Is Working Memory Load a Critical Factor in Distractor Processing?

A thesis submitted in partial fulfilment of the

requirements for the Degree of

Masters of Science in Psychology

By

Marion Davis

University of Canterbury

2007

Acknowledgments

I wish to express sincere thanks and appreciation to Dr. Zhe Chen for her support and assistance in the preparation of this manuscript. In addition, special thanks to Dr. Murray Simmonds in his role of co-supervisor. Thanks to Joyce and Leigh who read numerous drafts and made invaluable suggestions and corrections. Thank you to the participants and to my class mates for their encouragement and support. Last but not least a special thank you to Michael.

Table of Contents

Abstract

To achieve goal-orientated behaviour, selective attention is often needed to filter out irrelevant information. Past research has shown that working memory (WM) plays a critical role in selective attention, with high WM load leading to more distractor interference than low WM load. However, because WM load is usually manipulated by requiring participants to hold in memory either one or several digits that were presented simultaneously while performing a selective attention task, the extent of attentional focus was not controlled. The present study examined the effect of WM load on distractor inhibition while keeping attentional focus constant by presenting one digit (low load condition) or six digits (high load condition) sequentially. The participants in the high-load condition demonstrated greater distractor interference than the participants in the low-load condition, suggesting that WM load influences distractor inhibition even when the extent of attentional focus was controlled. This result provides converging evidence to Lavie's (1995, 2005) load theory of attention and cognitive control.

1 Introduction

The ability to maintain focus on a given task is a fundamental behavioural objective. Because we live in a world where task relevant information occurs together with task irrelevant information frequently, it is important that the latter be filtered out so that behavioural goals can be achieved. One way to accomplish that is through distractor inhibition. Among the factors that influence our ability to inhibit distractors are working memory (WM) capacity and WM load. Whereas it is generally agreed that a positive correlation exists between working memory (WM) capacity and the efficiency of distractor inhibition (Conway & Engle, 1994; Kane & Engle, 2003), the effect of WM load on selective attention is less clear. While some studies show that an increase in WM load leads to a decrease in distractor inhibition (e.g., Lavie, 1995, 2001; Lavie, Hirst, de Fockert & Viding, 2004; Lavie & Tsal, 1994), other experiments suggest a more limited role that WM load plays in selective attention (e.g., Chen & Chan, in press; Logan, 1978; Woodman, Vogel, & Luck, 2001).

The experiment reported below examined the role of WM load on selective attention while controlling for the extent of attentional focus. Participants performed a selective attention task that required them to make speeded identification of a target letter while ignoring surrounding distractor letters. During this task they were required to hold in memory either a single digit or a set of six digits presented sequentially. Of interest was whether the magnitude of distractor interference would vary as a function of WM load.

To understand the relationship between WM and selective attention, Section 2 provides an overview of WM research and memory processes. Section 3 provides a detailed review of Lavie's (2005) load theory of selective attention and cognitive control. Results which are inconsistent with the load theory will then be presented in section 4. Section 5 reported an experiment that investigated the effect of WM load on visual information processing while controlling the extent of attentional focus.

2 Overview of working memory research

Working Memory

Working memory consists of processing components that are deployed in the control, regulation, and active maintenance of task-relevant information used in cognitive tasks such as learning and problem solving (Baddeley, & Weiskrantz, 1993, Baddeley & Logie, 1999). The functions include: storing material for immediate recall as mentioned above and providing access to long-term memory (Atkinson & Shiffrin, 1971; Baddeley, 1982). According to Baddeley and Hitch (1974), information in WM is actively used and manipulated to allow the integration of newer, immediate information. WM therefore allows a person to keep a limited amount of information active for a brief period of time.

In order to understand how WM maintains task relevant information during the performance of a cognitive task, it is necessary to examine how the different components work collectively. For example selective attention and distractor inhibition, WM capacity, executive control processes, and WM load have all been postulated to contribute to the performance of a cognitive task. The rest of the section provides a brief review on each of these components.

Selective Attention and Distractor Inhibition

What people ‘perceive’ is determined by what people attend to (Mack & Rock, 1998). Attention is the cognitive process of selectively concentrating on only the task relevant information while ignoring other task irrelevant stimuli. A good example is the cocktail party problem, in which a person tries to follow one conversation while ignoring other conversations in the room (Cherry, 1953; Conway, Cowan & Bunting, 2001). Inhibitory mechanisms play a fundamental role in selective attention by reducing both ambiguity and distractor interference. In a visual search paradigm Watson and Humphreys (1997) demonstrated that in a visual search paradigm previously viewed objects could be visually marked provided that they differed in colour, or another feature, from new objects. They theorised that the visual system inhibits the locations of the old objects by the activity of an inhibitory memory template. Thus, inhibition prioritises the selection of new objects so that observers inhibit the locations of old or previously processed objects so that those objects no longer compete as strongly for selection (Watson & Humphreys, 1997).

Traditionally, there have been two divergent views of selection processes: early versus late selection. According to *early-selection* theories (e.g., Broadbent, 1958), unattended information is not processed beyond its most basic physical attributes. In other words, the meaning of an unattended stimulus is not processed. In contrast, researchers that support the *late-selection* view propose that selection occurs only after categorisation and meaningful analysis of input have occurred (Deutsch & Deutsch, 1963).

Both views have received considerable amount of empirical support. For example, in early experiments in which the dichotic listening procedure was used (i.e., the participants repeated aloud passages that were presented to one ear while ignoring passages that were delivered to the other ear), Moray (1959) found that the participants would fail to show any sign of having heard a list of words that had been presented up to 35 times to their non-attended ears. This finding is consistent with the early-selection view, suggesting that the meaning of unattended information is not processed. However, other experiments have supported the late-selection view. For example, Eriksen and Eriksen (1974) showed participants stimulus displays that consisted of a central target with two flanking distractors. They manipulated the relationship between the target and the distractors so that the response indicated by the distractors could either be compatible with the response of the target (the compatible condition), incompatible with that of the target (the incompatible condition), or not related to the response of the target (the neutral condition). The results show the compatibility effect, i.e., RTs were faster in the compatible condition than in the neutral condition, which in turn were faster than the incompatible condition. Consistent with the late-selection view, these findings suggest that attentional selection occurred at a semantic level.

As Kahneman and Treisman (1984) pointed out, these seemingly contradictory findings may very well be the result of a paradigmatic shift in the field of attention research. Whereas evidence in support of early selection is typically associated with the "filtering paradigm" characterised by heavy information load, evidence consistent with late selection is usually obtained with the use of the "selective set paradigm" that employs simple stimulus displays. The notion that the level of information load may be the key to the locus of selection was further developed by Lavie and her colleagues in the load theory of attentional selection (Lavie, 1995, 2000; Lavie & Tsal, 1994). A more detailed account of the theory will be provided later in section 3.

It is important in attention research to understand the factors that facilitate target selection and reduce distractor interference. A principal factor that influences the degree of distractor interference is the spatial separation between a target and distractors in a given task. For example, Eriksen and Eriksen (1974) manipulated the spatial separation between the target and the distractors in addition to the response competition between the two. The response compatibility effect was greater when the target was closer to the distractors than when it was farther away from them.

Eriksen and St James (1986) further showed that the extent of attentional focus influenced the degree of distractor interference. They proposed a “zoom-lens” model of selective attention. According to the model, as the size of the attentional field increases, the amount of processing resources within the field deceases. In their study, Eriksen and St. James presented participants with stimulus displays consisting of a target letter and either seven neutral letters (the neutral condition) or six neutral letters plus one incompatible letter (the incompatible condition). The letters were presented in a circular arrangement around a central fixation point and a precue to one, two, four, or all eight stimulus positions preceded the display onset. The results show that RT’s increased with Moreover, distractor interference decreased with increased distance from the target. They found that distractors produced more interference when they were within rather than outside the cued area. Consequently, allocating attention to or away from distractors influenced the extent of their processing. The findings they argue illustrate that when more positions are cued, attention must be spread out over a larger area, with fewer resources being allocated to each location. Thus, the effectiveness of visual filtering is related to the spatial range of attentional focus that can be expanded or contracted in a manner that is analogous to a zoom-lens. Visual search for a target in an array of distractors relies on flexible shifts between global and local approaches of attentional processing. The spotlight or zoom-lens models of attentional focus suggest that attention can be directed to a specific location aided by a precue that directs attention to a valid location. However, the finding was that attentional focus was unable to completely inhibit the processing of interference resulting in large RTs (Eriksen & St James, 1986; Yantis & Johnston, 1990).

The spatial extent of attentional focus has also been found to influence the degree of distractor processing The spotlight and zoom-lens models of attentional focus are reported to show that as attentional focus increases, participants' RT's became longer. Consequently, Eriksen & St James (1986) report the extent of the attentional focus changes with task demands, with processing efficiency having the opposite effect on the spatial extent of attentional focus. Such that when a task requires processing of stimuli in a narrow area, the attentional focus becomes relatively small. As the extent of the attentional focus decreases, the density of processing resources within the attended area increases, leading to more efficient processing. Conversely, when relevant stimuli occupy a broad area, the attentional focus expands.

However, research by LaBerge, Brown, Carter, Bash, & Hartley, (1991) showed that when the attentional focus was narrowed the effect of interference was reduced. Participants were required to respond to a display consisting of a target (7, H or Z) which was flanked by distractor letters (T or Z) this display was presented at varying durations. Participants then respond to a second a target letter (C, H, S or K) which was flanked by neutral, compatible, or incompatible letters again the presentation duration was varied. All displays were presented sequentially with a total of 17 characters per display. Participants were required to identify first the digit target then the letter target appearing in the same location. Results suggested that the main factor contributing to the elimination of distractor interference was the brief presentation time of the first target thus encouraging participants to narrow their focus of attention for the second task. La Berge et al. explain these findings by two mechanisms: a filter that quickly opens and closes at the location of the target and flanker, and by the high probability that the channel will open at the location previously focused. LaBerge et al. findings of more efficient distractor inhibition due to narrowing of attentional focus adds support to Eriksen & James (1986) findings that increasing the area of attentional focus reduces the ability to inhibit interference. Taken together these results indicate that the size of the spotlight can vary according to the demands of the task resulting in increases in distractor interference as the area of attentional focus increases.

Distractor inhibition is essential in selective attention. Very often, goal-directed behaviour depends on maintaining relevant information in WM while excluding irrelevant information from WM. The capacity to inhibit inappropriate responses decreases with an increase in WM load (Conway et al., 1999; Engle et al., 1995).The negative priming (NP) effect has been used by a number of researchers to examine the processes involved in selective attention tasks (e.g. Dalrymple-Alford & Budayr, 1966; Fox, 1995; May, Kane, & Hasher, 1995). Conway et al, and Engle et al. (1995) suggest that individual differences in NP that were observed between high WM capacity participants showed reliable NP while low WM capacity participants did not. The results indicate that NP effects result from distribution of controlled attention and that individual difference in WM capacity corresponds to the ability to efficiently handle irrelevant information.

Working Memory Capacity, Executive Control and Distractor Interference

Working memory capacity is "the capacity for controlled, sustained attention in the face of interference or distraction" (Engle, Kane & Tuholski, 1999, p.104). Cowan (1995) and Engle et al. (1999) view this capacity as a general resource, which contributes to cognitive performance in any area that demands controlled processing. Thus, the authors argue that WM capacity reflects the ability to keep a representation active, particularly in the face of interference and distraction.

The original WM capacity model proposed by Daneman and Carpenter (1980) emphasised a trade-off between processing and storage demands. Performance on a task could be impaired by a dual task if there were a need for the tasks to share resources such as attention, verbal or spatial processing, or both of them. To test individual differences in WM capacity researchers have traditionally used memory span tasks, in which words are presented to participants who are required to recall them at the end of the sequence. Daneman & Carpenter (1980) used a reading task in which participants read sentences and were required to remember the last word of each sentence for later recall. WM span was defined as the maximum number of sentences for which this task could be performed perfectly. Daneman and Carpenter found a high correlation between WM span and reading comprehension. Similar results occur when sentence processing is replaced by other tasks, such as arithmetic calculation or colour–word association. It was argued that individual differences in reading comprehension were due to reader's differing abilities of their processing skills. Therefore, good readers have more functional WM capacity simply because they have more efficient reading skills.

The central executive operates as the control processor of WM (Baddley, 1996). It is an attentional mechanism used to maintain current task objectives, process incoming information, block other task irrelevant information and internal interference (Unsworth, Schrock & Engle, 2004). Essentially, executive control is a mechanism of decision. It is the process by which the mind plans and exercises control allowing engagement in goal-directed activities (Logan, 2004). A recent review by Baddeley (2003) on the progress of WM research highlighted that the concept of a central executive remains a poorly understood component of the WM system with a paucity of research of the mechanisms that drive the system. However, a significant number of studies in this area (Conway, Cowan, Bunting, Therriault & Minkoff, 2002; Daneman & Carpenter, 1980; Engle, Carullo & Collins 1991; Engle, Tuholski, Laughlin & Conway, 1999; Kane, Bleckley, Conway & Engle, 2001) have established the existence of individual differences in WM span and that WM capacity is an important function for cognitive tasks.

Conway et al. (1999) carried out two experiments. In the first experiment, participants performed a letter naming task while memorizing words. Each trial consisted of a prime display (a red and a green letter) followed by a probe display. The participant's task was to name the red letter as quickly and as accurately as possible. After each trial, a word was presented for later recognition. After the 5th trial, a test word was presented and the participant had to indicate whether the test word matched one of the four previously presented words. In the second experiment, participants performed the same letter naming task but this time holding in memory a polygon for later recall. Both experiments varied load (zero to four) and trial type (control, filler, distractor-target and no selection). The results showed that on both verbal and nonverbal secondary tasks NP was consistently observed across the participants only under conditions of zero memory loads.

Engle and colleagues proposed that cognitive measures of WM capacity reflect an individual's capacity to maintain information in spite of distracting information which suggests that executive control is compatible with the idea of controlled attention and, consequently, cognitive control. Consistent with this claim, they have shown that people who are low in WM capacity are more susceptible to interference from irrelevant information. According to researchers (e.g. Daneman & Carpenter, 1980; Engle, Cantor, & Carullo, 1992; Cantor & Engle 1993), there is a direct relationship between an individual's WM capacity and his or her ability to inhibit irrelevant information. For example, Hasher and Zacks (1988) proposed that individuals with large WM capacity have more effective inhibitory mechanisms. As a result, they are able to process only information that is specifically relevant to the current goal. Engle and his colleagues (Engle, et al., 1995) also suggested that inhibition is an effortful and resource-demanding process. Therefore, relative to low-span individuals, high-span individuals would theoretically have more resources left over to allow them to inhibit irrelevant information more efficiently.

Empirical evidence from prior research is generally consistent with the above views. For instance, Kane and Engle (2003) used the Stroop task to examine the interaction of WM capacity, active goal maintenance, and inhibition of competing stimuli. In a typical Stroop task, individuals report the colours in which colour words are presented. When the colour and word are incongruent (e.g., *RED* written in green ink), colour naming is slower and less accurate than when the colour and word are congruent (e.g. *RED* written in red ink). The slower response time is known as the *Stroop interference effect.* In all five experiments, high-WM-span individuals demonstrated less interference than did low-span individuals. That is, low WM capacity individuals responded more slowly than high WM capacity individuals on incongruent trials. These findings support the suggestion that WM capacity is a valid predictor of attentional control. Furthermore, in three experiments, Unsworth, et al., (2004) tested high and low-WM span individuals in an antisaccade task. The participants were required to make a saccade (rapid eye movement) either towards a flashing cue (prosaccade) or away from it (antisaccade). The results show that high- and low-capacity individuals varied in their ability to efficiently suppress reflexive saccades in the antisaccade condition, with low-span individuals making more reflexive saccade errors on the antisaccade trials. These results suggest that WM capacity is positively related to one's ability to suppress irrelevant eye movements.

Individual differences in performance on complex span tasks such as reading span, operation span, and counting span were argued by Engle et al., (1999) to be principally due to differences in the central executive component of WM. Engle, Kane and colleagues (Engle, et al., 1999; Kane & Engle, 2003) have proposed that individual differences on measures of WM capacity reflect differences in a person's capability for controlled processing that are reflected in situations that either encourage or necessitate controlled attention. On an antisaccade task involving minimal memory demand, and no complex cognitive skill, high-WM-span individuals consistently performed better than low-WM span individuals. Kane, et al. (2001) hypothesised that individual differences in performance on tasks such as the Stroop task and antisaccade task, which are reported to be sensitive to interference were correlated with an individual's WM capacity. Results from Engle, Kane and colleagues supported this assumption, showing that low-span participants had significantly longer mean target identification times for the antisaccade task and higher interference scores for the Stroop task than their high-span counterparts. Both of these results have been taken as support for the hypothesis that WM performance reflects the capacity to control attention. Therefore, individuals with a high WM span may not necessarily have a greater store of information; rather, they are better able to retain information through the suppression of irrelevant stimuli or responses. Consistent with this claim, they have shown that people low in WM capacity are more susceptible to interference from extraneous information on classic tasks involving cognitive control, such as verbal fluency (Conway & Engle, 1994; Rosen & Engle, 1997), dichotic listening (Conway, Cowan & Bunting, 2001), negative priming (responses that are slower when the target stimulus on the present (probe) trial served as a distractor on the previous (prime) trial) (Conway, Tuholski, Shisler & Engle, 1999; Engle et al., 1995), antisaccade (Kane et al., 2001), and Stroop (Kane & Engle, 2003).

The results of the above research suggest that keeping relevant information highly active and easily accessible is an indication of an individual's ability to control attention. Thus, reflecting an individual's ability to maintain information while blocking irrelevant information (Engle, Tuholski, Laughlin & Conway, 1999; Kane, Bleckley, Conway & Engle, 2001; Kane & Engle, 2003). Coherent goal-oriented behaviour under interference conditions requires both active maintenance of relevant information and inhibition of irrelevant information. Tasks including cognitive control; Stroop; negative priming and antisaccade are sensitive to interference and suggest that increasing WM load reduces participant's ability to control attention. These results are measured through both the switching of attention and inhibitory control which are suggested to reflect an individual's WM capacity (Hester & Garavan, 2005; Kane, Bleckley, Conway & Engle, 2001). However, researchers have also noted that executive control is not compulsory for all cognitive processing; it comes into effect in situations necessitating inhibition of prepotent reactions (reactions that are typically seen in conditions where there is distraction or conflict in a task), error monitoring and correction, and decision making and planning (Engle, Conway, Tuholski & Shisler, 1995; Miyake, 2001; Unsworth et al., 2004).

3 The Load Theory of Selective Attention and Cognitive Control

Building on Kahneman and Treisman's (1984) notion of paradigm shift, Lavie and her colleagues (Lavie, 1995, 2000, 2005; Lavie & Tsal, 1994; Lavie, et al., 2004) recently proposed a load theory of selective attention and cognitive control. According to this theory, perception is an automatic process with a limited resource available to the perceiver at any given moment. Furthermore, perception proceeds from relevant to irrelevant information until all the available resources are used up. As a result, when the perceptual load of the relevant task is high, distractor interference is low because distractors are not perceived due to the unavailability of resources. In contrast, when the perceptual load of the relevant task is low, distractor interference is high because distractors are perceived due to the extra resources that are present and are not consumed by the task. To inhibit distractors, efficient cognitive control is needed. WM is part of the executive cognitive control mechanism. When WM is heavily loaded, efficient inhibition is not possible due to the lack of available resources. Thus, when distractors have been perceived because of low perceptual load, relative to low WM load, high WM load leads to greater distractor interference.

In a series of experiments (e.g., Lavie, 1995; Lavie & Cox, 1997; Lavie et al., 2004) Lavie and her colleagues demonstrated that while high perceptual load reduces distractor interference, high WM load increases distractor interference. For example, in one experiment (Lavie, 1995, Experiment 1), Lavie manipulated the level of perceptual load. She showed participants stimulus displays which consisted of a target, a critical distractor, and either zero or several other neutral irrelevant items. Relative to the target response, the critical distractor could be compatible, neutral, or incompatible, and the magnitude of response compatibility effect was taken to indicate the degree of distractor processing. The manipulation of perceptual load was achieved through different display sizes, with a low load display containing a target and only a single critical distractor while a high load display containing a target, a critical distractor and several other neutral distractors. Consistent with the prediction of the perceptual load hypothesis, participants showed response compatibility effect in the low load condition, but not in the high load condition.

Lavie and her colleagues have also examined the effect of WM load on selective attention (e.g., Lavie et al., 2004). In one experiment (Experiment 1), participants performed a selective attention task while holding in memory either one digit (the low memory load condition) or six simultaneously presented digits (the high memory load condition). As before, the response compatibility between the target and the distractor was manipulated. The results show that the compatibility effect was greater in the high memory load condition than in the low memory load condition, suggesting that an incompatible distractor interfered more in the high than the low WM condition. The researchers interpreted their results in terms of the load theory. Because the perceptual load of the selective attention task was low (the target was accompanied by only a single distractor), the distractor was perceived. To inhibit it, cognitive resources were assumed to be required. When WM was loaded in the high memory load condition, efficient inhibition was not possible due to the lack of available resources. Hence, there was greater distractor interference in the high memory load condition than in the low memory load condition.

Several studies have indicated that WM load and contents have important roles in controlling selective attention (Downing, 2000; de Fockert, Rees, Frith, & Lavie, 2001). De Fockert et al. combined two tasks, one requiring selective attention and the other a WM task. The selective attention task required the participants to classify written names of pop stars or politicians while ignoring the face over which the word was written. Half the faces and names were congruent (e.g. the name of pop star written over the face of a pop star); the other half were incongruent (e.g. the name of a pop star written over the face of a politician). The task was to ignore the face and respond to the name. Concurrently they performed a WM task requiring the participant to remember five digits and then indicate if a single digit presented had been in the memory list. The WM task was manipulated either by using the same digits on every trial (low-load) or digits in a different order on every trial (high-load). The results showed that when the naming task was combined with the high-load WM task the RT was slower in the incongruent condition than the congruent condition indicating that when WM was loaded, selective visual attention was less effective. The authors then repeated the experiment using fMRI measuring activity in face processing areas of the brain. The areas of the brain measured included areas that have been associated with WM i.e. the inferior frontal gyrus, the middle frontal gyrus and the precentral gyrus. The results found activity was greater in the high- than the low-load memory condition. The results of these two experimental approaches according to De Fockert et al., suggests that WM control visual selective attention.

In a series of four experiments Han & Kim, (2004) studied visual search using a dual-task paradigm. Participants performed a visual search while manipulating or maintaining information held in WM. In Experiments 1a and 2a, participants needed to actively manipulate a memory stimulus in WM. Experiment 1a required counting backward from a target digit, and Experiment 2a required sorting a string of letters alphabetically. While performing these tasks, participants were required to search for a target among a set of distractors. The search slopes in these two conditions were significantly steeper than those in a search-alone condition, indicating that performing the WM manipulation tasks impaired the efficiency of visual search. In contrast, when information was simply maintained (e.g. when participants were not required to perform any manipulations and were assumed to rehearse the memory items) in WM search slopes did not differ between the single- and dual-task conditions. These results are reported to suggest that executive functions may interfere with visual search, not the preservation of information in WM.

4 Results Contrary to the Load Theory

In contrast to Lavie et al., (2004), studies by Logan (1978) and Woodman, Vogel and Luck (2001) have provided results which are inconsistent with the load theory. For example, Woodman, Vogel and Luck (2001) examined the effect of visual WM in a search paradigm. Participants performed a search task either with or without a concurrent WM load task. The results indicated that although the addition of a WM load contributed to an increase in the overall search time, there was no change in the search slope. On the basis of this and similar results, the authors concluded that visual search requires only minimal visual WM resources.

Other results have been reported by Chen and Chan (in press) who manipulated WM load and the extent of attentional focus while requiring participants to perform a letter discrimination task. Participants were assigned to one of three groups: high-load/narrow-focus, low-load/narrow focus, and low-load/wide-focus. First, participants saw stimulus displays consisting of a fixation point, and a memory array consisting of either one digit or six different digits. This was followed by a fixation point followed by a cue that could be either large (four squares) or small (one square). The target display consisted of a target letter with four identical distractor letters. The distractors were either not associated with the target response or indicated a different response from that of the target. A memory probe that consisted of one digit and a question mark was then presented immediately after participants performed the letter discrimination task. In particular, Chen and Chan (2006) found larger interference effect in the low-load/wide-focus condition than the low-load/narrow-focus condition, but no difference between the low-load/narrow-focus and high-load/narrow-focus conditions. In other words, when the attentional focus was held constant, the effect of WM load was negligible. The authors suggested that because attentional focus is typically not controlled in previous experiments (e.g., de Fockert et al., 2001; Lavie et al., 2004), the effect of working memory load on distractor interference could be caused by differential extent of attentional focus instead of different levels of WM load or both. These results are inconsistent with the load theory, and they underscore the importance of controlling the extent of attentional focus while assessing the role of WM in selective attention.

WM load is traditionally manipulated by varying the number of items a participant holds in memory while performing a selective attention task. Lavie and colleagues (e.g., Lavie et al., 2004; Lavie & de Fockert, 2005) presented the items that were to be remembered simultaneously, in the low-load one digit was presented at the center of the display while the six digits in the high-load were presented equally spaced across the display. Thus, low-load was associated with a narrow attentional focus whereas high WM load was associated with a wide attentional focus.

Lavie's (1995, 2005) load theory suggests that distractor inhibition depends on the level and type of WM load involved. Her experiments demonstrate that the type of load i.e. high perceptual load reduces distractor interference, while cognitive control processes increase distractor interference. Other researcher (e.g. Logan 1978, 2004; Woodman, Vogel & Luck, 2001; Chen & Chan, 2006) have found that visual search require minimal visual WM resources. The goal of the present experiment was to provide converging evidence to Chen and Chan's proposal that WM load would have little effect on the magnitude of distractor interference when the extent of attentional focus is controlled. Instead of using spatial cues to equate the extent of attentional focus across different conditions, I employed sequentially presented digits to ensure that the manipulation of WM load was not contaminated by changes in attentional focus. The hypothesis of this experiment is that by controlling the extent of attentional focus variations in WM load will have negligible effects across high- and low-load conditions.

5 Experiment

The experiment reported here examined the effect of WM on distractor processing when the extent of attentional focus was controlled. Participants performed a letter discrimination task while holding either 1 digit (low-load condition) or 6 digits (high-load condition) in memory. The letter discrimination task consisted of a target letter surrounded by four identical distractor letters which could be neutral or incongruent with the target letter. Unlike previous research in this area, the digits were presented sequentially rather than simultaneously in the present experiment. In other words, the extent of attentional focus was held constant across the different experimental conditions. Of special interest was whether participants would show a larger response compatibility effect in the high load condition than in the low load condition as predicted by Lavie's load theory (Lavie, 2000, 2005).

Method

Participants

Approval to conduct this research was obtained from the Human Ethics Committee, Canterbury University. A verbal description of the task requirements was given to all participants prior to commencement of the experimental trials. Participants gave their informed consent before they started the experiment (Appendix 1). Thirty two undergraduate students from University of Canterbury ranging in age from 18 to 35 years old were recruited to take part in this experiment. Each participant was paid a petrol voucher of $10, and all of them had normal or corrected-to-normal vision.

Materials

The experiment was conducted via MacProbe 1.6.9 programming on a MacIntosh computer using a 13 inch RGB monitor and a standard keyboard. The experiment consisted of two tasks. The first task was a selective attention task in which participants were asked to make a speeded response to a target among four distractors while keeping in memory either one (in the low load condition) or six digits (in the high load condition). Both speed and accuracy were emphasised. After that, they were required to respond *Yes* or *No* to a memory probe. Only accuracy was stressed in the second task.

The stimuli were presented in black colour on a homogenous grey background. Each trial consisted of the following sequence presented at the centre on the horizontal meridian of the screen, with the exception of the target display which was presented on either the left or right side of the screen with equal probability: (1) a fixation consisting of a small black cross in the centre of the screen; (2) a memory set that consisted of six sequentially presented random digits (the high load condition) or a single digit (the low load condition), font size 72; (3) the target display consisted of a black target letter (H or S) in font size 48 surrounded by four identical distractor letters (H, S, or X). The target letter subtended 1.43° in length, 0.95° in width, with its center 4.95° from the fixation. The distractor letters were written in font size 72. Each subtended 1.94° in length and 1.43° in width. The four letters formed an imaginary rectangle that subtended 7.16 in length and 7.55 in width; and (4) a memory probe which consisted of a single digit and a question mark in font size 72 (see Figure 1).

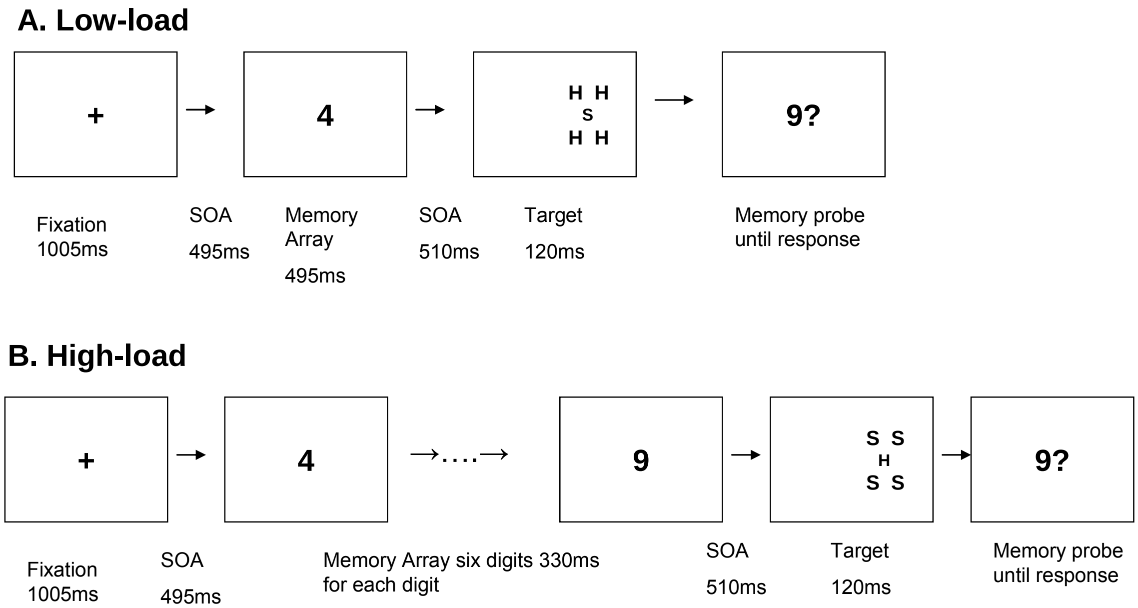

Figure 1. Examples of an incongruent trial in the low load condition (A) and a neutral trial in the high low condition (B). SOA refers to stimulus-onset-asynchrony. Participants performed two tasks one each trial. Task 1 was to respond to the target letter H or S and to react quickly and accurately after the target display was presented. Task 2 was to determine if the memory probe had been one of the digits in the memory set. This was an accuracy only task with the answer Yes or No.

The items in the memory set were chosen at random from digits 1 to 9. Each digit was equally likely to be present in the memory set for either the high load or low load condition. The order of the six digits in the memory set of the high WM load was randomly assigned, with the constraint that all digits were unique on a given trial.

Design and Procedure

The experiment was a mixed-subjects design with WM load as a between-subjects factor and target-distractor response compatibility as a within-subjects variable. Half of the participants performed the high-load condition, and the other half of the participants performed the low-load condition. For each participant, there were as many neutral trials as incongruent ones. In addition, the probe digit was equally likely to be present or absent in the memory set.

Participants were tested individually in a light-dimmed room. They were seated at a desk viewing the computer screen at a distance of approximately 60cm. The importance of keeping their eyes fixed at the center of the screen was stressed. The participants were required to remember all the digits presented. The experiment began when the participant pressed the spacebar on the computer keyboard. On each trial the fixation was displayed for 1005ms, this was followed by a stimulus-onset-asynchrony (SOA) of 495ms then the memory set which was presented for a period of 495ms in the low-load condition. In the high-load condition the six digits in the memory set were presented consecutively for a total of 1980ms with each digit being presented for 330ms. Another SOA of 510ms then preceded the target display.

The target display consisting of the target letter and 4 distractor letters was presented immediately after the memory set for 120ms on either the left or right side of the screen. All participants were required to respond as fast and as accurately as possible for the selective attention task by using their right hand to press the "." key (marked *H*) on the keyboard if the target letter on that trial was an *H*, and to press the "?" key (marked *S*) if the target was an *S*.

As soon as participants responded, the memory probe appeared. Participants were asked to use their left hand to press the "z" key (marked *Y* for yes) on the keyboard if the digit probe appeared in the memory set on that trial. Otherwise, they pressed the "x" (marked *N* for no) to indicate that the probe digit was absent from the trial's memory set.

Subjects were instructed to ignore the distractors, and to keep their eyes fixated at the center of the screen. Two blocks of sixteen practice trials preceded the test trials. The test trials consisted of 2 blocks of 144 trials for each participant, with a total of 288 trials for both the high-load and low-load conditions. The experiment took approximately 45 minutes to complete.

6 Results

Data Treatment

Table 1 presents RT's and error rates for the selective attention task .Only trials on which the participants were correct on the memory task were included in the analysis of the results for the selective attention task, and only trials on which the participants were correct on both the memory task and the attention task were included in the analyses of RT data for the selective attention task. In addition, a 2000ms cut-off was adopted for the selective attention task which resulted in less than 1% of participants' data being excluded. Two two-way mixed analyses of variance (ANOVAs), one on RT and the other on the accuracy data, were carried out, with load as the between-subject variable and congruency as the within-subject variable.

Selective Attention Task

Table 1: Mean RT's (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors.

	High Load				Low Load			
	Neutral		Incongruent		Neutral		Incongruent	
Measure	M	SE	M	SE	M	SE	M	SE
RT	617	32	630	33	578	24	597	21
% Error	1.98	0.74	4.1	0.76	3.26	0.93	4.58	0.70

Table 1 presents RTs and error rates for the selective attention task. Participants' RT's were *F* (1, 30) = 10.07, p< 0.01. No significant difference was found in the main effect of load, *F*(1,30) = 0.86, *p* > .05, or the load X congruency interaction, *F*(1,30) = 0.30, *p* > .05.

ANOVA on the error rates show that the error rates of the participants in the high-load condition did not differ from those in the low-load condition, *F*(1,30) = 0.25, *p* > .05. Similarly, the main effect of congruency was not significant, *F*(1,30) = 0.30, *p* > .05. The load X congruency interaction was significant, *F*(1,30) = 5.00, *p* < .05, with greater distractor interference in the high WM load condition than in the low WM load condition.

Memory Task

A t-test (high-load vs. low-load) was performed on the memory task data. There was a significant difference in WM error rates between the high-load (*M* = 11.8, *SD* = 6.6) and the low-load conditions (*M* = 4.4, *SD* = 3.15), *t*(-4.0) = 4.4, *p*< 0.01. This result indicates that the memory load manipulation was effective.

7 Discussion

Participants performed a dual-task consisting of a selective attention task and a memory task. They were required to make speeded identification of a target letter among surrounding distractor letters while simultaneously holding in WM either a sequence of six digits (high-load) or a single digit (low-load). The control of attentional focus was achieved by presenting the digits for the memory task sequentially rather than simultaneously as in prior studies (Chen & Chan, 2006; LaBerge et al. 1991). The results of this study found that for the selective attention task, participants were faster on the neutral trials than on incongruent trials. This result is consistent with prior research (e.g., Eriksen & Eriksen, 1974) revealing that participants were unable to inhibit task irrelevant information, resulting in longer RT's on the incongruent trials. However, there was no main effect of load or a load by compatibility interaction results. Although the lack of a significant interaction in RT is inconsistent with Lavie et al's (2004) finding, the participants in the high WM load condition made more errors than those in the low WM load condition. Taken together, the overall pattern of data supports Lavie's load theory. It provides converging evidence to the proposal that high WM load prevents participants from inhibiting task irrelevant information.

The aim of the current research was to study the impact of WM load on distractor inhibition when the extent of attentional focus was controlled. The hypothesis that WM load would have negligible effect on distractor interference when the extent of attentional focus is controlled was not supported by the results of this experiment. The data show that WM load influenced distractor interference even though attentional focus was controlled via sequential presentation of the digits in the memory set. These results are supportive of prior research by Lavie and her colleagues (e.g. Lavie 1995; 2004; Lavie & Cox, 1997; Lavie et al. 2004).

It has been proposed that visual WM has a central role in visual search. Woodman et al., (2001) examined visual WM search finding results that suggest only a small amount of WM resources were needed for the maintenance of information and that objects can be attended to at a perceptual level without automatically being entered into WM. They suggest their study shows minimal interference of information stored in visual WM and that the efficiency of visual search is not weakened when visual WM is filled to capacity. It was further suggested that the most meaningful interaction observed was that WM and search functions reflected a delay in the onset of the search process or a delay in response selection after the search but not as a result of WM being filled to capacity. While Woodman et al. found that holding items in visual WM did not impair search efficiency; further studies (e.g., Woodman and Luck, 2004) suggest that the effect of WM may depend on the content of the memory load and the specific selective attention task. Woodman and Luck (2004) extended these findings proposing that visual search and maintaining spatial representations in WM would interfere with visual search while visual search and colour and form change would not. They found that maintaining a few spatial locations interfered with the efficiency of visual search. This resulted in memory rates being less efficient as the number of items in the array increased. This was taken to demonstrate that memory tasks interfered with search performance, and the search task interfered with memory performance; with both types of interference increasing as the size of the array increased. Take together these results suggest that there are separate spatial and object memory subsystems. This would suggest that for this experiment the high WM load condition would not necessarily show greater distractor interference which was not supported in this case.

In conclusion this study aimed to examine the role of WM load on selective attention while holding constant the attentional focus. This research found that distractor inhibition was influenced by WM load even when attentional focus was held constant. The results of this research are consistent with Lavie and her associates (e.g., Lavie, 1995, 2001; Lavie, Hirst, de Fockert & Viding, 2004; Lavie & Tsal, 1994) who suggested that the level of WM load plays an important role in determining the efficiency of distractor rejection in selective attention tasks. The research therefore adds support to Lavie's load theory.

While the results of this experiment were supportive of Lavie's load theory the experimental paradigm was similar to that of Chen & Chan (2006). The differing results from those of Chan & Chen are discussed below. This experiment unlike that of Chen & Chan presented the high-load stimulus sequentially rather than simultaneously. However, the differing results may have been due to the extent of attentional control being more strictly controlled in Chen and Chan than in this experiment. Chen & Chan used exogenous cues to indicate the spatial location of the target thus controlling the extent of attentional focus. Exogenous cues attract attention automatically (Hasher & Zacks, 1979; Jonides, 1981), and would ensure that the extent of attentional focus was more or less constant between the two WM conditions. This experiment controlled attentional focus by sequential presentation of the digits in the memory set. Because there was only one digit in the low load condition, and the duration of the digit was quite long participants may not have been compelled to focus attention narrowly in order to recognise the digit.

Furthermore, while they may have initially had a narrow focus of attention during the digit recognition process, it possibly became more relaxed over time as in the high load condition participants had to focus their attention constantly for the appearance of new digits. These differences probably lead to a narrower attentional focus in the high load condition than in the low load condition.

Further Research

Previous research has shown that different types of WM load have different effects on attentional selection depending on whether WM load overlaps with target or distractor processing. Accordingly, loading WM does not always disrupt the efficiency of selective attention if the type of WM load does not interfere with processes required for the selective attention task. For example, a colour WM load does not disrupt visual search for shapes (Woodman et al. 2001) and a WM load of face targets does not disrupt background scene processing. Additional research might explore whether loading WM differently i.e. the important factor may be the specific tasks required in memory and attention task (e.g., both verbal or both spatial in nature), and to further clarify the role of attentional focus in distractor inhibition.

It may be necessary to differentiate specific cognitive processes involved in interference control. Working memory capacity and executive control have been shown to be a factor that influences distractor inhibition and impact on multiple everyday cognitive abilities (Kane & Engle, 2003). The extent of attentional focus has been investigated with results demonstrating reduced interference effects when the attentional area was narrowed (Chen, 2000; 2003; Chen & Chan, 2006; Eriksen & St James, 1986; LaBerge et al. 1991). Replication and extension of this experiment should be carried out to investigate if controlling the extent of attentional focus with exogenous cues would still see results similar to Lavie et al. (2004). While Chen and Chan have manipulated the extent of attentional focus the manipulation of the number and type of distractors would add clarity to this research area. Lavie et al. presented one target and one distractor while the target and distractor configuration in Chen & Chan was displayed as a target letter smaller than the four surrounding distractor letters.

Future research could utilize different participant populations, for example testing younger and older participants. In the past the majority of research into WM has utilised university graduate students. Very little work appears to have been directed at the issue of WM tasks in children and the elderly. Riggs et al. (2006) used the Luck and Vogel change detection paradigm (Luck & Vogel, 1997) to investigate the capacity of visual working memory in 5-, 7-, and 10-year-olds. They found that performance on the task improved significantly with age and also obtained evidence that the capacity of visual working memory approximately doubles between 5 and 10 years of age, to the point where it reaches adult levels of approximately three to four items. Functional magnetic resonance imaging (fMRI) studies have shown that children 8 – to 11- years old have functional brain activity similar to adults when tested with nonspatial WM tasks (Casey et al., 1995). This indicates that distinct functions of the prefrontal regions are already evident in children before the onset of puberty. Ongoing research into distractor inhibition is important to explain various aspects of behaviour for a number of different populations. While proposing to extending research to younger and older populations this is not to say that these populations will show the same results as adult participants it may reveal aspects that enhance the knowledge in this field.

8 References

Atkinson, R. C., & Shiffrin, R. M. (1971). The control of short-term memory. *Scientific American*, 82-90.

Baddeley, A. (1982). Your Memory. A Use's Guide. *MacMillian Publishing Co, Inc, New York.*

Baddeley, A. (1986). Working Memory. *Claredon Press, Oxford*.

Baddeley, A. D. (1997). Human memory: Theory and practice. *Hove, UK: Psychology Press*.

Baddeley, A. (2003). Working Memory: Looking Back and Looking Forward. *Nature Reviews,* 4, 829-839.

Baddeley, A., & Hitch, G. (1974). Working Memory. In Recent advances in learning and motivation. (Ed. G.A. Bower). *Academic Press, New York., 8*, 47-90.

Baddeley, A., & Logie, R. (1999). Working Memory: The Multiple-Component Model. *In Miyake, A., & Shah, P. (1999). Models of Working memory. Mechanisms of Active Maintenance and Executive Control. Cambridge University Press.*

Baddeley, A., & Weiskrantz, L. (1993). Attention: Selection, Awareness, and Control. *Clarendon Press, Oxford.*

Broadbent, D. E. (1958). Perception and communication. *London: Pergamon Press*.

Bunge, S., Ochsner, K., Desmond, J., Glover, G., & Gabrieli, J. (2001). Prefrontal regions involved in keeping information in and out of mind. *Brain, 124,* 2074-2086.

Cantor, J., & Engle, R.W. (1993). Working memory capacity as long-term memory activation: An individual differences approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 5,* 1101-1114.

Casey, B. J., Cohen, J. D., Jezzard, P., Turner, R., Noll, D. C., Trainor, R. J., Giedd, J., Kaysen, D., Hertz-Pannier, L., & Rapoport, J. L. (1995). Activation of prefrontal cortex in children during a non-spatial working memory task with functional MRI. *Neuroimage, 2,* 221-229.

Chen, Z. (2000). An object-based cost of visual filtering . *Perception & Psychophysics, 62*(3), 482-495.

Chen, Z. (2003). Attentional focus, processing load, and Stroop interference. *Perception & Psychophysics, 65*(6), 888-900.

Chen, Z., & Chan, C. (2006, May). Distractor interference stays constant despite variation in working memory load. Poster presented at the 6th Annual Meeting of the Vision Sciences Society, Florida, U.S.A.

Chen, Z., & Chan, C. (In press). Distractor interference stays constant despite variation in working memory load. *Psychonomic Bulletin and Review*.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *Journal of Acoustic Society of America, 25*, 975-979.

Chun, M. M., & Wolfe, J. M. (2000). Visual attention. In E. B. Goldstein (Ed.). *Blackwell Handbook of Perception*.

Conway, A. R. A., Cowan, N., & Bunting, M. F. (2001). The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychonomic Bulletin & Review, 8*(2), 331-335.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*, 163-183.

Conway, A. R. A., & Engle, R. W. (1994). Working Memory and Retrieval: A Resource-Dependent Inhibition Model. *Journal of Experimental Psychology: General, 123*(4), 354-373.

Conway, A. R. A., Tuholski, S. W., Shisler, R. J., & Engle, R. W. (1999). The effect of memory load on negative priming: An individual differences investigation. *Memory & Cognition, 27*, 1042-1050.

Cowan, N. (1995). Attention and memory: An integrated framework. *Oxford University Press, Oxford, England*.

Dalrymple-Alford, E. C., & Budayr, B. (1966). Examination of some aspects of the Stroop colour-word test. *Perceptual and Motor Skills, 23*, 1211 – 1214.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behaviour, 19*, 450-466.

de Fockert, J. W., Rees, G., Frith, C. D., & Lavie, N. (2001). The Role of Working Memory in Visual Selective Attention. *Science, 291*(5509), 1803 - 1806.

Desimone, R. (1996). Neural mechanisms for visual memory and their role in attention. *Proceedings of the National Academy of Sciences, USA, 93*, 13494–13499.

Deutsch, D., & Deutsch, J. (1963). Attention: Some theoretical considerations. *Psychological Review, 70*, 80-90.

Downing, P. E. (2000). Interaction between visual working memory and selective attention. *Psychological Science, 11*(467-473).

Engle, R. W., Cantor, J., & Carullo, J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18*, 972-992.

Engle, R. W., Conway, A. R. A., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science, 6*, 122-125.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence and functions of the prefrontal cortex. *Cambridge University Press, New York*, 102-134.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory and general fluid intelligence: A latent variable approach. *Journal of Experimental Psychology: General, 128*, 309-331.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a non-search task. *Perception & Psychophysics, 16*(1), 143-149.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysicsim, 40*(4), 225-240.

Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin & Review, 2*, 145-173.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. *In G. H. Bower (Ed.) The Psychology of Learning and Motivation. New York, NY: Academic Press, 22* 193-225.

Hester, R., & Garavan, H. (2005). Working memory and executive function: The influence of content and load on the control of attention. *Memory & Cognition, 33*(2), 221-233.

Han, S-H., & Kim, M-S. (2004). Visual Search Does Not Remain Efficient When Executive Working Memory Is Working. *American Psychological Society*, 15, 9, 623-628.

Jonides, J. (1981). Voluntary vs. automatic control over the mind's eye's movement. In J. B. Long & A. D. Baddeley (Eds.), *Attention and performance IX* (pp. 187–203). Hillsdale, NJ: Erlbaum.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. *In R. Parasuraman & D. R. Davies (Eds.) Varieties of attention. New York: Academic Press.*

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A Controlled-Attention View of Working-Memory Capacity. *Journal of Experimental Psychology: General*, *130*(2), 169-183.

Kane, M. J., & Engle, R. W. (2000). Working-Memory Capacity, Proactive Interference, and Divided Attention: Limits on Long-Term Memory Retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(2), 336-358.

Kane, M. J., & Engle, R. W. (2003). Working-Memory Capacity and the Control of Attention: The Contributions of Goal Neglect, Response Competition, and Task Set to Stroop Interference,. *Journal of Experimental Psychology: General*, *132*(1), 47-70.

LaBerge, D., Brown, V., Carter, M., Bash, D., & Hartley, A. (1991). Reducing the Effects of Adjacent Distractors by Narrowing Attention. *Journal of Experimental Psychology: Human Perception and Performance,* 17, 1, 65-76

Lavie, N. (1995). Perceptual Load as a Necessary Condition for Selective Attention. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(3), 451-468.

Lavie, N. (2000). Selective attention and cognitive control: Dissociating attentional functions through different types of load. *In S. Monsell & J.Driver (Eds.), Control of cognitive processes: Attention and performance XVIII (pp. 175-194), Cambridge, MA: MIT Press*.

Lavie, N. (2001). Capacity limits in selective attention: behavioral evidence and implications for neural activity. *Visual Attention and Cortical Circuits*(J. Braun & C. Koch (Eds.). MIT press Cambridge, Massachusetts.), 49-68.

Lavie, N. (2005). Distracted and confused?: selective attention under load. *Trends in Cognitive Sciences, 9*, 75-82.

Lavie, N., & Cox, S. (1997). On the efficiency of visual selective attention: Efficient visual search leads to inefficient distractor rejection. *Psychological Science*, *8*(5), 395-398.

Lavie, N., & de Fockert, J. W. (2005). The role of working memory in attentional capture. *Psychonomic Bulletin & Review,* 12 669-764.

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load Theory of Selective Attention and Cognitive Control. *Journal of Experimental Psychology: General, 133*(3), 339-354.

Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & Psychophysics, 56*(2), 183-197.

Logan, G. D. (1978). Attention in character classification tasks: Evidence for the automaticity of component stages. *Journal of Experimental Psychology: General, 107,* 32-63.

Logan, G. D. (2004). Working Memory, Task Switching, and Executive Control in the Task Span Procedure. *Journal of Experimental Psychology: General, 133*(2), 218-236.

Lustig, C., May, C. P., & Hasher, L. (2001). Working Memory Span and the Role of Proactive Interference. *Journal of Experimental Psychology: General, 130*(2), 199-207.

Mack, A., & Rock, I. (1998). Inattentional Blindness. *MIT Press, Cambridge, MA.*

May, C.P., Kane, M.J. & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118,* 35-54.

Miller K.E., Cohen D.J. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24,* p.167-202.

Miyake, A. (2001). Individual Differences in Working Memory: Introduction to the Special Section. *Journal of Experimental Psychology: General, 130*(2), 163-168.

Moray, N. (1959). Attention and dichotic listening: Affective cues and the influence of instructions. *Quarterly Journal of Experimental Psychology, 11,* 56 - 60.

Riggs, K. J., McTaggart, J., Simpson, A. Freeman, & R. P. J. (2006). Changes in the capacity of visual working memory in 5- to 10-year-olds. *Experimental Child Psychology,* 16, 678-845.

Rosen, V. M., & Engle, R. W. (1997). The role of working-memory capacity in retrieval. *Journal of Experimental Psychology: General, 126* 211-227.

Rosen, V. M., & Engle, R. W. (1998). Working memory capacity and suppression. *Journal of Memory and Language, 39,* 418-436.

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive Functioning as a Potential Mediator of Age-Related Cognitive Decline in Normal Adults. *Journal of Experimental Psychology: General*, 132, 4, 566-944.

Sternberg, S. (1996). High speed scanning in human memory. *Science, 153*, 652-654.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28*, 127-154.

Unsworth, N., Schrock, J. C., & Engle, R. W. (2004). Working Memory Capacity and the Antisaccade Task: Individual Differences in Voluntary Saccade Control. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *30*(6), 1302-1321.

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review, 104*, 90-122.

Woodman, G. F., & Luck, S. J. (2004). Visual search is slowed when visuospatial working memory is occupied. *Psychological Bulletin & Review, 11*(2), 269-274.

Woodman, G. F., Vogel, E. K., & Luck, S. J. (2001). Visual Search Remains Efficient When Visual Working Memory is Full. *Psychological Science, 12*(3), 219-224.

Yantis, S., & Johnston, J. C. (1990). On the locus of visual selection: Evidence from focused attention tasks. *Journal of Experimental Psychology: Human Perception & Performance*, 16, 135-149.

9 Appendix 1.

University of Canterbury Department of Psychology

Visual Perception and Selective Attention Study.

Project Description
You are invited to participate in the research project of visual perception and selective attention. The aim of this project is to understand cognitive mechanisms underlying the perception of simple displays. Your involvement in this project will involve looking at a series of displays containing one or several objects. Your task is to respond to the target stimulus by pressing an appropriate key on the keyboard as quickly and as accurately as possible. The test will take about 40-50 minutes to finish.

Risks and Benefits
In the performance of the task and application of the procedures there are no risks of any sort. I will talk with you about the hypothesis of this study at the end of the experiment.

Costs and Payments
There are not costs for participating ain this study. You will be paid a $10-00 petrol voucher for participating in this project.

Confidentiality
The results of the project may be published, but you may be assured of the complete confidentiality of the data gathered in this investigation: the identity of participants will not be made public. Only group data will be reported in my master's thesis, professional conferences and journals. To ensure anonymity and confidentiality, you are not required to enter your real name during the testing session.

Right to Withdraw
You do not have to take part in this study. If you start the study and decide that you do not want to finish, all you have to do is to tell the experimenter.

Principal Researcher
The project is being carried out as a requirement of a master's thesis from Marion Davis; I can be contacted on 3642987 ext. 3635, or mdd33@student.canterbury.ac.nz.

Human Ethic Committee Approval
This project has been reviewed by the University of Canterbury Human Ethics Committee. The committee has determined that the project meets the ethical obligations required by law and University policies.

Consent Form
I certify that I have read the preceding information, and that I understand the content. I have been given the opportunity to ask questions regarding the study, including questions about hazards, discomforts, and benefits that were not clear to me. My questions were fully answered. My signature below means that I freely agree to participate in this experimental study.

____________________ ____________________ ________

Name (print) Signature Date