tests that were carried out despite this non significant interaction. The authors also suggest that this data should only really be treated as “pilot data”. One possible reason for the non-significant interaction is that some of the emotional images that were used in the study may not have been very effective when rapidly presented (200ms) in the “bars + image” paradigm used by Erthal et al. Although some of the more graphic images in their original image set can very quickly be identified as being highly negative and arousing, some of the more perceptually complex emotional images are less obviously highly negative and arousing when presented very rapidly e.g. scenes involving multiple people.

Image complexity may well be critical in determining whether load impacts on emotional stimuli or not. Bradley et al. (2007) have demonstrated that the late positive potential (LPP), an ERP component considered to index the effects of emotional visual stimuli on attention (e.g. Cuthbert et al., 2000; Bradley, 2009) is enhanced when processing simple emotional images (i.e. a single central object and plain background) compared to complex emotional scenes (no single central object and a complex background). Furthermore, Sand and Wiens (2011) have demonstrated that the magnitude of the LPP response to simple emotional images presented at fixation is not reduced under high perceptual load, which indicates that the processing of these images is not affected by high load. Although an image may have previously been rated as highly negative and arousing by participants undergoing the IAPS ratings procedure (where participants view the image for six seconds before rating it for valence/arousal), this does not necessarily mean that the full impact of the image would be conveyed in a 200ms presentation of the image. Furthermore, as this was a study on task-irrelevant image processing, participants were not required to attend to and categorise the images as negative/neutral throughout the experiment, so there is no objective behavioural measure of how easily discriminable all the negative and neutral images were. In order to address this, only images that could easily be identified as negative or neutral were used in the current study. The near-ceiling performance on the categorisation task studies 5b - 5f confirms that participants found it relatively easy to identify the images as negative or neutral.

5.26.2 Control for the presence or absence of human faces

Erthal et al. did not control for the presence or absence of faces in their image set, and it appears that their set is heavily biased towards images that contained faces (see Study 5a Introduction section5.1 for a discussion on this). One of the primary reasons the authors carried out this study was to address their concern that previous studies revealing attentional load effects exclusively employed the use of emotional face stimuli (which are considered to be quite weak, according to Ochsner et al. (2002)). They wanted to test whether these attentional load effects would still be observed if the stimuli were even more negative/arousing i.e. could very potent images overcome the impact of high perceptual load? However, it is not clear how the "special" impact of faces can be separated from the the effects of increased image potency when the presence or absence of faces in the image set were not controlled for. Faces are highly socially and biologically relevant (e.g. Öhman and Mineka, 2001) and there is evidence that faces are processed even when presented outside of conscious awareness (Whalen et al., 2004) or at unattended locations (Vuilleumier et al., 2001). If faces are processed more readily or automatically than other objects, then it might be the case that the emotional images that contain faces are less distracting than emotional images that don't contain faces. The new images set designed in Study 5a comprises an equal number of “face” and “body” images - this meant that in the current study the effects of negative and neutral faces on bar discrimination performance under high perceptual load could be compared with the effects of negative and neutral images that do not contain faces.

5.26.3 Test whether stimuli duration can impact on perceptual load effects

Erthal et al. presented their load task stimuli and image for 200ms per trial. It is possible that eye movements could occur during these presentations, which may confound the results (see Section 5.5 for further discussion on this topic). Indeed, one might speculate that eye movements may be more likely under low attentional load, as successful performance on the bars task does not require such highly focused attention as in the high load condition. Typically, perceptual load tasks based around the response competition paradigm (e.g. Lavie, 1995; Macdonald and Lavie, 2008a) have clearly demonstrated attentional load effects using a more rapid, 100ms stimulus duration. Accordingly, to test whether stimuli duration does interact in any way with load/image valence, stimuli duration was manipulated between 200ms and 100ms in the current study.

5.26.4 Study overview and predictions

The current study essentially just used the “task-irrelevant images” paradigm develop in Study 5b (see Figure 5.2a). The primary measure of bar discrimination task performance was expected to be RT, as this is the main measure reported in Erthal et al. - however, there was also the possibility that main/interaction effects in the accuracy data colour also occur. First, one might predict that compared to the somewhat complex images used by Erthal et al. (2005), the relatively simple highly negative images employed in the current study may have an even greater impact on bar discrimination, meaning that they are more able to resist the effects of high perceptual load. If this is the case then there will be a main effect of image valence on load task performance, and no load*valence interaction. Second, due to the automaticity of face processing, the face-present images are predicted to be less distracting across both high and low conditions than than the face-absent images. If this is case then there will be a main effect of "face present/absent". However, it is also plausible that any effects of "face present/absent" could be reduced/eliminated under high perceptual load and a load*face interaction may occur. Third, based on the outcome of Study 5b, reducing stimulus duration from 200ms to 100ms is expected to result in a decline in bar discrimination accuracy across all conditions.

5.27 Method

5.27.1 Participants

36 undergraduate students (18 were male, mean age = 20 years , SD = 3.2 years, 32 were right handed) were each paid 5 pounds for their participation.

5.27.2 Design

The study was a 2x2x2x2 design, with the within-subjects factors of load [low, high], image valence [negative, neutral], stimulus duration [100ms, 200ms] and image type [face, body]. The design was as close to Erthal et al. as possible and was identical to the “task-irrelevant” images condition detailed in Study 5b. Load was manipulated between blocks by making the difference in bar orientation either easy (90° difference) or hard (6° difference) to discriminate; stimulus duration was manipulated between blocks by varying presentation time between 100 and 200ms, and image valence was manipulated within each block by presenting equal numbers of negative and neutral images. Equal numbers of face-present and face-absent images were also presented within every block. Four blocks were created: low load 100ms duration, high load 100ms duration, low load 200ms duration, high load 200ms duration. Each block consisted of 40 trials, in which 10 negative face-present, 10 negative face-absent, 10 neutral face-present and 10 neutral face-absent images were presented in a randomised order. The study was essentially a direct replication of Erthal et al., but with the additional manipulations of face present/absent, and stimulus duration. Given the emphasis on replication, the cardinal angles were not excluded from this study (unlike in Study 5f), as Erthal et al. did not appear to have done this in their study. Note also that in-line with the original version of the paradigm, bar onset was simultaneous, rather than consecutive as in Study 5f.

5.27.3 Procedure

The procedure for the practice and main trials was the same as detailed in Section 5.7.3 for the "task-irrelevant images" condition (see Figure 5.2a). Participants completed two blocks of 20 practice trials (one low load block and one high load block) followed by all four blocks of main trials. The order that the four main blocks was completed in was counterbalanced between participants.

5.28 Results

5.28.1 Load Task Accuracy

The low load accuracy data were negatively skewed because a high proportion of participants were at or close to ceiling in the low load conditions. Non-parametric equivalent tests were therefore computed to check that these concur with the results of the parametric tests (see footnotes). A 2x2x2x2 repeated measures ANOVA with the within-subjects factors of load [low, high], image valence [negative, neutral], stimulus duration [100ms, 200ms] and image type [face, body] revealed significant main effects of load, F(1,35) = 903.03, p<.001, $\eta_p{}^2$=.96, and image type, F(1,35) = 8.12, p=.007, $\eta_p{}^2$=.19[8]. The data confirmed that the load manipulation was successful i.e. participants were significantly more accurate at bar discrimination under low load than high load, and also that responses to face-present trials were significantly more accurate than responses to face-absent trials. However, further inspection of the data suggested that

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[8] Unsurprisingly, a Friedman's ANOVA also revealed significant differences between conditions, X^2=402.66, df = 36, p<.001..

overall performance in the high load condition was very close to chance, and Bonferroni corrected single-samples t-tests (corrected alpha criterion $p<.013$) confirmed that while performance in the high load neutral face-present condition was significantly above chance, $t(35) = 3.16$, $p=.003$, performance in the high load negative face-present condition was only marginally above chance, $t(35) = 2.45$, $p=.02$, and performance in the low load neutral face-absent and low load negative face-absent conditions, $t(35) = .65$, $p=.52$, and $t(35) = .53$, $p=.60$, respectively. This suggested that participants were only just able to engage in the high load task properly on face-present trials, and that only the face-present trial data should be subject to further analysis. *Accordingly, the face-absent data were discarded from any further accuracy or RT analysis.*

The remaining face-present data were collapsed over the variable “duration”, as the duration manipulation had no significant main or interaction effects in the original ANOVA. A 2[load: low, high] x 2[valence: negative, neutral] repeated-measures ANOVA on the face-present accuracy data revealed a main effect of load, $F(1,35) = 611.37$, $p<.001$, $\eta_p{}^2=.95$. There were no main or interaction effects of any of the other variables.

5.28.2 Load Task RT

The RT data were all normally distributed, with the exception of the “neutral low load face” condition. Again, non-parametric equivalent tests were computed to check that these concur with the results of the parametric tests. As discussed in the previous section, only the face-present trial data were included in this analysis. A 2x2x2 repeated-measures ANOVA with the within-subjects factors of load [low, high], image valence [negative, neutral] and duration [100ms, 200ms] revealed significant main effects of load, F(1,35) = 20.6, $p<.001$, $\eta_p{}^2=.37$, and valence, F(1,35) = 11.86, p=.002, $\eta_p{}^2=.25$. Participants responded more rapidly to the bar discrimination task under low load than high load, and more rapidly if the accompanying image was neutral rather than negative. However, critically, there was no significant interaction between valence and load, F(1,35) = 1.26, p=.27, $\eta_p{}^2=.04$.

In one sense, these results concur with Erthal et al.'s findings - they also reported main effects of image valence and load, and no significant interaction between valence and load. However, despite the non-significant interaction the authors carried out paired-samples t-tests and discovered that RTs on negative trials were significantly longer than RTs on neutral trials under low load, but that this effect was eliminated under high load. Paired samples t-tests on the *current data* reveal a similar pattern of results; RTs on negative trials were significantly longer than RTs on neutral trials under low load, t(35) = 3.49, p=.001, *d*=.31, but there was no significant difference between RTs in the two conditions under high load, t(35) = 1.54, p=.13, *d*=.14[9].

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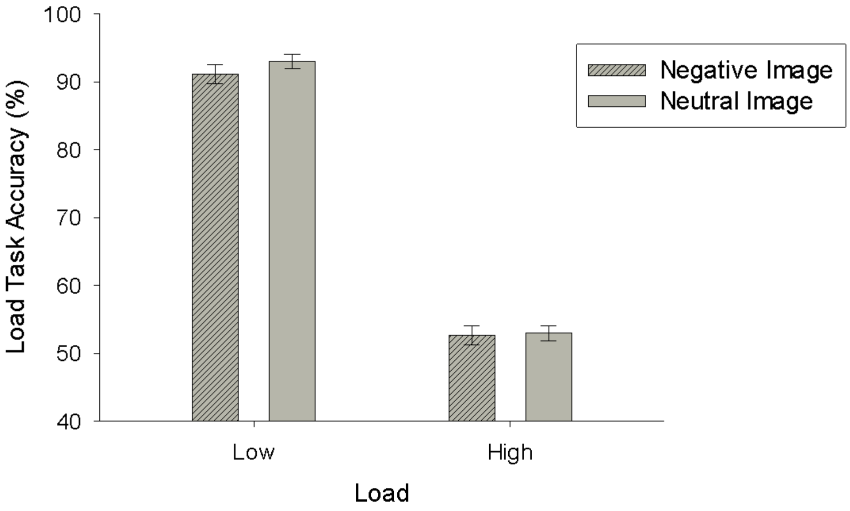
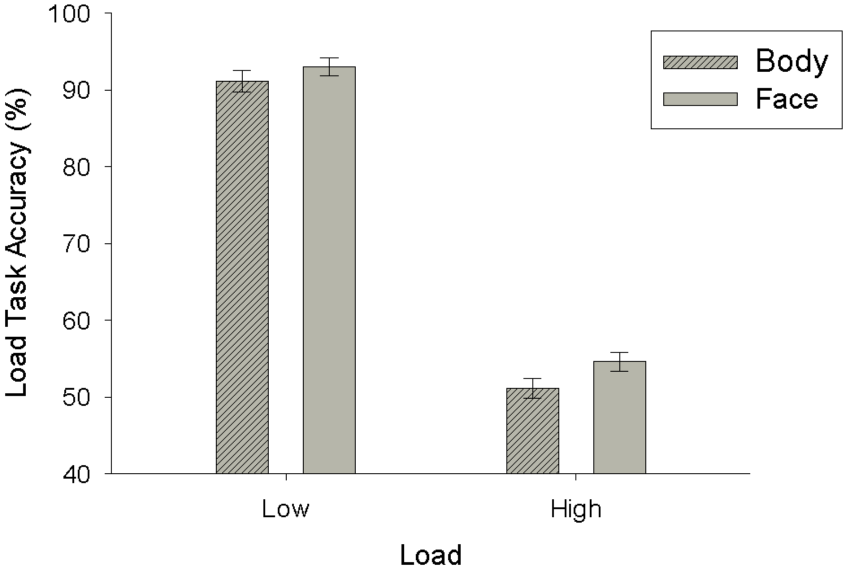
[9] Related-samples Wilcoxon Signed Ranks Tests concurred with these results i.e. RTs on negative trials were significantly longer than RTs on neutral trials under low load, T=10, z=-3.08, p=.002, but there was no significant difference between RTs in the two conditions under high load, T=14, z=-1.52, p=.13.



(a) Mean accuracy data - load and image valence



(b) Mean accuracy data - load and image type

Figure 5.13: Mean accuracy data representing the relationship between perceptual load, image valence and image type (these graphs both include both the face-present and face-absent data)

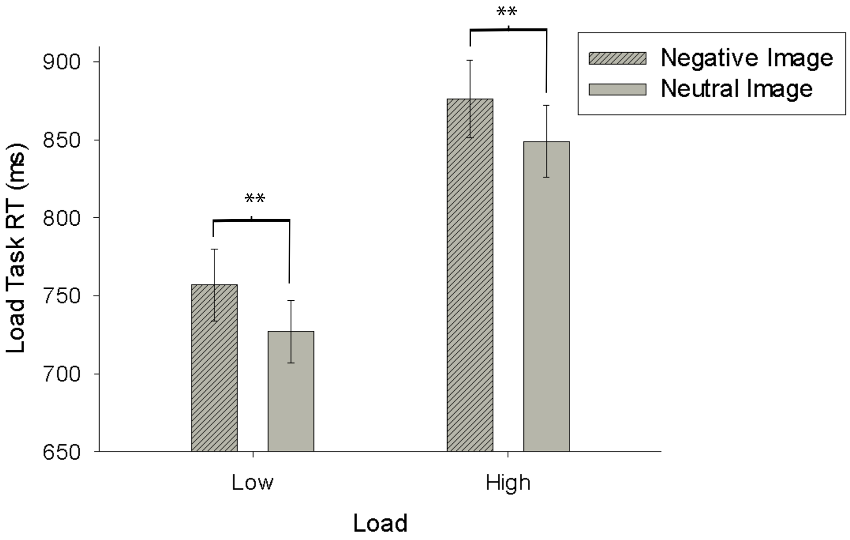


Figure 5.14: Mean RT data representing the relationship between perceptual load and image valence. **p<.01

5.29 Discussion

The main purpose of this study was to determine whether the processing of highly negative/arousing images can be eliminated under conditions of extremely high visual perceptual load. In answering this question, the study aimed to replicate, examine and build upon Erthal et al. (2005)'s findings. Stimuli presentation duration was also manipulated in order to rule out any possible effects of eye movements. The stimuli were carefully selected so that they were all relatively simple compared to Erthal et al.'s stimuli set, which contained a mix of simple and complex images. Finally, the number of face and body images was equal in each condition, ensuring that any effects of the images were not face-specific and also allowing load effects on negative and neutral face and body images to be assessed. In this section a number of comparisons are drawn between the current findings and Erthal et al.. Although some of the discrepancies in our data can be accounted for by the factors discussed below, it must also be acknowledged that a number of factors beyond my control may have contributed to the differences, such as differences in instruction and subject motivation etc.

First, contrary to predictions, reducing stimuli duration from 200 to 100ms did not impact on bar discrimination accuracy and there were no main or interaction effects of duration. This prediction was based on the results of Study 5b, where reducing stimuli presentation from 200 to 100ms did impact on bar discrimination accuracy across all conditions. In Study 5b there were both task-irrelevant and task-relevant trials, and the sample size was relatively small, so it is possible that with a larger sample size image relevance (whether or not the images were task-relevant or task-irrelevant) might have interacted with duration and shown that duration only impacted on the task-relevant trials. Importantly for the current study, this suggests that presenting stimuli at 200ms (like Erthal et al.) or at 100ms is irrelevant when testing load effects on emotional stimuli.

Second, as predicted, it appears that the simple, emotional images had a greater overall impact on bar discrimination accuracy in the current study than in Erthal et al.. The accuracy rates in the current study were as follows (face-present only data): low load negative, 91.0%; low load neutral, 95.0%; high load negative, 54.3%; high load neutral, 54.9%. The accuracy rates in Erthal et al. were as follows: low load negative, 94.6%; low load neutral, 95.3%; high load negative, 60.5%; high load neutral, 61.7%. The fact that there were no main or interaction effects of the "duration" variable suggests that the enhanced potency and relatively clear figure-ground composition of the images was primarily responsible for the reduced bar task accuracy in the current study relative to bar task performance in Erthal et al.. The relatively clear figure-ground composition may have also been part of the reason that the was no load*valence interaction i.e. emotional images were not modulated under high perceptual load. However, one caveat of this assumption was that the subjective judgement regarding whether an image was simple or complex was just made by myself. Ideally, a set of simple and complex images would have been selected, and an independent sample of raters would have been asked to rate the scenes for figure-ground complexity, using the ratings procedure described in Bradley et al. (2007). The ratings would have lent conviction to the argument that these stimuli are "simple". This procedure will be adhered to in any follow-up work on load and image complexity.

Third, as predicted, the face-present stimuli were less distracting under high perceptual load than the face-absent stimuli. Performance under high perceptual load was above chance for neutral face-present images, and just marginally above chance for negative face-present images. This drop in accuracy from above chance to chance as a result of the negative face-present images suggests that negative images are resistant to the effects of high perceptual load. Furthermore, exclusive analysis of the face-present RT data revealed no load*valence interaction. Together, these results concur with *behavioural* findings from numerous other studies that have tested emotional processing under low Vs high perceptual load and found no load*valence interaction (Pessoa, 2005; Erthal et al., 2005; Norberg et al., 2010; Wiens et al., 2012; Sand and Wiens, 2011), and they suggest that emotional image processing is not modulated by perceptual load. Critically, the current results indicate that even if perceptual load is increased to a level where performance is close to chance (and at chance in some conditions), this still cannot modulate the processing of very potent, simple, emotionally salient stimuli.

Norberg et al. (2010), Sand and Wiens (2011) and Wiens et al. (2012) all corroborate their behavioural data with neuroimaging data demonstrating that the ERP response to emotional stimuli (as indexed by the LPP) is not impacted by perceptual load. Pessoa et al. (2005) do not discuss their non-significant load*valence interaction in the behavioural data, but it somewhat contradicts their neuroimaging data, where load is found to modulate the activation in the right amygdala in response to the emotional stimuli. The discrepancy in these two sets of neuroimaging findings may be as a result of the stimuli; the EEG studies all used quite potent negative/arousing images from the IAPS, or showed images of spiders to spider phobics; Pessoa et al. used relatively weak fearful faces, which may not have been potent enough to overcome the effects of perceptual load. Erthal et al. found a non-significant load*valence interaction but carried out post-hoc t-tests regardless and suggested that perceptual load modulates emotional image processing. Overall, none of these studies provide any behavioural support for the processing of emotional stimuli being modulated under high perceptual load , and my study corroborates this. However, the current findings do contradict one study that *does* demonstrate reduced interference from emotional images under high perceptual load. Okon-Singer et al. (2007) found an load*valence interaction and their data indicated reduced interference from task-irrelevant negative IAPS images when the relevant task required search for a target letter among 5 other letters (high load), compared to when search was among fewer letters (low load), suggesting modulatory effects of high load. It is very difficult to account for the discrepancy between our two sets of results, other than to suggest that the differences stem from us using quite different paradigms. Okon-Singer et al. presented images at fixation surrounded by the target letter and none, one, three or five non-target letters, whereas in the current study images were presented at fixation flanked by two bars. Participants had to search for the target in Okon-Singer et al. because the target changed position in each trial, which may have required a greater number of covert attentional shifts than in the current study, where there was no search involved as the flanking bars were in fixed locations. Although both tasks required discimination, perhaps the active search in Okon-Singer et al. exhausts perceptual capacity in a qualitatively different way to the discimination judgements in the current study, hence their task was more effective in reducing available capacity for the processing of emotional stimuli than the current task.

Furthermore, it is also plausible that if the distribution of the attentional spotlight can become "doughnut shaped" in tasks that require the centrally fixated stimuli to be ignored, and peripherally presented stimuli attended (Müller and Hübner, 2002) (see 5.25 for further discussion on this topic). Thus, in the the current study and others that have used the bars/images paradigm (Erthal et al., 2005; Pessoa et al., 2005), the slight (albeit non-significant) perceptual load modulation effect could just be due to the placements of the image i.e. the image is more likely to be suppressed under high perceptual load due to attention being shifted away from the centre to the flanking bars. A potentially interesting follow-up experiment could compare emotional image interference in the standard image/flankers paradigm against interference in a modified version of the paradigm where the load task is superimposed over the image. This would allow us to test whether there is any modulation of emotional images by high perceptual load in a task where the image is not centrally fixated and thus more readily suppressed. Given the current findings, it might be the case that removing the physical separation of bars and image would further reduce modulation by high perceptual load.

It was clearly not ideal that the face-absent accuracy data were at chance, as this meant that a meaningful analysis of the face-absent RT data could not be carried out. Nevertheless, it does indicate that the face-absent images were particularly distracting, perhaps due to a novelty effect of the stimuli i.e. while participants are used to seeing images of faces and complete people, they are probably less used to seeing shots of isolated body parts. This novelty effect would have been reduced in Erthal et al., as the majority of their images contained faces, whereas the current study contained an equal ratio of face-present to face-absent images.

In conclusion, the current results cast doubt on the suggestion that the processing of very highly emotive stimuli can be modulated by perceptual load, even if the level of perceptual load is extremely high. It should be noted that if one ignores the non-significant load*valence interaction and proceeds with post-hoc tests, as Erthal et al. did with their data, then the findings do suggest that emotional image processing is modulated under high perceptual load. However, in my opinion, given the statistical invalidity of this procedure, neither Erthal et al. or the current study provide *convincing* evidence for this effect.

Chapter 5 Overview

Given that the two main studies in this chapter have already been discussed at length, this section will serve to overview the chapter. The main aim of this chapter was to test whether visual and auditory perceptual load can modulate the processing of task-relevant emotional images. A new set of emotional and neutral stimuli were compiled and rated, with the goal of developing a set of very potent stimuli with an equal ration of face-present and face-absent stimuli. Preliminary studies were carried out in an attempt to determine suitable task difficulty levels for the visual and auditory perceptual load tasks. The data indicated that due to participant variability it was not really feasible to have fixed task difficulty levels, particularly for the auditory perceptual load task. Accordingly, a calibration task was developed based on the method of constant stimuli and this was used in an attempt to ascertain individual task difficulty abilities on the visual and auditory discrimination tasks, so that these values could then be used in the final version of the study, which tested whether visual and auditory perceptual load can modulate the processing of affective images. Unfortunately, performance at the calibration task proved to be an unreliable estimator of performance in the main study, and the majority of participants performance at chance, so it was not possible to draw any meaningful conclusions from this data.

One further aim of this chapter was to test visual perceptual load effects on task-irrelevant affective images, with the specific aim of testing whether very high perceptual load can modulate the processing of very potent emotional stimuli. This study replicated and expanded upon Erthal et al. (2005) by testing the role of stimuli duration, image simplicity and face presence/absence in determining a possible load modulation effect. The current pattern of results were are very similar to the results obtained Erthal et al.. The outcome of both our studies was a non-significant load*valence interaction, but if I disregard this and carry out post-hoc paired samples t-tests, as Erthal et al. did, then the tests reveal that high perceptual load can modulate affective stimuli processing. However, given that this is a statistically invalid procedure, I have decided to err on the side of caution and conclude that while these findings perhaps hint that very potent emotional stimuli may undergo a degree of modulation under high perceptual load, this paradigm does not provide conclusive evidence for it. This is more in-line with claims made by Norberg et al. (2010) and Sand and Wiens (2011) that there is a “limit” to load theory, in that affective stimuli are able to overcome load effects. Importantly, these findings do not present a challenge to the basic premise of load theory, they just suggest that perceptual load has very little, if any modulatory effect on distraction from task-irrelevant affective images. This contradicts other findings, such as Okon-Singer et al., but it is likely that the disparity in results is due to big differences between the paradigms (see Study 5g discussion).

In follow-up work, Study 5g (testing visual perceptual load effects on task-irrelevant image processing) could be repeated with a slightly less challenging load task in order to avoid participants performing at chance and data having to be scrapped. Furthermore, a better controlled set of negative/neutral images could also be developed in order to further investigate the observation that “face” images were less distracting under high visual perceptual load than “body” images. Ideally, as much extraneous information would be removed from the images as possible (e.g. just face or body part on a plain white background), so that any distraction effects could be directly attributed to the face/body image, not some other inconsistencies in the images. Furthermore, it might be a good idea to greyscale the images, as this would reduce any effects of colour i.e. due to their nature, the negative images typically contain more of the colour red than neutral images (although recent work by Codispoti et al. (2012) indicates that processing of the emotional content in natural scenes, even if they are presented very rapidly, is not critically reliant on colour information).

Further research needs to be conducted in order to tease apart the effects of perceptual load from a number of variables, such as spatial effects, task difficulty and the emotional potency of the images. Some more suggestions are made in the next section.

Chapter 6

Thesis Discussion

As highlighted in Chapter 1, there has been considerable debate over the locus of selection in attention for the last 60 plus years, with contradictory evidence for both early (Broadbent, 1958) and late (Deutsch and Deutsch, 1963) selection. A comprehensive review of the selective attention literature identified perceptual load theory (Lavie and Tsal, 1994; Lavie, 1995; Lavie et al., 2004b) as an area of research that has received much attention as a possible resolution to the early/late selection debate, with the proposal that the locus of selection can be influenced by perceptual demands of a relevant task. Perceptual load theory has been expanded to account for the effects of cognitive load on selective attention (e.g. de Fockert et al., 2001; Lavie et al., 2004b) and there is also evidence that load theory can apply to the processing of highly emotionally salient stimuli (e.g. Pessoa, 2005; Erthal et al., 2005).

However, in Chapter 2, several under-researched aspects of load theory were identified. First, although there is plenty of support for load effects within the visual modality, very few studies test load theory across the visual *and* auditory modalities. Second, although perceptual load theory receives extensive support from numerous different behavioural (e.g. Lavie, 1995; Lavie and Cox, 1997) and neuroimaging studies (e.g. Yi et al., 2004; Schwartz et al., 2005) on task-irrelevant distractor processing, very little is known about the extent to which perceptual load impacts on visual change detection. Third, while the updated load theory of selective attention and cognitive control (Lavie et al., 2004b) suggests that WM and perceptual load effects are diametrically opposed, there is a body of evidence that suggests this opposition only occurs under specific experimental conditions, and in fact WM load can operate to reduce stimuli processing in the same way as perceptual load. Fourth, although there is conflicting evidence with regards to whether high perceptual load can eliminate distraction from emotional stimuli, no study has tested whether high visual and auditory perceptual load can reduce distraction from task-relevant emotional stimuli.

The first point regarding the lack of cross-modality testing was addressed by all three experimental chapters in this thesis. Results indicated that crossmodal effects were seen in perceptual load, but not in cognitive (WM) load. Second, the results detailed in Chapter 3 indicate that high perceptual load can impact on change detection in a relevant task - a finding that corroborates with existing evidence that perceptual load impacts on the processing of task-irrelevant distractors. Third, in contrast to the prediction that the effects of perceptual and WM load are diametrically opposed, the results in Chapter 4 indicate that high WM load can impact on concurrent stimuli processing in the same direction as perceptual load, thus lending support to a more “generalised” theory of load.

Fourth, although my attempts to test the effects of visual and auditory perceptual load on task-relevant emotional stimuli in Chapter 5 were unsuccessful and this question thus remains unresolved, an important further study carried out at the end of Chapter 5 (Study 5g) does suggest a "limit" to load theory, in that distraction by highly potent emotional images can occur despite high levels of perceptual load in a concurrent visual task. These findings and their implications are all discussed in greater depth in the next section.

6.1 Overview and implications

Section 2.3 of the literature review identified discrepancies in findings pertaining to cross-modal load effects, and a lack of research into the effects of perceptual load on subjective conscious awareness. Accordingly, the primary aim of Chapter 3 was to test whether high visual and auditory perceptual load impacted on visual change detection. Visual and auditory perceptual search tasks (based on tasks used by Lavie and Cox (1997) and Dalton and Lavie (2004, 2007)) were combined with a change blindness flicker task (Rensink et al., 1997) in order to directly test whether perceptual load impacted on change detection in a "flicker" paradigm. Visual and auditory perceptual load were manipulated by increasing the visual or phonological similarity of the non-targets to the target. It was hypothesised, based on previous findings (Beck and Lavie, as cited in Lavie, 2006; Makovski et al., 2006), that increasing both auditory and visual perceptual load would impact on change detection performance. The results indicated that high visual and auditory perceptual load did impact on change detection, although the results should be treated with caution, because whereas visual perceptual load impacted on change detection accuracy and RT, auditory perceptual load only impacted on accuracy and not RT.

These findings offer tentative support that perceptual load theory can account for load effects on change blindness when load is manipulated both within and between different sensory modalities. This is important as it concurs with other studies that demonstrate visual perceptual load effects on detection of critical stimuli in inattentional blindness (Cartwright-Finch and Lavie, 2007) and change blindness (Beck and Lavie, as cited in Lavie, 2006) paradigms. Furthermore, it concurs with previous findings that demonstrate that a task-irrelevant auditory stimulus timed to coincide with the blank between scenes in a change-blindness task, can also lead to reduced change detection (Makovski et al., 2006). This suggests that load theory can be expanded to accommodate for load effects across different modalities, which implies that under certain circumstances, visual and auditory stimuli compete for a shared, limited capacity set of resources.

Section 2.2 of the literature review summarised support for a "generalised" theory of load proposed by Klemen et al. (2010) which suggests that high WM load as well as high perceptual load can reduce processing of task-irrelevant stimuli. The review also identified several studies based on visual search, AB and IB paradigms that suggest high WM load can impact on the successful processing of task-relevant visual stimuli, which implies that the generalised load theory may also account for the effects of high WM load on the conscious processing of attended stimuli. However, it was also apparent that each of these studies was limited with regards to the conclusions that could be drawn from it. Accordingly, the primary aim of Chapter 4 was to test whether the generalised load theory can be applied to the processing of task-relevant stimuli. Across three studies, visual and auditory n-back WM tasks (based on tasks used by Rose et al. 2005 and Klemen et al. 2010) were combined with a change blindness flicker task (Rensink et al., 1997) in order to directly test whether WM load impacted on change detection.

In studies 4a & 4b, auditory WM load was manipulated by increasing the difficulty of an auditory n-back task. The results from Studies 4a & 4b suggest that auditory WM load does not impact on change detection. These findings are at odds with previous findings that demonstrate auditory WM load can impact on the processing of task-irrelevant stimuli (Klemen et al., 2010) and task-relevant stimuli (Han and Kim, 2004; Akyürek and Hommel, 2005, 2006; Fougnie and Marois, 2007). This challenges the notion discussed in Section 2.2.5 that a "generalised" theory of load can account for the effects of WM load on the processing task-relevant stimuli. However, these null findings should perhaps be treated with caution, as it is possible an even more challenging auditory n-back task, or a different type of WM task altogether, may have had a significant impact on change detection.

In Study 4c visual WM load was manipulated by increasing the difficulty of a visual n-back task. In contrast to the auditory WM findings, increasing WM load in a visually presented n-back task did lead to reduced change detection accuracy; a result that is line with previous findings which demonstrate visual WM load can impact on the processing of task-irrelevant stimuli (Rose et al., 2005; Bingel et al., 2007; Gläscher et al., 2007). This finding supports the notion discussed in Section 2.2.5 that a "generalised" theory load can account for the effects of visual WM load on the processing of task-relevant stimuli. However, this result must also be treated with caution because there were issues with effectively manipulating the visual n-back task and one of the conditions had to be removed from this experiment (see Section 4.13).

As explained in Chapter 4, the WM findings from Studies 4a, 4b and 4c do not specifically challenge the load theory of selective attention and cognitive control (Lavie et al., 2004b), as the studies directly test WM load effects on relevant task processing, rather than testing WM effects on concurrent selection between task-relevant and irrelevant stimuli. Instead, the findings were hypothesised to be accountable by the generalised theory of load proposed by Klemen et al. (2010), which predicts that increasing WM load leads to reduced processing of task-irrelevant stimuli. Given the inconsistency in the current visual and auditory WM results, it is difficult to make any firm assertions as to whether the generalised theory can account for WM load effects on attended stimuli processing. It appears that the generalised theory does not apply when testing auditory WM effects on change detection, which seems logical given that the two tasks use separate WM resources, according to the WM framework (Bower, 1974). This suggests a possible (albeit rather specific) limit to the generalised load theory, in that it cannot account for auditory WM load effects on attended stimuli processing when the second task requires focused visual attention and places demands on visual WM. However, the theory can account for visual WM load effects on change detection demonstrated in Study 4c. Again, this seems logical as the two tasks are competing for the same, limited visual WM resources, according to the WM framework.

Section 2.3 reviewed evidence both for and against the notion that task-irrelevant emotional stimuli can have a distracting effect despite high perceptual load in a relevant task. It was identified that a) no study had tested perceptual load effects on task-relevant emotional stimuli, and b) no study had tested cross-modal load effects on emotional stimuli. Accordingly, in Chapter 5, one set of studies (5b - 5f) was concerned with testing the effects of visual and auditory perceptual load on task-relevant affective stimuli processing. Preliminary studies were carried out to develop an improved, well balanced set of emotional and neutral images (5a) and to determine suitable difficulty levels for the visual and auditory perceptual load tasks (5b - 5e). It eventually proved impossible to set appropriate levels for the load tasks (particularly in the high auditory condition) so a calibration task was devised so that high perceptual and auditory load levels could be calibrated on a per-participant basis. Despite this, participants still performed at chance throughout the study, rendering the data inconsequential. The effects of auditory and visual perceptual load on task-relevant emotional stimuli remains unclear.

However, one final study (5g) which tested the effects of visual perceptual load on the processing of task-irrelevant emotional stimuli was more successful. This study addressed a number of concerns with a previous study (Erthal et al., 2005) which demonstrated that distracting effects of highly negative and arousing images can be eliminated under high load. Stimuli of relatively simple figure/ground composition were used, the presence or absence of human faces in the images was controlled for, and the Stimulus Onset Asynchrony (SOA) was reduced to completely eliminate any possible effects of eye movements. The findings suggest that extremely highly salient emotional stimuli are able to overcome extremely high perceptual load effects - a result that contradicts Erthal et al. (2005), and suggests that there may well be a “limit” to perceptual load theory. The current results are in line with recent EEG data that also suggest a limit to load theory (Norberg et al., 2010; Sand and Wiens, 2011), and also with behavioural data from Pessoa et al. (2005) (although imaging results from that study did demonstrate reduced processing of task-irrelevant emotional faces under high perceptual load). The findings form part of a growing body of evidence indicating the perceptual load theory does not always hold in circumstances where highly salient negative and arousing stimuli are involved. This adds to the growing body of literature that presents a challenge to load theory - a topic that is discussed in Section 6.3.

6.2 MacDonald and Lavie (2008) - a critical comparison

Not long after I had completed the studies outlined in Chapter 3, Macdonald and Lavie (2008a) published a paper with several experiments that also test the effects of perceptual and working memory load on subjective conscious awareness. There is some overlap between their research and mine; particularly the results of their studies on perceptual load and conscious perception (Experiments 1-5) and the results of my Study 3b. Rather than discount their paper from this thesis, as it was published after the completion of my work on perceptual load and change detection, I decided that it would be more valuable to critically compare our work and how both sets of studies separately contribute to the literature.

Macdonald and Lavie (2008a) manipulated visual perceptual load in letter search task using similar displays to Lavie and Cox (1997). In certain trials the critical stimulus (a search irrelevant meaningless small grey symbol) would appear in the periphery of the circle of letters, and at the end of each trial participants indicated whether the stimulus was present or absent. This meant that the impact of increased visual perceptual load on subjective conscious awareness of the critical stimulus could be directly tested. This is unlike Lavie and colleagues' previous response competition based studies (e.g. Lavie, 1995; Lavie and Cox, 1997), which rely on measures of distractor effects on target detection RTs; although these studies do tell us that distractors are being implicitly processed to the level of semantic analysis, they do not directly inform us of the extent to which participants have become consciously aware of the distractors. In their new study, Macdonald and Lavie also confirmed that high perceptual load in an task-relevant visual search task can reduce awareness of a search-irrelevant critical stimulus. These results fall in line with previous studies that have tested visual perceptual load effects on task-relevant stimuli (Beck and Lavie, unpublished; Cartwright-Finch and Lavie, 2007).

There is clearly some overlap between our studies, in that they both test whether high visual perceptual load (manipulated by increasing the difficulty of a visual search task) impacts on detection of a search task irrelevant critical stimulus. It is also true that both studies essentially reach the same conclusion with regards to the effects of visual perceptual load on detection of this critical stimulus i.e. high visual perceptual load leads to reduced detection of the critical stimulus. However, despite the overlap in research question and the similar results, there are a number of distinctions that can be drawn between Study 3b and Macdonald and Lavie. First, Study 3b tested both unimodal and cross-modal load effects, whereas Macdonald and Lavie focused exclusively on unimodal load effects. Second, change detection in the current study required participants to actively monitor the scene, as change detection is reliant on focused visual attention to a particular area; whereas in Macdonald and Lavie the “awareness” task was to report the presence or absence of the critical stimulus - a task that may have required a different type of processing to change detection. Third, the present study is also an addition to the change-blindness literature, as it is the first to test cross-modal load effects on change detection.

Macdonald and Lavie also ran a study testing the effects of WM load on awareness (Experiment 6). As in their previous five studies, participants were required to attend to a letter search task while also attempting to detect the presence of a search task-irrelevant critical stimulus (see Section 6.2 for more details), but additionally they were required to hold either one digit (low load) or a set of six digits (high load) in WM, and then recall this after completing the selective attention task, as is standard in the WM set/probe task. The authors found no effects of WM load on detection of the critical stimulus, which demonstrates that under certain circumstances WM load does not impact on task-relevant stimuli processing. However, this task, like most of the research done by Lavie and colleagues is based around the set/probe paradigm and tests WM on selection between task relevant and irrelevant stimuli, hence this null effect of WM is limited to these indirect testing circumstances and therefore not directly comparable with my results in Chapter 4.

Overall, Macdonald and Lavie and the research outlined in Chapters 3 & 4 of this thesis both make useful and independent contributions to the literature on perceptual and cognitive load effects on awareness/change detection. Admittedly, the Macdonald and Lavie paradigm is a more straightforward and manageable task, which importantly has allowed it to be adapted for use with clinical populations (Remington et al., 2009). Furthermore, as the paradigm does not involve change-detection, this eliminates the WM component that is involved in comparing changes between images; although WM will still be involved as a result of the retrospective reporting of the critical stimulus. However, Study 3b effectively expands on Macdonald and Lavie's findings by suggesting that an increase in *auditory* perceptual load in an auditory search task can impact on stimulus detection (albeit in a very different experimental paradigm), and furthermore, it is the first study to demonstrate that both visual and auditory perceptual load impact on change detection in a change blindness "flicker" paradigm.

6.3 Dilution and Other Challenges

Over the past two years there has been something of a backlash against the perceptual load model. Given the massive implications this has for the integrity of load theory, it is important that I give an account of this new material and highlight exactly how the findings presented in this thesis can contribute to this debate. Khetrapal (2010) has suggested that the perceptual load hypothesis is too simplistic and that the model needs to be revised to accommodate a whole host of other factors that impact on selective control in attention. Khetrapal cites work by Eltiti et al. (2005) which manipulates target salience to show distractor interference under high perceptual load and focused attention under low perceptual load - a pattern of results that is diametrically opposed to load theory predictions. Furthermore, studies by Johnson et al. (2002) and Paquet and Craig (1997) demonstrate that distractor interference in a flankers task can be eliminated when attention is cued towards the targets, or when the distractors are spatially distinct to the targets. Additionally, Sato et al. (2012) recently demonstrated that conditions of high stress/anxiety can also serve to eliminate distractor processing under low load, which suggests that stress and perceptual demands compete for the same attentional resources. Khetrapal suggests that it is imperative that further studies investigate target/distractor salience, precuing and spatial dynamics, in order to build up a more comprehensive model of selective attention. Khetrapal certainly has a point, and to my knowledge there has not been any attempt to reconcile these contradictory results with load theory.

Surprisingly the most sustained criticism of the perceptual load model has come from the original co-founders of the theory - Yehoshua Tsal (Lavie and Tsal, 1994). Benoni and Tsal (2010) highlight the fact that the majority of evidence for perceptual load theory comes from manipulations of display size in response competition tasks, such as the go/no-go task used by Lavie (1995). In this example, under low load the target appears by itself, whereas under high load the target was flanked by several neutral non-targets. Benoni and Tsal argue that in manipulations like this any implications of perceptual load are confounded by "dilution" of the distractor by the neutral non-target letters. Under low load an incongruent distractor that appears alongside a target will will have a large impact; whereas under high load an incongruent distractor that appears alongside a target and several non-targets will be diluted as a result of the non-targets' features being activated while searching for the target. In other words, in order for an incongruent distractor to distract, it must be processed to the level of semantic representation, allowing it to active a competing response and thus increase response time to the target. This representation is easily achievable in a low load condition that consist of a solitary target and distractor, but in a high load condition features of the non-targets compete with features of the distractor for representation. This means that under high load the distractor incongruency effect is substantially reduced or eliminated. So, rather than high perceptual load reducing distractor interference, Benoni and Tsal claim that this effect can be accounted for by dilution.

Benoni and Tsal also point out than another attractive quality of the dilution account is the fact that "dilution" can be clearly and simply defined as "the mere presence of different neutral letters whose features are visually similar to those of the distractor" (Benoni and Tsal, 2010, p.1293), whereas "perceptual load" has never really been satisfactorily defined, and perceptual load manipulation often just appears to rely on intuition about making a task easier/harder. To test this theory the authors modified the task used by Lavie (1995) so that, in addition to the standard low and high perceptual load conditions, there was also a condition that was high in dilution (high set size) but low in perceptual load. For example, in Experiment 1 participants were required to respond to a target that was either a letter C or S (one response) or a letter H or K (another response). The conditions involved detecting the target among a set of place markers (low load/dilution) or same colour non-target letters (high load/dilution) or different coloured non-target letters (low load/high dilution). Critically, although the "dilution" display contained the same amount of non-target letters as the "standard" high load display, the target was a different colour to the non-targets which made it easier to detect (low load). In this experiment and three follow-ups, they demonstrated that the distractor incompatibility effect was eliminated in the dilution condition as well as the high load condition, thus supporting the dilution account.

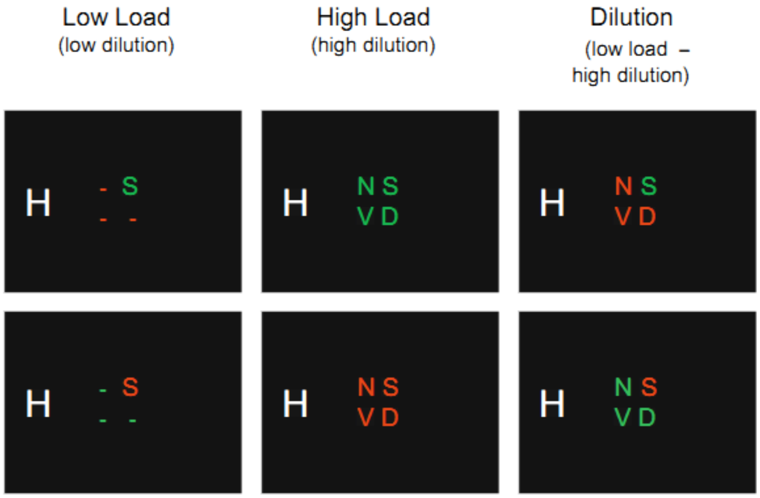


Figure 6.1: In this example of the dilution paradigm used by Benoni and Tsal (2010), participants were required to respond to a letter C or S (one response) or a letter H or K (another response). Red targets and green non-targets were used in one version of the experiment; these were switched in another version. In the high load/dilution condition the target and non-target colours were homogeneous. In the dilution condition the target and non-targets differed in colour, hence the target was easy to detect among the non-targets (low load) but the presence of the non-targets meant that the display was high dilution.

Lavie and Torralbo (2010) counter-argue that the Benoni and Tsal findings which show reduced competition from distractors under low perceptual load but with high set size can be accounted for within the framework of load theory, and they present a new study that challenges Benoni and Tsal findings; although in their rebuttal, Tsal and Benoni (2010) point out that this new study only actually challenges their first experiment, and not the remaining three experiments, so is not an effective challenge to the dilution account. Importantly, Lavie and Torralbo argue that the dilution arguments only applies to one manipulation of load i.e. tasks that manipulate the set size of the display in order to test load effects on distractor processing, and that this argument cannot be applied to studies that support perceptual load theory which use the same stimulus displays across low and high load (e.g. Rees et al., 1997; Cartwright-Finch and Lavie, 2007, see Lavie and Torralbo for a full review). This is important for load theory, as it does somewhat limit the challenge presented by the dilution argument.

Critically, the work presented in this thesis is particularly relevant to the dilution/load debate, as the results cannot be attributed to the effects of dilution because set size manipulations or distractor competition paradigms were not used in any of the studies. The task in Chapter 3 used a letter search task to manipulate load, but set size remained consistent and there were no competing distractors to be diluted among non-targets. This finding therefore offers "dilution proof" support for perceptual load theory - a result that corroborates with existing work that cannot be explained by dilution (e.g. Beck and Lavie, as cited in Lavie, 2006; Cartwright-Finch and Lavie, 2007, Lavie and Torralbo also discuss several other "dilution proof" studies). Chapter 4 was concerned with cognitive load and used an *n*-back task to directly manipulate WM load effects on change detection, hence the dilution argument is not relevant here, and the results lend some support to the generalised theory of load proposed by Klemen et al. (2010). It is also worth noting that the dilution argument does not appear to apply to the studies that support the load theory of selective attention and cognitive control (Lavie et al., 2004a; de Fockert et al., 2001; Brand-D'Abrescia and Lavie, 2008), as these studies either a) manipulate cognitive load while keeping perceptual load in the selective attention task constant, or b) do not use letter search tasks. Finally, the dilution argument is not be applicable to the studies presented in Chapter 5, as they used bar or tone stimuli to manipulate perceptual load, and the amount of information displayed on screen remained consistent across low and high load conditions. In fact, dilution cannot occur in any of the paradigms which test load effects on emotionally salient stimuli, given that none of the tasks test the effects of interference from competing distractor letters. However, the evidence from Study 5g which suggests that high perceptual load effects can be overcome by highly negative and arousing stimuli, plus the corroborating evidence from recent EEG studies (Norberg et al., 2010; Sand and Wiens, 2011), creates another problem for the general applicability of the perceptual load model, although to be fair, Lavie has never made any specific assertions about the application of load theory to emotional stimuli processing.

6.4 Further Study and Theory Development

Throughout this thesis suggestions have been made for how each of the current studies could potentially be improved in order to make them more robust. Rather than focussing on the specific details, this section will try and look at the big picture and suggest what further work needs to be carried out to allow this field to move forwards.

Although the work carried out for this thesis has demonstrated that the perceptual load model does hold when testing both visual and auditory perceptual load effects on change detection, it also draws attention to the discrepancy between the load theory of selective attention and cognitive control and the generalised effects of cognitive load. This work also suggests that the perceptual load model does not always hold when faced with distraction from highly salient emotional stimuli. Furthermore, perceptual load theory has been criticised for not producing a satisfactory definition of what perceptual load actually is; for being over-simplistic; for not accounting for contradictory findings, and for the fact that dilution offers a credible alternative explanation to many of the studies that support load theory.

The arguments against load theory are, admittedly, not fully developed (yet), and Lavie and Torralbo are justified in drawing attention to the fact that load theory is backed up by a range of findings that are robust to the dilution explanation. However, dilution does present a very real challenge to load theory; further recently published studies also support this account (Wilson et al., 2011; Kyllingsbaek et al., 2011; Marciano and Yeshurun, 2011; Benoni and Tsal, 2012), suggesting that this argument is gaining momentum, and cannot be overlooked. It seems like this could either go one of two ways. Either evidence will be produced which demonstrates that both dilution and the contradictory findings discussed by Khetrapal (2010) can somehow be accounted for within the perceptual load model (see Wilson et al. for a breakdown of how this possibly could work). Or, alternatively it may be accepted that perceptual load is just one of many factors that influence control of selection in attention, and this may be accounted for within a new theory which offers a more comprehensive resolution to the early/late selection debate in attention.

The role of perceptual load across different sensory modalities certainly warrants further investigation. My findings indicate that increased perceptual load in the auditory modality can lead to reduced processing in the visual modality, and this corroborates evidence from another change detection study (Makovski et al., 2006). However, this does contradict both behavioural and imaging results from Rees et al. (2001) which suggest that auditory load does not impact on irrelevant motion processing. In order to further our understanding of cross-modality interference, it is important to test cross-modal load effects in a range of different paradigms, in order to determine when interference does and does not occur. Furthermore, imaging methods could be applied in order to elucidate our understanding of the neural correlates of cross-modal load effects. In fact, cross-modal research could provide a useful line of argument against dilution, as there is clearly no potential for low-level visual interference when competing stimuli are presented in different modalities. Additionally, cross-modal influence of perceptual load on the processing of emotional visual stimuli processing also needs to be tested, as to my knowledge this remains an unexplored area. Having investigated the effects of visual and auditory perceptual load on visual change detection, a possible next step could be expand this research to investigate visual and auditory perceptual load effects on the auditory analogue of change-blindness: change deafness (Gregg and Samuel, 2008). This could help provide a useful insight into the nature of auditory attention and possibly provide further support for cross-modal load effects. It appears that the effects of visual perceptual load on the auditory analogue of inattentional blindness: inattentional deafness, have already been demonstrated (Macdonald and Lavie, 2011). Furthermore, the impact of auditory perceptual load could be investigated in the auditory version of the AB task, to investigate whether cross-modal load impacts on the temporal distribution of attention.

Although the expanded load theory of selective attention and cognitive control (Lavie et al., 2004a) does not appear to be susceptible to the dilution argument, the assertion that the effects of cognitive load are diametrically opposed to those of perceptual load clearly only applies when cognitive load is increased while participants perform a selective attention task. It appears that under most other circumstances where cognitive load is increased, the processing of task-irrelevant stimuli is reduced (e.g. Rose et al., 2005; Bingel et al., 2007; Gläscher et al., 2007; Klemen et al., 2010), and the processing of task-relevant stimuli is either unaffected (Woodman et al., 2001, ; Studies 4a and 4b) or reduced (Han and Kim, 2004; Akyürek and Hommel, 2005, 2006; Fougnie and Marois, 2007, Study 3c), which supports a more generalised theory of load (Klemen et al., 2010). These are essentially two different theories that account for WM effects under entirely different circumstances, and this needs to be made explicit in order to avoid possible confusion. A review article that overviews both sets of literature and makes an explicit distinction between them would be a useful addition to the literature.

Finally, there is a growing body of literature concerned with the interaction between perceptual load and individual differences in selective attention. For example, Sato et al. (2012) have recently shown that state anxiety can interact with perceptual load. Under typical conditions interference from distracting flankers was eliminated by increasing the level of perceptual load in a response competition task. However, when high levels of state anxiety were induced in one group of participants, the distractor competition effect was also eliminated in the low perceptual load condition; whereas, substantial distractor interference was shown in the high perceptual load condition. Furthermore, Fox et al. (2012) have shown that while fear conditioned angry faces had a strong distraction effect under low perceptual load in a low-trait anxious group of participants, there was a complete reversal of this effect in a high trait anxious group i.e. highly anxious participants responded faster to targets while ignoring the fear conditioned distracting faces. This suggests avoidance of fear conditioned emotional stimuli by participants with high trait-anxiety. Both state and trait anxiety need to be explored across a range of different perceptual load paradigms in order to build up a more comprehensive account of the interaction between perceptual load and anxiety.

6.5 Conclusion

This thesis identified and investigated several under-researched aspects of load theory. The work had three principle aims. First, to directly test the effects of perceptual and cognitive load on change detection. Second, to determine whether highly negative and arousing images are able to overcome the effects of high perceptual load. Third, to test both perceptual and cognitive load effects both within and between different sensory modalities.

The findings offer preliminary support that both high visual and high auditory perceptual load can impact on detection of change in visual scene. This is important as it suggests that the perceptual load model can explain load effects across different modalities, as under these experimental conditions the visual and auditory stimuli can compete for a shared set of attentional resources. Critically, the current findings offer support for load theory in the form of a testing methodology that cannot be accounted for by the dilution argument.

The results of the WM load studies also offer some support for a more “generalised” theory of load, as proposed by Klemen et al. (2010), whereby an increase in any type of load (e.g. perceptual, WM, stress) in a relevant task results in reduced processing of task-irrelevant stimuli. Importantly, the results of Study 4c suggest that the generalised theory of load can account for the effects of high visual WM load on the processing of task-relevant visual stimuli. However, the results of Studies 4a and 4b suggest that, under this specific testing paradigm, increasing auditory WM load does not impact on the processing of task-relevant visual stimuli. Overall these findings suggest that the generalised load model can account for WM load effects on the processing of task-relevant visual stimuli, but only when both tasks are presented within the visual modality. It is important to note that while these new findings do not directly challenge the load theory of selective attention and cognitive control (Lavie et al., 2004b), they do highlight the need for a clear distinction to be drawn between the two different theories that account for WM effects under different circumstances.

Finally, although the attempt to investigate the effects of auditory and visual perceptual load on emotional stimuli processing was unsuccessful, a separate study demonstrated that extremely high perceptual load does not eliminate distractor interference from highly negative and arousing stimuli. This result adds to a growing body of literature that suggests perceptual load theory does not always hold when highly potent emotional stimuli are involved, which clearly presents a problem for the general application of perceptual load theory.

In addition to providing new evidence for and against load theory, this thesis has also synthesised information from numerous different research areas and provided an overview of the recent challenges to load theory from studies with contradictory results and the dilution account, along with suggestions for further avenues for research. It is hoped that by gaining a greater understanding of the applications and limitations of the perceptual load model we can move closer towards a more comprehensive theory of selective attention.

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Appendix A

Participant	Visual 65% Accuracy Level	Auditory 65% Accuracy Level
1	6	90
2	10	50
3	8	40
4	6	40
5	8	n/a
6	10	n/a
7*	12	40
8	6	120
9	12	30
10	n/a	n/a
11	8	20
12	8	120
13	10	40
14	8	40
15	8	110
16	10	30
17	6	50
18	6	50
19	12	n/a
20	14	n/a

Table 1: Participant's 65% Accuracy Scores on the Method of Constant Stimuli. N/A in a column implies that it was not possible to fit a curve to that participant's data, either due to highly variable or chance performance.*Participant seven did not attend the final testing session.