Visual selective attention: The effect of stimulus onset, perceptual load, and working memory demand on distractor interference

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ABSTRACT

Humans are capable of selecting information that is goal-relevant. Irrelevant (distractor) information, however, typically is not filtered completely and impacts on responses to the goal. Recent theories of selective attention indicate that distractor interference is determined by the perceptual load of a visual display and the availability of cognitive control mechanisms (working memory load). It is unclear however, which mechanisms assist efficient selective attention and how irrelevant distracting information is rejected. Using a go/no-go visual attention task (Experiment 1) and a visual search task (Experiment 2), this series of experiments examined distractor processing in visual selective attention. Participants responded to a target letter based on the identity of an additional adjacent item (Experiment 1A). An incongruent distractor letter appeared either above or below the central fixation point in the high and low perceptual load conditions (HPL and LPL). Perceptual load was successfully manipulated, such that reaction times were faster in the LPL compared to the HPL condition. Subsequently target-distractor congruence was manipulated (Experiment 1B) such that distractor letters could be congruent, incongruent, or neutral compared with the target. In addition, distractors were either presented simultaneously or 200ms in advance of the target. The temporal separation of irrelevant and relevant stimuli in a visual attention task provides a useful approach for isolating the time-course of interference effects; how information is selected, particularly new information, and how it is prioritized over old information (Donk, 2006). There was no significant difference in reaction times to the target letter between the preceding and simultaneous conditions. In both the preceding and simultaneous conditions, reaction times were significantly faster in the HPL than in the

LPL condition. These results suggest that the temporal separation of the distractor and target did not determine the extent of distractor interference. Furthermore, the perceptual load theory cannot account for distractor interference when stimulus onset asynchrony is manipulated. Experiment 2 examined the cognitive control theory of visual selective attention (Lavie, Hurst, de Fockert, & Viding, 2004) which proposes two mechanisms of selective attention: a passive perceptual selection mechanism which prevents distractor interference in cases of HPL, and a more active mechanism of cognitive control which rejects irrelevant information in situations of low cognitive load. Participants performed a visual selective attention task with a working memory component. While performance was consistent with the perceptual load theory, reaction times in the LPL condition were significantly faster than in the HPL condition and reaction times in the low working memory condition were significantly faster than the high working memory load condition. Crucially, distractor congruence interacted with working memory load but not with perceptual load. Thus, in the high working memory load condition, reaction times were significantly faster to congruent and incongruent distractor letters compared to neutral distractor letters while the opposite effect was seen in the low working memory load condition. Distractor congruence effects were eliminated across both perceptual and working memory load. These results suggest that, in contrast to recent formulations of load and working memory in distractor interference paradigms, (Lavie et al., 2004) visual search processes and working memory storage may utilize the same limited capacity mechanisms.

DECLARATION

I, Eleftheria Kotsopoulos, declare that the Doctor of Psychology (Clinical Neuropsychology) thesis entitled “Visual selective attention: The effect of stimulus onset, perceptual load, and working memory demand on distractor interference” is no more than 40,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: Date:

DEDICATION

This thesis is dedicated to my loving and supportive parents, Neopoula and Theodoros Kotsopoulos. This is but a small token of my appreciation and gratitude for all the sacrifices they have made for me.

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INTRODUCTION

We are constantly bombarded with many sights and sounds simultaneously and sequentially, yet we are able to select and process relevant (target) information while ignoring irrelevant (distractor) information. Whilst selective attention mediates goal-directed attention through selection of information relevant to goal objects, irrelevant stimuli (distractors) may alter responses to goal-relevant objects (Keulan, Adam, Fischer, Kuipers, & Jolles, 2002). In an experimental setting, the visual selective attention system is typically examined using visual reaction time tasks in which participants are required to focus on a relevant target while ignoring other irrelevant items. Evidence of distractor processing is reflected in increased response latency and reduced accuracy (Driver, 2001; Eriksen & Eriksen, 1974; Lavie & Tsal, 1994). This effect is termed distractor interference and indicates that information not directly relevant to the goals of the intact visuo-motor system is processed and capable of altering responses to goal relevant information.

A considerable amount of research has been directed towards understanding factors that influence attention and the extent to which distracting information will be processed. A key issue in the field of visual attention is determining when selection of relevant information actually occurs. Early selection theories state that only goal-relevant information is selected for further processing and irrelevant information is processed in a preliminary manner or not at all and thus does not impact upon goal-relevant behaviour (e.g. Cherry, 1953; Sperling, 1960). In contrast, late selection theories suggest that all information is processed in an automatic fashion but that relevant information is responded to at a much later stage following semantic analysis (Deutsch & Deutsch, 1963). Lavie (1995) proposed a compromise between these two views stating that the perceptual load of the visual display determined the extent of distractor processing; late selection occurred when perceptual load was low whereas early selection occurred when perceptual load was high.

In a typical distractor interference paradigm, both relevant and irrelevant information is presented simultaneously which results in slower reaction times and decreased accuracy. A handful of studies have also investigated distractor interference when distractors and targets are temporally separated (Flowers & Wilcox, 1982; Kahneman, Treisman, & Burkell, 1983; Watson & Humphreys, 1997). The systematic manipulation of stimulus presentation and target-distractor compatibility provides a useful approach for isolating interactions occurring at various stages of processing visual information (Taylor, 1977). Furthermore, temporally separating the presentation of distractors and targets may provide greater information about the internal representation of objects, on subsequent goal-directed responses over time. Indeed, research has shown that the advance presentation of distractors attenuates interference (Kritikos et al., 2008). This suggests that processing a distractor but inhibiting a response to it may alter a subsequent response to the target (Chelazzi, Miller, Duncan, & Desimone, 1993).

Many theories have implicated working memory involvement during visual attention and particularly during a visual search task (Awe, Vogel, & Oh, 2006; Cowan, 1995;

Desimone & Duncan, 1995; Duncan & Humphreys, 1989). These studies have examined this relationship using a dual-task paradigm. The ability to complete more than one task efficiently and accurately is determined by the availability of working memory, suggesting that attention and working memory may share the same limited-capacity processes (Oh & Kim, 2004). This is particularly evident when higher-order cognitive processes are required, such as the manipulation of information in working memory while completing a visual attention task (Han & Kim, 2004).

The aim of the current thesis is to examine the visual selective attention processing system, with specific reference to factors modulating distractor interference. The time-course of visual selective attention will also be examined to determine how the internal representation of relevant objects assists with efficient visual attention. A number of theories have postulated that processes involved in maintaining information in a temporary store and visual search are closely related; thus, working memory and visual search will be investigated in an attempt to elucidate the nature of this proposed relationship. This thesis will review early and late theories of selection and will then discuss more recent distractor interference paradigms. The modulation of distractor interference will be reviewed within the context of the perceptual load theory and the cognitive load theory of visual selective attention.

1.1 Early and Late Selection Theories of Attention

Selective attention implies that information is gated / filtered before it is processed fully to aid goal-directed actions. There has been considerable debate, however, about how early this gating mechanism comes into place, and thus how early irrelevant information is rejected from further processing. Early selection theories assume that the attentional filter occurs soon after presentation of the information. In contrast, late selection theories postulate that goal-irrelevant information is filtered out only after all information has undergone semantic analysis.

1.1.1. Early Selection Theories

Early conceptualizations of selective attention were based on research conducted on the auditory attention system (Broadbent, 1958; Cherry, 1953; Treisman & Riley, 1969) using the dichotic listening paradigm. Participants were asked to attend to a message presented to one ear and to ignore the message presented to the other ear. Subsequent recall tests revealed that when participants attempted to repeat the relevant message aloud as it arrived (shadowing), they were only able to recall fragments of information that had been presented to the unattended ear (Broadbent; Cherry). Thus, irrelevant information was discarded prior to being fully processed. Consequently, Broadbent proposed his filter model. A filter operated at the level of physical features (such as pitch, tone, and volume), which allowed only the information characterized by that feature through for further processing. Although multiple items of information enter the system in parallel, they are held temporarily in the 'buffer' memory, until relevant information is selected for further processing. Information is identified only after it passes through the filter into the limited capacity channel, where information is processed in a serial manner. According to Broadbent’s framework, irrelevant information that does not pass through the filter is only processed in a very preliminary manner or not at all and thus does not impact upon responses.

Following on from studies conducted on the auditory attention system, Sperling (1960) examined the capacity limits of the visual attention system. Participants viewed a brief visual display of up to twelve items (letters and/or numbers) and provided a ‘whole report’ of all the items in the display. Although participants often stated that they could see more than they could report, they typically only named four to five items. This suggested that there is a limit to the amount of information that can be retrieved before the visual image decays. Sperling subsequently used the ‘partial report’ technique to examine the storage and duration of the visual image following its termination from the visual display. In these experiments, a low, middle, or high frequency auditory tone was used to signal which one of three rows participants were required to report following removal of the visual stimulus. The tone sounded only after the visual stimulus offset, therefore the participants did not know which signal to expect. Sperling found that recall accuracy improved when the row was cued and that participants could still ‘read’ the stimulus display up to 150 milliseconds (ms) following termination of the display. These results suggested that the participants must have perceived all twelve items in the display and were able to recall a subset of the display when cued. While this finding supported Broadbent’s filter (limited capacity) model and an early selection view of visual attention, it also revealed that the internal representation of visually presented information assisted information being selected at an early stage.

Bjork and Murray (1977) also used a partial report cuing procedure to determine the locus of visual processing. Participants were initially shown a premask matrix which indicated the location of stimuli to be remembered and then a stimulus matrix which included the presentation of one or two letters. This was subsequently replaced by a postmask matrix that remained displayed until participants reported the cued letter which was either a B or R. They found that detection of the target was strongly influenced by the additional letter that was presented with the target. Specifically, participants were faster and more accurate when both the target and the additional item were incongruent (e.g. B with P) compared with when they were congruent (e.g. B and B). They suggested that prior to the commencement of the trial, target items were represented in the perceptual and memory systems (internal representation) to assist with response selection. However, interference effects occur as a result of feature specific interference between the relevant and irrelevant items in the display. Thus, competition between items occurs at an early level of feature extraction.

Temporally separating the presentation of distractors and targets in a visual display appears to modulate the extent of distractor interference. Yantis and Johnston (1990) used this approach to examine whether relevant information is selected at an early stage. In each trial of the task, a target letter was displayed at fixation for 500ms. Similar to Sperling (1960), participants were provided with a cue (peripheral, central, or neutral in different sessions), for either 100ms or 200ms which was then followed by the visual array. Each letter in the visual display was unique, with one exception; on redundant-target trials, two of the letters were identical (one in the cued location and the other in one of the seven uncued positions). Yantis and Johnston found that when cues were both completely and partially reliable (100% and 80% valid, respectively), participants were able to efficiently focus their attention to a nonfoveal spatial location and prevent interference from irrelevant items. Furthermore, focussed attention was possible when a cue was presented 100ms in advance of the target and was equally effective with both central and peripheral cues. Yantis and Johnston proposed that providing a cue prior to the presentation of the target allowed selection to occur at an early stage with very minimal distractor processing.

In summary, early selection theories of attention indicate that irrelevant information can be excluded from perceptual processing because relevant information is selected at an early stage. Specifically, the role of internal representations and the timing of stimuli presentation are highlighted as modulating the extent of distractor interference.

1.1.2. Late Selection Theories

Late selection theories postulate that selection of relevant information occurs only after all stimuli have undergone full processing (Deutsch & Deutsch, 1963; Driver & Tipper, 1989; Duncan, 1980; Eriksen & Eriksen, 1974; Shiffrin & Schneider, 1977). Deutsch and Deutsch suggested that all incoming information is processed regardless of whether attention is directed to it. They proposed that as multiple signals of information arrive, each signal is compared against a fluctuating reference standard and weighted according to importance or relevance to the individual; in a visual search task this is related to task requirements. Selection of the most relevant stimuli is dependent on both the importance of the message and the degree to which an individual's overall attention is focussed. Information that falls below the reference standard is given a lower priority and is less likely to be acted on. Furthermore, signals which are similar to signals of highest priority are mistakenly perceived when they are presented together (Deutsch & Deutsch). Thus, all information is processed and compared together at a later stage to determine the appropriate response.

Treisman (1960; 1969) demonstrated that information not relevant to task goals was processed and could have an impact on goal-directed action. Her initial experiments focussed on the capacity limits of the auditory attention system, in particular Broadbent's limited capacity model. Treisman (1960) used a dichotic listening task and presented participants with four passages which were swapped unexpectedly halfway during the session. When participants shadowed the spoken passage on one ear while ignoring the passage to the opposite ear, they would occasionally switch the ear they were repeating. Typically participants repeated only one or two words from the wrong message before quickly resuming their attention to the correct ear. Although not all participants swapped to the other passage, the finding that some did revealed that irrelevant or unattended information was attenuated rather than completely blocked out. The relative meaningfulness of the message was also related to whether information from the unattended ear would be attended to (Treisman, 1960). Treisman (1969) subsequently adapted these findings to the visual attention system. She showed that basic physical properties of stimuli, such as colour or location, were selected at an early stage but that irrelevant information was attenuated rather than filtered out entirely. She suggested that irrelevant information underwent some level of semantic analysis and consequently produced slower response times. Treisman's results showed that the extent of distractor interference could be determined by the relative meaningfulness of the stimuli. This idea was examined further by Eriksen and Eriksen (1974) who manipulated the compatibility of relevant and irrelevant stimuli to determine the extent of distractor interference.

In a typical visual search task, the target letter is embedded within a number of other items in a display (e.g. Yantis & Johnston, 1990). Thus, the individual is required to process a number of irrelevant items while searching for the relevant item. However, Eriksen and Eriksen (1974) eliminated the 'search' process from their visual search experiments by presenting the target item in the same location. This cleverly allowed them to determine how much interference, as revealed through increased reaction times, could be attributed to the processing of irrelevant information rather than how long it took for the participant to find the target. They also introduced the widely used technique for examining the extent of distractor processing in normal vision, the response-competition method. This involved a stimulus-response map in which two sets of letters were each mapped onto two possible manual responses (i.e. levers; e.g. H and K mapped onto one response lever and S and C mapped onto another). In this study, participants were required to respond to a central target letter which was flanked on both sides by other letters. The two identical flanking letters could either be from the same (compatible) response set as the target letter (e.g. KHK) or from the different (incompatible) response set (e.g. SHS).

Participants responded to two sets of letters by moving a lever either to the left or right upon identification of the target letter and were asked to inhibit responses until they were able to discriminate which letter was in the target position. Eriksen and Eriksen (1974) showed that when two letters, H and K, were assigned to the same lever response and another letter, S, was assigned to another lever response, a target H produced slower reaction times in displays like SHS compared to displays such as KHK. They called this the flanker compatibility effect. Distractor letters (interference) of the opposite response set slowed reaction times significantly more than same response set distractor letters. Consequently, Eriksen and Eriksen suggested that all information was processed to some extent, but that relevant information was discriminated from irrelevant information at the stage of response selection.

Miller (1991) provided further evidence against the early selection of visual information. He manipulated five factors he proposed may have contributed to unattended stimuli being processed. These included spatial resolution (that is, a small visual angle), long-tem attentional focus on a fixed location, fixation of attention on an empty display location, the exclusion of transient stimuli presented during a task from semantic processing, and ignoring stimuli when there was insufficient demand by the attended items. Miller found that the flanker compatibility effect could not be reduced when these factors were manipulated. Importantly, he demonstrated that visual angle was the only manipulation that contributed to the size of the flanker compatibility effect. However, this was contingent on the target-distractor relationship; that is, whether the target and distractor letter were compatible or incompatible. Such results highlighted that completely irrelevant visual information was not fully excluded from semantic processing, even when it was detrimental to completing a task. Furthermore, semantic processing of unattended stimuli in these visual conditions provided strong evidence that individuals were not able to restrict their attention to one part of the visual array (van der Heijden, 1981). The flanker compatibility effect suggested that selective visual attention occurred at a late stage of processing, only after all items were perceived (Miller). Miller concluded that early selection could not completely exclude unattended information from semantic analysis.

The literature reviewed above shows that selective attention occurs because of the excitation or enhancement of relevant information (Chun & Wolfe, 2001). However, other theorists have shown that efficient selection is due to the suppression and/or inhibition of irrelevant information. A series of studies by Tipper and his colleagues (Allport, Tipper, & Chmiel, 1985; Tipper, 1985) were based on the premise that irrelevant information is inhibited. Tipper utilised a priming paradigm in which participants were briefly presented with a prime display which contained two superimposed objects (one red and one green object), and was followed one second later by a probe display. When the second (probe) stimulus appeared, participants were required to name the red drawing as quickly as possible. They were subsequently asked to recall the selected prime. In a typical priming paradigm, reaction times are faster to the primed object because, presumably, the object has been perceived. However, Tipper demonstrated slower reaction times when participants responded to an item which had been presented as a distractor on a preceding trial (Tipper, 2001). Specifically, when the to-be-ignored object in the prime display was identical to the object in the probe display, participants were slower to name the red prime object. Tipper proposed that while all information in a visual field underwent processing, selection of relevant information was possible due to an inhibitory mechanism. This effect was termed 'negative priming'. This inhibition mechanism was able to suppress the activation levels of the internal representation of a distractor (Allport, Tipper, & Chmiel, 1985; Tipper, 1985). Negative priming was subsequently found under a number of experimental conditions (Allport et al; Tipper & Cranston, 1985; Tipper & Driver, 1988; Tipper, MacQueen, & Brehaut, 1988) which provided strong support that unattended visual objects underwent full perceptual processing, but were actively inhibited to ensure that relevant items were acted on appropriately (Tipper, 1985).

Despite the extensive number of studies in this field, the debate surrounding the locus of visual selective attention remains unresolved. Early selection theories proposed that irrelevant distracting information could be discarded from processing at a very early stage. In contrast, late selection theories postulated that both irrelevant and relevant information underwent full processing and that selection of relevant information occurred at a later stage. These theories also differed in the way in which they accounted for distractor interference effects. In early selection theories, distractor interference effects were viewed as failures of the attention system to completely block out irrelevant information, while in late selection theories, interference effects were viewed as a consequence of the full processing of all information. Thus, each position was able to accommodate distractor interference effects and how these influenced visual selective attention.

1.2. Efficiency of Visual Search

Visual search paradigms subsequently focussed on the mechanisms of information processing leading to proposals for the resolution of the debate regarding the locus of visual selective attention. Treisman's feature integration theory (FIT; Treisman, 1988; 2006; Treisman & Gelade, 1980; Treisman & Schmidt, 1982; Treisman, Sykes, & Gelade, 1977) has been one of the most influential models to account for how information is processed. Treisman stated that perception could occur in either a parallel or serial manner depending on whether the individual is searching for a particular feature or a conjunction of features. Perception of basic features, such as size, colour, and orientation, occur automatically, in parallel with other non-relevant items, and does not require focussed attention. This means that irrelevant items are processed to some extent. In particular, each feature corresponds to a different value along a feature map, thus a target with a unique feature can be located quickly. In contrast, an item made up of a conjunction of features requires focussed attention to recombine the individual features for object recognition (Treisman et al; Treisman & Gelade).

Treisman and Gelade (1980) demonstrated that when participants searched for a target in a visual display defined only by a conjunction of properties, such as a green T amongst green Xs and brown Ts, reaction times increased based on the number of other items in the display (such as non-target letters or distractor letters). When participants searched for a target defined by a unique feature, for example, a blue S amongst green Xs and brown Ts, search time was independent of the number of distractors. Detection of a conjunction of features was slowed compared with single features, indicating attention is focussed serially on each object in the display. Treisman and Gelade suggested that distinctive features automatically pop out in a visual search task and therefore the rest of the visual array does not need to be searched, resulting in faster reaction times.

Following on from these studies, several investigators have produced results suggesting that conjunction search may also occur in a parallel manner (Luck & Vogel, 1997; Nakayama & Silverman, 1986a, 1986b; Treisman & Sato, 1990; Wolfe, Cave, & Franzel, 1989). Nakayama and Silverman (1986b) showed that conjunction search approximated parallel processing when each feature was highly discriminable. In their study, Wolfe and colleagues presented participants with a target item, a red O, among distractor letters, green Os and red Xs, thus the target was defined by a conjunction of colour and form. The items could be at any one of 36 locations (presented in a 6 by 6 visual array) at 8, 12, or 32 randomly determined loci within the display. On target trials, the target letter appeared at one of these loci. Wolfe et al. reported completely shallow search slopes reflecting parallel rather than serial processing of information. In light of these results, they proposed the guided search model, which stated that conjunction search could be guided by parallel processes which were able to separate relevant from irrelevant display items. The efficiency of visual search was based on the guidance provided by the parallel processes; visual search occurs automatically by continuously updating information from parallel to serial processes.

Similar results by Treisman and Sato (1990) led to the alternative proposal of the feature inhibition hypothesis. This formulation posited that during conjunction search, each single feature was independently examined and contributed additively to the search process. Furthermore, emerging properties of specific features could be ‘sensed’ and a conjunction of features could be coded early (Pomeranzt, Sager, & Stoever, 1977). Each dimension was processed separately and the target could be identified quickly when presented among irrelevant information due to the distinctiveness of the feature. In addition, feature distinctiveness allowed information to be inhibited and rejected quickly, suggesting parallel processing. Inhibition was more effective the greater the distinctiveness of the feature, and this also determined how easily distractors which shared that feature could be rejected.

Initial conceptualizations about the nature of visual search were based on FIT (Treisman, 1988; Treisman & Gelade, 1980; Treisman et al., 1977). This stated that basic feature properties are selected at a relatively early stage of visual processing while feature integration occurred at a later stage. Typically, reaction times are faster during a feature search task compared to a conjunction search task. Subsequent research found that both feature and conjunction search tasks produce similar search slopes when features are highly discriminable, suggesting that object identification could occur in parallel, similar to detection of basic features (Nakayama & Silverman, 1986b; Treisman & Sato, 1990; Wolfe et al., 1989). These experiments highlight the need for further research in order to understand the mechanisms of efficient information processing.

1.3. The Locus of Visual Selective Attention

The debate surrounding the locus of visual selective attention has been ongoing for the last five decades with very little resolution (Driver & Tipper, 1989; Duncan, 1980; Eriksen & Eriksen, 1974; Kahneman & Treisman, 1984; Tipper, 2001; Yantis & Johnston, 1990). However, the discrepant findings were reportedly the result of a paradigmatic shift that occurred within the field of attention (Kahneman & Treisman). Earlier studies were typically conducted using the ‘filtering paradigm’ in which visual displays consisted of multiple relevant and irrelevant stimuli and required more elaborate response types; classic examples include the shadowing task and the partial report technique (Broadbent, 1965; Cherry, 1953). From the late 1970’s onwards, studies belonged to the ‘selective set’ paradigm in which a stimulus required detection or identification and was presented alone or among a small number of irrelevant stimuli (e.g. Neely, 1977; Schneider & Shiffrin, 1977). Kahneman and Treisman suggested that these experimental designs utilised very different attentional resources and thus the results could not be generalised between the two paradigms.

Following an extensive review, Lavie and Tsal (1994) proposed that the locus of visual selective attention is determined by perceptual load. In a visual search task, this is based on either the number of potentially task relevant items in a visual array (that is, display set size; Duncan, 1980; Navon, 1989) or the nature of the processing required for each item (for example, feature search versus conjunction search). Lavie and Tsal proposed that findings supporting the early selection theory of attention had been obtained in experimental designs with high perceptual load; that is, when more stimuli were presented and/or a more demanding task was used. Experimental designs with low perceptual load, that is, when a single target and distractor were presented in addition to an undemanding task, provided support for the late selection theory of attention (Lavie & Tsal). Evidence supporting the perceptual load theory has been provided using various experimental designs, including the response competition paradigm (Eriksen & Eriksen, 1974; Lavie, 1995; Lavie & Cox, 1997), negative priming (Lavie & Fox, 2000), inattentional blindness (Cartwright-Finch & Lavie, 2006), change blindness (Beck, Muggleton, Walsh, & Lavie, 2006), attentional capture (Dalton & Lavie, 2004; 2006; 2007; Forster & Lavie, 2008; Lavie & de Fockert, 2005), unilateral neglect (Lavie & Robertson, 2001), and the healthy aging brain (Maylor & Lavie, 1998). Together, these studies have demonstrated that the perceptual load of a visual display determines the extent to which task-irrelevant stimuli will enter visual awareness (Lavie, 2005). Importantly, the perceptual load theory may potentially resolve the debate surrounding the locus of selective attention.

1.3.1. Manipulation of Perceptual Load and Distractor Interference

The perceptual load theory proposes that when lower demands are placed on the perceptual system, all stimuli (both relevant and irrelevant) are processed automatically regardless of their task relevance, until attentional capacity is exhausted. By contrast, high perceptual load prevents (or reduces) perception of distracting task-irrelevant information because the available attentional capacity is consumed only by the relevant items. In situations of low perceptual load, irrelevant information produces interference because attentional selection occurs in the later stages of visual processing (Lavie, 1995). Lavie and colleagues conducted a series of experiments to test whether perceptual load modulates distractor interference in visual selective attention tasks (Lavie, 1995; Lavie & Cox, 1997; Lavie & de Fockert, 2003; Lavie & Fox, 2000).

Lavie (1995) examined the perceptual load theory using the response competition paradigm (Eriksen & Eriksen, 1974) to measure distractor interference. In Experiment 1, Lavie manipulated perceptual load by varying the number of items in the visual display (i.e. set size; Duncan, 1980; Navon, 1989). Participants searched for a target letter which appeared in one of six equally spaced locations along a central horizontal row. During the low load condition, the remaining five locations were empty. In the high load condition, five neutral letter nontargets (which had no associated response in the experiment) occupied the five locations. Each display also contained a distractor letter which could be compatible, incompatible, or neutral in relation to the target letter. The distractor appeared either above or below the central horizontal row.

In the low perceptual load condition, reactions times to the target were faster when presented with a compatible versus a neutral distractor. Reaction times to the target were slower when presented with an incongruent versus a neutral distractor. These results suggested that the compatible distractors produced facilitation effects while incompatible distractors produced interference effects. Evidence of distractor processing, as demonstrated through compatibility effects, was found only under conditions of low perceptual load and was eliminated under conditions of high perceptual load. That is, no significant differences in reaction times were found across distractor type in the high perceptual load condition. The overall slower reaction times in the high perceptual load condition suggested that increased demands on attentional capacity affected how efficiently low-priority items could be blocked from perceptual processing. Furthermore, the results suggested a potential trade-off between speed and accuracy, whereby slower reaction times was related to greater accuracy when perceptual load was high. Conversely, response accuracy was significantly reduced in the low perceptual load condition when targets were presented with incompatible distractors. Relevant to this series of experiments, Lavie showed that by manipulating perceptual load, distractor processing can be eliminated under high perceptual load conditions due to reduced attentional capacity.

In a further experiment, Lavie (1995) examined the processing requirements of feature and conjunction search proposed by FIT (Treisman & Gelade, 1980). According to FIT, perception of features is load free and occurs in a parallel manner, while the search for a conjunction of features requires the focusing of attention (as in serial search). Thus, FIT allows the comparison of two different processing loads on attentional resources. Lavie used a go/no-go procedure in which participants made a response to the target letter only when an additional item was presented with it. The additional items consisted of a square and circle which could be either blue or red. In the feature demand condition participants were required to make their response to the target letter (H or U) when the colour of the additional item was blue and to withhold response when it was red, regardless of whether the shape was a circle or a square. Thus, analysis of only one feature was required. In the conjunction demand condition, participants were required to process the specific conjunction of colour and shape of the additional items prior to making a response to the target letter, for example, they were instructed to respond to the target letter H only when a blue square or red circle (depending on the instructional manipulation) was presented.

Typical of distractor interference paradigms, the identity of the distractor letter could be compatible with the target letter (i.e. both target and distractor letter were H), incompatible to the target letter (target H and distractor U), or neutral (the letter H which had no response associated with it). Crucial to her postulations, Lavie (1995) found that low perceptual load increased interference effects produced by the incongruent distractor letters. Specifically, reaction times to the target in the low perceptual load condition were significantly slower when an incompatible distractor was presented compared to a neutral distractor. Lavie's interpretation of the pattern of findings was that a single feature can be detected with little or no increase in the load of the relevant processing, leaving spare capacity to spill over automatically to the distractor letter. Conversely, reaction times to the target in the high perceptual load condition were significantly slower when a compatible distractor was presented compared to a neutral distractor. Lavie argued that in the conjunction demand condition, the very same display imposes a greater demand on attentional capacity, leaving considerably less attentional capacity for the irrelevant distractor. This results in reduced interference effects which consequently eliminated the flanker compatibility effect (Lavie, 1995).

Subsequently, Lavie and Cox (1997) manipulated search load by varying the similarity between target and nontarget letters. In the ‘hard’ search condition all letters in the display were angular, that is, the target letter X was presented among nontarget letters V, Z, or H. In the ‘easy’ search condition, all nontarget letters were curved while the target letter was angular, such that the target letter X was presented among nontarget letters O. Lavie and Cox presented their participants with a circular array which consisted of a target letter among five nontarget letters and an irrelevant distractor presented in the periphery outside the central search array which they were asked to ignore. Once again, targets were compatible, incompatible, or neutral in relation to the distractor. They found reaction times were significantly slower in the easy search task (low perceptual load) compared to the hard search task (high perceptual load). Furthermore, their results indicated greater distractor processing in the easy search condition, whereby incompatible distractors interfered with accurate response selection. Conversely, participants were able to prevent processing of the irrelevant peripheral distractor during the hard search task. Specifically, the incongruent distractors could be excluded from processing only when more than four nontargets were presented with the target letter. These results suggest that efficient distractor rejection could only occur when perceptual capacity was exhausted, that is, under high load conditions, and that under low load conditions, spare attentional capacity resulted in distractor processing (Lavie & Cox, 1997).

A number of studies since Lavie (1995) have provided evidence of efficient distractor rejection in conditions of low perceptual load (Johnson, McGrath, & McNeill, 2002; Paquet & Craig, 1997; Theeuwes, Kramer, & Belopolsky, 2004). While these studies worked within the parameters of the perceptual load theory, they incorporated other experimental manipulations which subsequently determined distractor interference. In their series of experiments, Paquet and Craig manipulated the predictive relationship between flankers and responses using the flanker validity effect. This effect typically results in slower reaction times when a target is presented with an uncorrelated flanker (and therefore has reduced predictive value) and faster reaction times when a target is presented with a correlated flanker (high predictive value). Thus, flanker identity serves as a cue for the correct response. They found reliable flanker validity effects in the cued condition when flankers were presented closest to the target. Paquet and Craig (1997) suggested that in low perceptual load displays, eliminating flanker effects required sufficient separation of the target from flankers (location selection), flankers from a different category to the target (categorical selection), and cuing attention to the target location (object selection). They argued that the elimination of the effects of the far flankers is not restricted to high perceptual load displays but can also occur in low perceptual load displays. Specifically, when attention was cued, moving the flankers away from the target was sufficient to eliminate the flanker effect regardless of categorical overlap. Paquet and Craig suggested that distractor distinctiveness may also play a role in capturing attention and consequently produced interference effects. Although distractors did not automatically capture attention, interference effects were likely to occur in situations where distractors were placed physically near the target, when far flankers and the target belonged to the same category (that is, both letters or both numbers), and when attention was not directed to the location of the target prior to its appearance (e.g. Yantis & Johnston, 1990).

Under ideal situations, such as cueing, effective selective attention seems possible in conditions of low perceptual load (Paquet & Craig, 1997; Yantis & Johnston, 1990). Johnson and colleagues (2002) examined selective attention in low perceptual load conditions. They manipulated perceptual load (high and low perceptual load), compatibility of flanker letters (compatible, incompatible, and neutral) and cue validity (either 100% valid spatial cue or no cue; similar to conditions employed by Yantis & Johnston, 1990 and Lavie & Cox, 1997). The results from the no-cue condition supported the perceptual load theory (Lavie, 1995; Lavie & Cox, 1997) such that there were reduced flanker effects in the high perceptual load compared to the low perceptual load condition. Furthermore, reaction times were faster in the low load condition and were significantly faster when flankers were compatible with the target than when they were incompatible (Johnson et al). When targets were preceded by a cue, reaction times were again faster in the low load conditions compared to the high load conditions;

however there was very little evidence of flanker processing. This suggested that when participants were provided with a valid cue, selective attention was possible even under conditions of low perceptual load. Consistent with Yantis and Johnston, they found reduced distractor processing under ideal cueing conditions in low perceptual load displays. These results also highlighted the possibility that top-down attentional mechanisms may play a role in determining efficient selective attention.

In a similar vein, Theeuwes and colleagues (2004) proposed that distractor processing may be determined by a combination of top-down search strategies adopted by an observer and the perceptual load of a visual display. They replicated Lavie and Cox's (1997) experimental design using the flanker compatibility paradigm (Eriksen & Eriksen, 1974). In experiment 1, conditions of high and low perceptual load were placed in separate blocks of trials. Consistent with perceptual load theory predictions, reaction times to targets were significantly faster in low perceptual load displays than in high perceptual load displays. Participants also responded significantly faster to targets when the flanker was compatible than when it was incompatible with the target; large compatibility effects were found in the low load displays while small flanker compatibility effects were found in the high load displays. In the second experiment, high and low perceptual load displays were varied randomly within blocks of trials. They found that when a high load trial was preceded by another high load trial, there was no significant flanker compatibility effect (Theeuwes et al). However, the flanker compatibility effect occurred when a high load display was preceded by a low load display. The interference effect was not reduced in the high load condition when the trial changed from low load to high load; there was always a reliable flanker compatibility effect. Under conditions of low perceptual load, processing appeared to be more stimulus driven, due to the target and distractor standing out against a homogenous background and consequently, when elements were highly salient (Theeuwes, 2004). However, under high load conditions, expectancy appeared to play a greater role in determining the extent of processing irrelevant information. Overall, they suggested that perceptual load was not the only factor which determined selective attention, but rather, top-down processes (that is, expectancy) may also play an important role in modulating the distractor effect of irrelevant flankers (Theeuwes et al).

Eltiti, Wallace, and Fox (2005) used experimental conditions similar to Lavie's original studies (Lavie, 1995; Lavie & Cox, 1997) but instead proposed the salience hypothesis of selective attention. This states that the salience of the distractor item itself is largely determined by the attentional control settings of the individual. According to this hypothesis, perceptual load modulated interference not because of the attentional capacity available but because of the change in the saliency of distractors. In their series of experiments, Eltiti and colleagues manipulated the salience of distractors by presenting them as either 'onsets' or 'offsets'; Abrupt onsets have been shown to automatically capture attention (Theeuwes, 1991; Yantis & Jonides, 1990) which ultimately results in attention being drawn to the location of the abrupt-onset stimulus. Using three different manipulations, Eltiti and associates found evidence of distractor interference in high-load displays; distractor offsets did not capture attention when targets were presented as onsets even in low-load displays and distractor offsets captured attention when the target also appeared as an onset. These results suggested that perceptual load was not the primary determinant of selective processing. Rather, the level of distractor processing was determined by distractor salience. They argued that the typical perceptual load effect may have occurred simply because the distractor in a high-perceptual load display was less likely to capture attention and not because capacity had been fully utilized (Eltiti et al).

In summary, the perceptual load theory appears to provide a resolution to the long-standing debate regarding the locus of visual selective attention by combining both early and late selection theories. This theory postulated that distractor processing could be eliminated only when attentional resources were fully utilized, as in situations of high perceptual load, while distractor processing was inevitable in low perceptual load conditions. Since then, a number of studies have demonstrated that selective attention is still possible in situations of low perceptual load. While these findings further illustrated the difficulty in determining the locus of visual selective attention, they also revealed that the extent of distractor interference is amenable to a number of various experimental manipulations. In particular, Eltiti and colleagues (2005) showed that presenting distracting information prior to the presentation of relevant information (i.e. abrupt onsets) modulated distractor processing. This finding is particularly relevant to the current series of experiments as it shows that stimulus onset can interfere with efficient selective attention. The next section will discuss distractor interference produced by abrupt visual onsets and will then review studies which have manipulated stimulus onset asynchrony of distractors and targets.

1.4. Attentional Capture and Abrupt Visual Onset

Efficient selective attention is dependent on the visual system's ability to distinguish between relevant and irrelevant information and to allocate processing resources appropriately (Hay, Milders, Sahraie, & Niedeggen, 2006). Under some conditions, irrelevant (distractor) information or irrelevant stimulus events involuntarily receive attentional priority, a phenomenon which has been referred to as "attentional capture" (Folk & Remington, 1998). Although most distractor items that have irrelevant features can be successfully ignored, distractors with unique features will usually distract attention from focusing on relevant stimuli (de Fockert et al., 2004; Yantis, 2000). For example, a colour singleton will interfere with search when trying to locate a shape, which suggests that the singleton distractor has captured attention involuntarily (Theeuwes, 1996). Attentional capture has been extensively examined using abrupt onsets (Folk, Remington, & Johnston, 1992; Lamy & Egeth, 2003; Theeuwes, 1991; Yantis & Jonides, 1990), which appear to be unique in their ability to capture attention compared to other stimulus characteristics (i.e. luminance and hue; Jonides & Yantis, 1988). In visual search tasks, abrupt visual onsets have been found to capture attention by significantly delaying reaction times when searching for a particular feature (Theeuwes, 1994). Numerous researchers have investigated attentional capture in order to determine the degree to which it could be modulated by top-down or bottom-up processes with little resolution to this debate (Folk & Remington, 1998; Folk et al., 1992; Johnson, Hutchinson, & Neill, 2001; Jonides & Yantis, 1988; Theeuwes, 1996; Yantis & Jonides, 1984; Yantis & Jonides, 1990).

Much like the debate between early and late selection views of visual attention, the difficulty in determining the type of processing that occurs in situations of attentional capture is related to the two fundamentally different experimental paradigms that have been used in such studies (Folk & Remington, 2006). Evidence of top-down processing is supported by the contingent capture perspective which utilizes the modified spatial cuing paradigm (Folk & Remington, 1998). In this paradigm, singleton target displays are preceded by a "cue" that contains a singleton distractor at one of four locations. Across trials, the location of the distractor is completely uncorrelated with the location of the target, providing no benefit if attention is voluntarily allocated to the distractor location. Thus, any location congruence or "cueing" effects can be attributed to the involuntary capture of attention by the distractor. Attentional capture appears to be contingent on whether an attention-capturing stimulus is consistent with a top-down attentional control setting such as task demands (Folk et al., 1992, 1993; Folk, Remington, & Wright, 1994). Once the allocation system has been configured with appropriate control settings, stimulus properties that match the settings will result in the "on-line" involuntary allocation of spatial attention to the stimulus exhibiting those properties. Consequently, stimuli that do not match the top-down control settings will not capture attention (Folk et al., 1992).

Using this paradigm, the influence of top-down set can be examined by manipulating the relationship between the features of the target and distractor singletons. For example, Folk and colleagues (Folk et al., 1992) presented participants with target displays consisting of either a single, abrupt onset character (onset target) which appeared in one of four boxes, or one red character in one box and three white characters in each of the other boxes (colour target). Target displays were preceded by a distractor display consisting of the abrupt onset of four small circles surrounding one box (onset distractor) or a set of red circles surrounding one box and three sets of white circles surrounding the other three boxes (colour distractor). They found location congruence effects consistent with attentional capture only when targets and distractors shared a feature, such as when both were defined by onsets or defined by colour. Conversely, there were no location congruence effects when onset colour distractors were paired with colour (onset) targets.

Folk and Remington (1998) reported a similar pattern whereby coloured distractors produced evidence of capture when paired with targets of the same colour, but not when paired with different coloured targets. Based on these findings, they proposed that capture of spatial attention was contingent on top-down control settings that prevented processing of an irrelevant singleton distractor which did not share the same feature as the target (Folk & Remington). When the distractor shared the defining property of the target singleton, it produced an involuntary shift of spatial attention. When it did not share the defining property of the target, it produced a filtering cost that was not spatially specific. These "filtering costs" were first proposed by Kahneman and colleagues (1983) who argued that when the visual display consisted of both a target and an irrelevant singleton distractor, both of these objects would ‘pop out’. Thus, an increase in reaction times associated with the presence of an irrelevant distractor occurred as a consequence of the system determining where attention should be allocated. In visual displays with no distractors, the target would ‘pop out’ leading to efficient allocation of attention to the desired location.

Conversely, Theeuwes (1992, 1996) argued against the “filtering cost” interpretation of irrelevant singleton effects. Instead, he proposed that early preattentive processing was driven by bottom-up factors such as salience. Specifically, attention was captured by the most salient singleton in the display, irrespective of whether the feature of the singleton was relevant to the task. If that singleton was the target, a response was made. If it was not the target, attention was directed to the next most salient singleton. Theeuwes (1992) found that the presence of an irrelevant singleton in one location significantly increased reaction times when looking for a target singleton in the other location. Attention was captured by the most salient singleton in the display regardless of whether the property defining that singleton was relevant. Moreover, top-down control could not override the stimulus-driven capture that arose due to the appearance of a more salient stimulus attribute and therefore, selection occurred in a purely bottom-up, stimulus-driven manner.

In a further study, Theeuwes (1996) conducted a similar visual search task in which he manipulated the response compatibility of the character at the distractor location. The visual display consisted of either seven or nine coloured shapes placed around the fixation point on an imaginary circle. The nontarget shapes were circles presented in the same colour as the target shape, which was a diamond. In the no-distractor condition, the green diamond target shape appeared among green circles. In the distractor condition, one of the circles was presented in red. In the compatible distractor condition, the letter inside the diamond (target) matched the letter inside the red circle distractor (e.g. an R in the green diamond and an R in the red circle or an L in the green diamond and an L in the red circle). In the incompatible distractor condition, the letter inside the diamond was different from the letter inside the red circle distractor (e.g. an L in the green diamond and R in the red circle or an R in the green diamond and L in the green circle). On half the trials, the response associated with the character at the distractor location was identical to that required by the target. On the remaining trials, it was associated with the opposite response from the target.

Theeuwes found a flanker compatibility effect such that when the letter inside both the distractor and target singleton were compatible with the response, reaction times were faster compared to when the letter inside the distractor and target singleton were incompatible with the response. This compatibility effect was determined by the character at the distractor location and indicated that spatial attention must have been directed to that location. Thus, he proposed that during early preattentive processing, attention was driven solely by bottom-up feature salience factors in which attention shifted towards the location of the singleton regardless of whether it was a target or a distractor (Forster & Lavie, 2008; Theeuwes, 1992).

This conceptualisation of visual selective attention was recently modified by Theeuwes and associates (Theeuwes, Atchley, & Kramer, 2000). They proposed that during early preattentive processing, selection was driven in a bottom-up manner and therefore attention was captured by the most salient singleton present in the visual field. However, once attention had been captured by the singleton distractor, attentive processing exerted top-down activation that allowed attention to be redirected to the appropriate stimulus. Consistent with other models of visual attention (e.g. Treisman & Sato, 1990), Theeuwes et al. proposed that visual search was the result of an interplay between goal-directed and stimulus driven factors which had a different time course.

To determine this time course they presented the singleton distractor (the red circle) at different stimulus onset asynchronies (SOAs) prior to the appearance of the target display. Theeuwes and colleagues (2000) used a visual search task similar to Theeuwes (1992), in which participants had to search for a feature singleton (diamond) among distractors (eight grey circles). In the control condition each display contained one grey outlined diamond. In the distractor condition, one of the grey circles was replaced by a red circle and therefore the target had a unique shape (shape singleton) while the distractor had a unique colour (colour singleton). Each diamond contained a letter: either a C or a reversed C, and the orientation of the letter determined the response. In addition, letters appeared inside the other eight circles and were presented in grey. On some trials, an irrelevant salient colour singleton was presented along with a premask display at different SOAs before the onset of the search display. Consistent with previous results (Theeuwes, 1992; 1996), Theeuwes et al. found that an irrelevant salient distractor interfered with search for a relevant target singleton.

Specifically, early SOAs (50 and 100ms) produced a reliable interference effect while later SOAs (150, 200, 250, and 300ms) did not. This suggested that when the distractor and target were presented in close succession, that is, within 50ms and 100ms of each other, there was a clear distractor interference effect (Theeuwes et al., 2000). Furthermore, top-down control could not be exerted in such a short timeframe and could not prevent attentional capture by the salient distractor. When, however, the singleton distractor was presented between 150ms and 300ms prior to the target singleton, top-down control processes could be exerted and attentional capture by the distractor was eliminated (Theeuwes et al).

To further examine whether attention was captured by an irrelevant distractor, Theeuwes et al. (2000) used the response congruency paradigm (Eriksen & Eriksen, 1974). As in their previous experiment, they presented the letter C or a reversed C inside the colour singleton distractor at various SOAs (50, 100, 200, and 400ms), which were either congruent or incongruent with the response. A red singleton distractor was presented in each display and the letter inside the singleton distractor was revealed simultaneously with the red singleton distractor letter. They found that attentional capture by the distractor could be eliminated when the distractor was presented prior to the target, as indicated by faster reaction times, as SOA increased. In addition, they found a response congruency effect, such that reaction times were faster when the letter inside the distractor was identical to the letter inside the target singleton (and therefore congruent with the response) compared to when the letter inside the distractor was incongruent to the letter inside the target singleton. The results provided further support that attention was captured by the irrelevant singleton and had an effect on the speed of response to the target (Theeuwes et al). Overall, their findings suggested that visual attention could be guided by both bottom-up and top-down processes and that each process has a different time-course. Thus, early preattentive parallel processing may not accessible to top-down control, however once an item was selected, top-down processing assisted attention to be redeployed from the distractor to the target.

In summary, the ability of the visual system to effectively focus attention on relevant information and reject irrelevant information from processing may be dependent on a combination of bottom-up and top-down processes. Recently, Theeuwes and colleagues (Theeuwes et al., 2000) proposed that these two mechanisms had a different time course. Bottom-up mechanisms were responsible for selection of information in the early stages of attention, while top-down factors assisted attention to be redeployed from irrelevant to relevant information at a later stage. These studies provide an alternative explanation to the perceptual load theory about the nature of distractor processing. In addition, they provide information about the locus of visual attention and highlight the importance of investigating the temporal nature of selective attention.

The vast majority of the literature reviewed thus far examined distractor interference effects when distractors and targets were presented within the same visual display, simultaneously. In daily life, however, we receive inputs both simultaneously and consecutively. A major aim of this thesis is to examine temporal separation between visual inputs. In the next section, perceptual load is set aside briefly to discuss temporal order of targets and distractors, before returning to integrate temporal order, perceptual, and top-down / bottom-up factors in distractor processing.

1.5. Temporal Order of Distractor-Target Presentation

A limited number of studies have investigated distractor interference effects produced when distractors and targets are separated temporally (e.g. Flowers & Wilcox, 1982; Kahneman et al., 1983; Kritikos, McNeil, & Pavlis, 2008; Watson & Humphreys, 1997). Typically these experimental designs have added targets to existing distractor displays (e.g. Kahneman et al), manipulated the congruence of distractors and targets (e.g. Kritikos et al) and manipulated stimulus onset asynchrony (e.g. Watson & Humphreys, 1997) to examine the effects of facilitation and interference on visual selective attention. Because the human visual system processes a limited amount of information at any one time, the most task-relevant information needs to be selected and processed accordingly (Jiang, Chun, & Marks, 2002b; Pashler, 1998). The systematic manipulation of the stimulus onset asynchrony (SOA) and target-distractor compatibility provides a useful approach for isolating interactions occurring at various stages of processing visual information (Taylor, 1977). Furthermore, this can provide greater information about the locus of visual selective attention; how information is selected, particularly new information, and how it is prioritized over old information (Donk, 2006).

Using a classic distractor interference paradigm, Kahneman, Treisman, and Burkell (1983) proposed that new information can be prioritized over old. They showed reduced distractor interference when distractors were displayed prior to target onset. In their Experiment 5, participants were presented a single word together with 0, 1, 2, or 3 distractors (nonsense shapes which could be red, yellow, green, or pink) and asked to read the word aloud; manipulating the number of distractors enabled the examination of filtering costs which were determined by a change in reaction times. This experimental design allowed them to distinguish between visual objects (in this case, words) and visual events (defined as a change, appearance, or disappearance of visual objects).

Kahneman and colleagues (1983) explored distractor-target temporal and spatial separation to determine whether increased reaction times were due to competition between visual objects or visual events. They used several intervals of temporal separation. In the Simultaneous condition, distractor and target onset occurred 800ms following the warning signal. In the Continuous condition, the distractors were presented with the warning signal and remained onscreen at target onset 800ms later. In the Interrupted condition, the onset of the warning signal, distractors and target was concurrent, however distractor and target offset occurred after 300ms and was followed by a blank interval of 500ms; subsequently the same distractors and target were presented again. In the Removed condition, the distractors were displayed for 800ms (similar to the Continuous condition), however distractor offset occurred immediately before target onset. Finally, in the Removed Early condition, distractor offset occurred 300ms after the warning signal and was followed by a blank interval of 500ms; subsequently, target onset occurred with no distractors.

When irrelevant objects were presented simultaneously with the target, Kahneman et al. (1983) found that response times increased, that is, produced interference, by 31ms compared to when a word was shown alone. Adding two more distractors further increased interference in the simultaneous condition. Compared with the target word alone condition, reaction times were greater under the simultaneous and removed early conditions, suggesting that the presence of distractors had an effect on selective attention. Importantly, however they found that the advance presentation of irrelevant objects (removed early condition) eliminated or greatly reduced interference. The authors speculated that the reappearance of the distractors after the blank interval was treated as a new event and therefore produced a filtering cost. Kahneman and associates suggested that simultaneous appearance of target and distractors affected how relevant information was processed. Importantly, they argued that changes in reaction times were not attributed to response conflict associated to the target and distractors because (see Eriksen & Eriksen, 1974) the distractors were nonsense items which did not have mapped responses. In addition, they suggested that filtering costs were not determined by the difficulty in locating or discriminating the target when presented with distractors; rather, the change in the amount of distractors presented had a greater effect on reading the word compared to locating it.

Kahneman and colleagues (1983) speculated that distractor interference could be modulated by the relationship between two objects or events, and the extent of perceptual processing of each. They introduced the term ‘object file’ to describe a temporary perceptual representation of the features present in a particular object. They argued that both the success and failure of selective attention – including filtering costs – could be explained by the effects of attention on object files. Kahneman and colleagues proposed that filtering costs occurred either when a new object file needed to be created or when some change in the status of a previously registered object needed to be recorded. They found reduced interference when a pre-existing file required updating (Interrupted and Removed conditions) than when a new file needed to be created (Simultaneous conditions), and no interference when files were simply being maintained (Continuous condition).

Kahneman and colleagues (1983) found that distractors preceding the target reduced reaction times (interference) compared to the simultaneous presentation of distractors and targets. When all items are presented simultaneously, several object files are created, one for each item, so the creation of the object files for the distractors interfere with the creation of the object file for the target. In contrast, presenting the distractors before the target allows time for the distractor object files to be created prior to presentation of the (single) target item (Kahneman et al). These results suggest that distractor interference is modulated by the temporal separation of relevant and irrelevant information. Furthermore, these results show that manipulating the number of distractors (and therefore perceptual load of the visual display) also determines the amount of distractor processing, particularly when distractor offset occurs immediately prior to distractor onset.

Flankers produce either facilitation or interference effects depending on the temporal separation of distractor and target letters (Eriksen & Schultz, 1979; Taylor, 1977). Watson and Humphreys (1997) used a novel colour-form conjunction search task to demonstrate that previewing a set of elements produces faster reaction times compared with viewing distractors and a target letter simultaneously. They introduced a temporal interval (a gap) between the distractors from each colour and presented the target with the second set of distractors (the search display). There were three conditions: a standard colour-form conjunction baseline (blue Hs vs. blue As); a standard single-feature baseline (blue H vs. blue As); and a gap conjunction condition (green Hs followed by blue As and, on target-present trials, a blue H). In the standard conjunction search condition, the search display was presented until a response was made to either the presence or absence of the blue letter H target. The single feature baseline condition was identical to the conjunction search condition except that no green distractors were present in the display. For the gap conjunction condition, following the fixation cross, the green distractors were first displayed for 1000ms, after which the blue items were added to the display.

Watson and Humphreys (1997) found that performance was as efficient in the gap condition as in the single-feature baseline and was more efficient than in the standard conjunction search condition. In the gap condition, search became as efficient as if only the second set of items had been presented alone: this was termed the gap effect. Thus, participants were able to exclude the initial distractors from search and prioritize selection of the new items. By manipulating the temporal interval (gap) between distractors and targets (Experiment 3), they found that the minimum interval required to allow old distractors to be separated from new stimuli was 400ms; few gains in performance were found beyond that time interval (Watson & Humphreys).

The results of Watson and Humphreys (1997) demonstrate a preview benefit, that is, greater search efficiency manifesting as faster reaction times in the preview condition than in the condition in which all elements were simultaneously presented. Participants selectively ignored the old stimuli such that search efficiency in the preview condition was equivalent to the condition in which only the new stimuli were presented; participants were able to prioritize new over old elements. Watson and Humphreys proposed that observers were able to inhibit the locations of old elements in anticipation of new elements, a process they called visual marking. Visual marking presumably occurs in a top-down fashion, such that observers inhibit the locations of the old elements during the preview only if it was advantageous for them to do so. The top-down inhibition of the old elements biases selection towards the new elements when they initially appeared (Donk, 2006). Thus, reaction times to visual tasks are faster when observers are given a brief preview of the location of the distractor items in the search task (Hay et al., 2006). Inhibitory templates are generated which allow the search task to be performed as though the previewed distractors were not present

(Watson & Humphreys). Watson and Humphreys proposed that the mechanism involved in marking was specific for prioritising new objects and filtering out old ones. These results suggest that distractor interference is modulated by temporal presentation between relevant and irrelevant information; distractor interference can be reduced or eliminated when distractors are presented in advance of targets.

Flowers and Wilcox (1982) manipulated the temporal and spatial separation of relevant and irrelevant information in addition to changing flanker-target compatibility. Relevant to this series of experiments, they showed that flanker compatibility modulated distractor interference and that the magnitude of the compatibility effect changed across SOAs. The facilitation effects built up over the first 100ms, but were maintained throughout the longer SOA levels, and were largely attenuated by 200ms. In contrast, interference effects (i.e. slower reaction times to the incompatible than to the neutral distractor displays) were evident for SOAs of 200ms and less. These results indicated that the degree of facilitation and interference altered depending on the onset of asynchrony between distractors and target letters (Flowers & Wilcox). Flowers and Wilcox (see also Santee & Egeth, 1982) suggested that facilitative priming (i.e. flankers were identical to the target) may need to overcome some initial perceptual interference that occurred when similar visual features were presented simultaneously. Segregation of new and old items via this temporal grouping process enabled visual attention to prioritize one set of items over another (e.g. Driver & Baylis, 1989) thus, attention could be focussed on the group that contained the target.

According to Jiang and colleagues (2002b), selective attention could be allocated to any behaviourally relevant group, once temporal segregation had occurred. In their experiment 4, Jiang et al. reversed the roles of old and new items, such that the old items were behaviourally important while the new items were irrelevant. Jiang and associates found that participants were able to prioritize the old items and ignore new items when they were temporally separated but that this was also influenced by which temporal group contained information that was behaviourally relevant to the task. While this view dismisses the role of inhibitory mechanisms in assisting visual attention (e.g. Watson & Humphreys, 1997), it still highlights the importance of examining SOA and its effects on distractor processing.

Overall, these experiments demonstrate that the extent of distractor processing can be modulated by the onset of visual stimuli. Search for visual information when it is presented simultaneously produces interference (i.e. increased reaction times), while the advance presentation can greatly reduce or eliminate interference. Temporal separation is, therefore, an important experimental manipulation which may help determine the mechanisms involved in visual selective attention.

Recently, Kritikos and associates (2008) further examined the role of inhibitory mechanisms following the temporal separation of distractor and target letters. They suggested that there may be a critical period during which distractor processing and inhibition of responses associated with the distractor, altered the response to the target. In one of their experiments, a single target letter that was either an x or o appeared randomly and at one of four locations, either to the left or right, or above or below the centre of the computer screen. Under certain trial conditions the target appeared with a single distractor letter that was either an x or an o. The distractor was always incompatible to the target and always appeared equiprobably at one of four locations. Participants were required to respond to the target letter as quickly as possible without compromising accuracy, and to ignore the distractors. The experiment consisted of seven conditions; target alone, preceding-200, preceding-400, preceding-600, simultaneous-200, simultaneously-400, and simultaneous-600. Consistent with Kahneman and colleagues (1983), interference was greatest when distractors and targets were presented simultaneously and was significant though attenuated when the distractor preceded the target by 200ms. Further, interference could be eliminated when distractors were presented 400ms prior to the presentation of the target which suggested that by this time, processing of the distractor was completed; performance in this condition was comparable to the target alone condition. Reaction times were faster overall when the distractor preceded the target by 600ms. They proposed that by 600ms, the distractor was fully processed and capable of facilitating target processing by acting as an orienting cue. These findings suggested that the impact of distractors changed over time and that brief intervals between distractors and targets produced the greatest interference due to residual processing of the distractor (Kritikos et al).

In a further experiment, Kritikos et al. (2008) examined the effect of presenting distractors either simultaneously with the target or 93-200ms in advance while manipulating distractor-target congruence. This experiment consisted of seven conditions: target alone, preceding congruent, preceding incongruent, preceding neutral, simultaneous congruent, simultaneous incongruent, simultaneous neutral. Consistent with their previous experiment, performance was slower in the simultaneous condition than the preceding condition. Distractor interference was evident though attenuated when the distractor preceded the target compared with the simultaneous presentation of distractor and target. In the simultaneous condition, incongruent distractors were associated with the greatest reaction times, followed by neutral and congruent distractors. Within the 93-200ms interval between distractor and target presentation, the same compatibility effects were evident. Kritikos and colleagues demonstrated that the same (or similar) processes occurred in the preceding condition as they did in the simultaneous condition and that they occurred within the first 200ms. They postulated that the internal representation of the distractor consisted of an ongoing process and that interference occurred because the internal representation of the distractor formed the basis for comparison with the target.

The temporal separation of irrelevant and relevant stimuli in a visual attention task provides a useful approach for isolating the time-course of interference effects. Collectively, findings have suggested that reaction times are significantly slower when distractors and target letters are presented simultaneously compared to when they are separated in time. That is, presenting distractors in advance of a display with the target produces a highly efficient search compared to conditions in which the distractors and target are presented simultaneously (Watson & Humphreys, 1997). Furthermore, varying the time of onset of distractors and targets also changes the relative influence of these processes, thereby resulting in different patterns of interference or facilitation effects (Flowers & Wilcox, 1982). Despite these generalised findings of efficient search when distractor and target presentation are separated in time, there is very little consensus regarding the processes involved which reduce or eliminate distractor processing. A number of researchers have begun to investigate the possibility that an inhibitory mechanism is responsible for effective selective attention (Watson & Humphreys). This is thought to involve the generation of an inhibitory template which enables the search task to be performed as though the previously presented distractor was never presented. This memory representation, a feature of working memory, may be able to assist selective attention by preventing distractor interference through a process of maintaining the prioritization of relevant information (de Fockert et al., 2001).

1.6. Attention and Working Memory

Efficient cognitive functioning depends upon the ability to select among relevant and irrelevant information and to allocate processing resources accordingly (Hay et al., 2006). Therefore, goal-directed behaviour requires top-down attentional control, such that attention is directed to goal-relevant stimuli rather than to irrelevant distractors. Cognitive control refers to those functions that are typically associated with the frontal lobes, such as working memory, and have been thought to play a major role in goal directed behaviour in reducing distractor interference (Baddeley, 1996; Desimone &

Duncan, 1995; Lavie & de Fockert, 2005, 2006; Lavie, Hirst, de Fockert, & Viding, 2004).

Working memory is defined as a limited capacity system which maintains and stores information, temporarily, and orchestrates processes involved with perception, long term memory, and action (Baddeley, 2003; Jonides, Lacey, & Nee, 2005). It has been argued that working memory capacity is limited because of an individual's ability to use controlled processing (Engle, Kane, & Tuholski, 1998). Controlled processing involves the activation and maintenance of goal (task) relevant information in addition to the active inhibition of irrelevant information that actively compete for attention (Tuholski, Engle, & Bayliss, 2001). In addition, a number of models of cognition (e.g. ACT-R, Anderson, 1993; EPIC, Meyer & Kieras, 1997) have suggested that when higher level cognitive processes are utilised, such as during a high working memory load task, working memory allows a rapidly accessible and easily updated memory system.

The relationship between attention and working memory has been referred to in a number of theories. These theories have suggested that features of a target are used to bias attentional allocation to incoming information. Furthermore, that the contents of working memory, through 'activated' representations within long term memory assist selective attention (Cowan, 1995). Examples of these include Duncan and Humphreys' (1989) attentional engagement theory which proposes that selection of relevant information occurs on the basis of a match to an internal template which is actively held in working memory; Folk and colleagues' (1992) contingent involuntary attentional capture model which proposes that attentional set (i.e. task goals) enables attention to be automatically oriented to a particular stimulus; Wolfe's (Wolfe, 1994; Wolfe et al., 1989) guided search model, and Treisman's feature integration/inhibition model (Treisman & Sato, 1990) which also propose that search occurs based on the spreading of activation in the master map, through connections between feature maps and location maps. Thus, attention and working memory appear to overlap in their information processing goals (Awh et al., 2006). However, in order to understand the interactions between working memory and visual attention, it is important to determine which type of working memory and visual attention is being examined (Awh et al). The dual-task paradigm uses both a visual search task and working memory task to examine the interactions between these constructs. This may help to clarify whether working memory is implicated in visual attention and how such processes may prevent distractor processing.

One of the models in which the relationship between attention and working memory has been made most explicit is the biased competition model of Desimone and Duncan (1995). Attention is conceptualized as an evolving property of many neural mechanisms which attempts to resolve the competition for visual processing and provide controlled behaviour (that is, selective attention). According to the model, visual inputs compete for representation, analysis, or control during the stage between initial input and response. However, selection is biased towards objects which are most relevant. Search for a specific target amongst multiple competing objects in a visual display (such as a triangle amongst squares and circles), is possible because the representation of the target is pre-activated in working memory; sensory inputs have a competitive advantage when they match internal representations. This memory representation – the attentional template (Duncan & Humphreys, 1989) can be viewed as one aspect of working memory (Baddeley, 1986) which is able to specify any required property depending on task requirements. Duncan and Humphreys proposed three components which assist selective visual attention: a parallel stage of perceptual description which produces a representation of the input across the visual field, a process of selection which matches input descriptions against an internal representation of the information needed in current behaviour, and entry of selected information into visual short-term memory.

Information actively held in working memory can guide attention even without an explicit search task (Downing, 2000). Downing examined the interaction between working memory and selective attention and showed that working memory could determine the type of information that was selected for further processing (see also Downing & Dodds, 2004). Similarly, Soto, Heinke, Humphreys, and Blanco (2005) suggested that once an item is held in working memory, it can guide the initial parts of the search process in an involuntary manner. However, they showed that maintaining an item in working memory could produce both costs and benefits with respect to reaction times. In their series of studies, Soto et al. asked their participants to first remember a particular shape, a particular colour, or a conjunction of these features (e.g. a red triangle), then to search for a tilted line segment among upright distractor line segments, and finally to perform a memory test. Although the memory and search tasks were designed to involve two different task sets, the two tasks could overlap in terms of stimulus content: the line segments of the search task were each placed inside a shape that could match the to-be-remembered item in shape, colour, or both. Relative to a neutral baseline condition in which no shapes matched the memory item, search was more efficient when the memory cue matched the shape containing the target, and less efficient when the cued stimulus contained a distractor. Furthermore, increased distractor interference occurred even when the memory-matching shape never coincided with the search target, which suggested that attention was captured even though it was detrimental to the task. Soto and colleagues suggested that information held in working memory guided the early parts of the search process in an automatic fashion. That is, an early involuntary top-down process directed attention to information in working memory, which consequently biased attention in favour of activated internal representations (Desimone & Duncan, 1995; Szabo, Almeida, Deco, & Stetter, 2004).

1.6.1. Working Memory and Attentional Capture

Both visual attention and visual working memory processes selectively activate and prioritize certain visual representations over others. However, with regards to working memory, this is possible in the absence of the actual stimulus (Olivers, Meijer, & Theeuwes, 2006). Thus, an object has a direct advantage in the competition for selective attention if its features have already been activated through a memory representation (Desimone & Duncan, 1995). Olivers et al. explored the possibility of content-based memory-driven attentional capture. In their experiment, each trial commenced with the presentation of a disk, and in the memory conditions, participants were asked to remember the colour of the disk. This was followed by a visual search display which consisted of a number of disks and a diamond-shaped target. The target was not always the only unique item in the display, such that one of the distractors could also carry a unique colour; a singleton distractor (Pashler, 1988). Importantly, the singleton distractor, when presented, could carry the same colour as the to-be remembered item. The trial ended with a memory test, in which the participants were asked to choose the remembered colour from three presented colours. Performance in the memory condition was compared with a no-memory condition, in which participants were instructed to simply look at the initial coloured disk, without the need to remember it. They found that singletons captured attention, despite being detrimental to the task, but especially so under conditions of increased memory load. Thus, the additional memory task drained the cognitive control mechanism required to reject irrelevant distracting information (Olivers et al).

The capacity of working memory and visual attention was further examined by Lavie and de Fockert (2005) in a series of studies which manipulated working memory load. Specifically, they argued that the ability to prevent processing of irrelevant information is determined by the load of the working memory task. That is, goal-directed control of visual attention is possible when cognitive capacity is available to prevent processing of goal-irrelevant information. Lavie and de Fockert compared attentional capture by an irrelevant singleton in a visual search task between a single-task condition (a visual search task) and a dual-task condition (a visual search task in addition to a working memory task). During the visual search task, participants searched for a circle among diamonds and were asked to respond to the orientation of a line within it. The presentation of an irrelevant colour singleton was varied across trials and attentional capture was determined by slower reaction times to the target when the singleton appeared. In the dual-task condition, working memory was manipulated by asking participants to rehearse either a set of six digits (experiment 1) or four digits in exact order (experiment 2) in order to decide whether a memory probe following the visual search task was present or absent in the memory set of that trial (experiment 1) or in order to recall a digit that followed the probe digit in the memory set (experiment 2).

Lavie and de Fockert (2005) found significantly greater singleton interference effects under conditions of high working memory load compared to no or low working memory load conditions. This suggested that working memory load determined visual search efficiency and also modulated attentional capture by irrelevant singleton distractors (Lavie & de Fockert). Based on these findings, they proposed that attentional capture may be determined by a combination of top-down and bottom-up processes. Thus, attentional control could be modulated by working memory and clearly implicated top-down control processes. However, a stimulus driven component also appeared to play a role such that an irrelevant singleton captured attention even when top-down control functions were not loaded (that is, in no-load or low-load conditions; Lavie & de Fockert).

de Fockert and colleagues (de Fockert, Rees, Frith & Lavie, 2001) also used a dual-task paradigm to demonstrate that manipulating working memory load could modulate distractor processing in a selective attention task. In their visual selective attention task, participants were asked to categorize famous written names as either politicians or pop stars while ignoring distractor faces which could either be congruent with the target name, incongruent with the target name, or anonymous. In the low working memory load task, participants were required to remember either a fixed order of digits, while in the high working memory load task, they were provided with a different order of digits on each trial. Participants were presented with the memory set which was followed by two, three, or four attention displays. Following the final attention display, a memory probe was presented and participants were required to report the digit that followed this probe in the memory set.

de Fockert et al. (2001) found that reaction times to the memory probe were faster in the low working memory load condition compared to the high working memory load condition (953ms and 1394ms respectively). Furthermore, in the selective attention task, distractor interference effects were significantly greater during high (78ms) than low (46ms) working memory load. de Fockert and colleagues argued that working memory plays a crucial role in actively maintaining stimulus-processing priorities in order to direct attention to relevant rather than irrelevant stimuli which subsequently minimized the interference effects of irrelevant distractors. This was further supported by their neuroimaging data which revealed that areas of prefrontal cortex involved in face processing were more activated in conditions of load, consistent with these areas being sensitive to load and distractor interference (from the irrelevant faces). Collectively, these results supported their hypothesis that the availability of working memory is essential for top-down attentional control towards relevant information (de Fockert et al; see also de Fockert, Rees, Frith, & Lavie, 2004).

The preceding literature review highlights the relationship between working memory and selective attention. Firstly, working memory content aids efficient selective attention because attention is biased towards information in the internal template. Furthermore, the extent of distractor interference in a visual attention task is determined by the availability of cognitive resources.

1.6.2. Cognitive Control Theory of Selective Visual Attention

In their load theory of selective attention and cognitive control, Lavie and colleagues (Lavie, 2000; Lavie et al., 2004) proposed that the ability to reject irrelevant distractors and focus attention was a result of two dissociable mechanisms; one passive and the other active. The passive perceptual mechanism is able to prevent distractor interference purely because there is insufficient availability for their processing, such as during a high perceptual load task. The active mechanism of attentional control prevents irrelevant distractors being processed in situations of low perceptual load, even when there is sufficient capacity for them to be processed. Consequently, this form of attentional control requires the activation of higher order functions, such as working memory, to ensure that irrelevant (low priority) stimuli are not processed (Lavie). As mentioned above, these two mechanisms of selective attention can be dissociated purely by the extent of interference effects found in tasks consisting of different loads; while high perceptual load reduces distractor processing, high working memory load increases distractor processing (Lavie et al).

Lavie and associates (2004) tested the cognitive load theory by combining a selective attention task with a short-term recognition memory task. In their Experiment 3 (the experiment of particular interest to this study), Lavie et al. manipulated both perceptual load and working memory load to determine the level of distractor interference these conditions could produce. For the selective attention task, they used the flanker response-competition task (Eriksen & Eriksen, 1974) and manipulated target-distractor compatibility. Perceptual load in the selective attention task was manipulated by varying the relevant set size (Lavie, 1995; experiment 1), while working memory load was manipulated by varying the memory set size. Participants were asked to memorise either one (low memory load) or six (high memory load) different digits on each trial. In conditions of low perceptual load, a single target letter could appear in one of six randomly selected positions along an imaginary horizontal line while the irrelevant distractor appeared in the periphery. During the high perceptual load condition, the remaining five positions were replaced with nontarget letters which were all response neutral (that is, letters that were not associated with any response in the task) and only served to force participants to search for the target letter among them. In the low working memory load condition, the memory set was presented for 250ms while in the high working memory load condition, it was displayed for 1500ms. The masking display was presented for 1250 ms (in the low working memory load condition) or

2500ms (in the high working memory load condition), which was followed by the memory probe.

Slower reaction times were found during the high working memory load conditions than the low working memory load conditions, suggesting that working memory load was effectively manipulated (Lavie et al., 2004). In the selective attention task, they found slower reaction times in high perceptual load conditions compared with low perceptual load displays. The level of distractor interference also changed as a result of working memory load. Specifically, significantly greater distractor interference effects were found in the high working memory load compared to the low working memory load condition. In contrast, significantly less distractor interference effects were found in the high perceptual load condition compared to the low perceptual load condition. Thus, Lavie et al. suggested that the ability to reduce distractor interference was possible only when perceptual load was high and working memory load was low. These findings provided support for their theory that two dissociable mechanisms are responsible for efficient selective attention: a perceptual selection mechanism which assists distractor rejection when perceptual load is high and an active control mechanism which ensures that attention is allocated accordingly, even when working memory load is low (Lavie et al).

1.6.3. Working Memory and Visual Search Efficiency

Many theories have implicated working memory involvement during visual attention and particularly during a visual search task (Awe et al., 2006; Cowan, 1995; Desimone

& Duncan, 1995; Duncan & Humphreys, 1989). The majority of these claim that visual attention is influenced by object representations stored in working memory which can be used as either reference points or a guide to the most relevant information. However, Woodman, Vogel, and Luck (2001) proposed that the constant transfer of such information into working memory was a highly inefficient process and that another mechanism must be implicated in visual search efficiency. They investigated the role of working memory in visual attention by using a dual-task paradigm. Participants were presented with four, eight, or twelve black objects (outline of squares), in groups of four. The target object had a gap on either the top or the bottom, while the nontargets had a gap on either the left or right side. The memory array consisted of four coloured squares placed around a central fixation cross. In the dual-task condition, participants were initially presented with a memory array, followed by a visual search task, and then a memory-test display. Participants were asked to respond whether the memory test display was identical to the memory array that was initially presented, or whether one of the squares was a different colour. In the single-task condition, only the visual search task was administered.

Woodman et al. (2001) revealed that participants were able to perform both tasks without a significant disruption to either such that the search slopes were virtually identical in both conditions. However, they also found that a constant value was added to the visual search reaction times when participants maintained information in working memory, such that there appeared to be a general slowing that either preceded or followed the search task. They speculated that this was related to a delay in the onset of search processes or a delay in post-search processes such as response selection (see Jolicoeur & Dell'Acqua, 1999). While accuracy during the search task was very high, accuracy in the memory task was reduced particularly in the dual-task condition, which suggested that memory capacity was exceeded. Woodman and associates suggested that information stored in visual working memory did not disrupt visual search, even when visual working memory was filled to capacity. In contrast to other theories, these results suggested that during visual search, targets were not stored in working memory and that objects could be attended to purely at a perceptual level without being automatically entered into working memory (Woodman et al).

These findings demonstrate that working memory load influences the ability to complete an additional task both efficiently and accurately. While some theorists believe that working memory content assists visual search (Desimone & Duncan, 1995), others claim that increased working memory load reduces accuracy (Woodman et al., 2001).

Oh and Kim (2004) examined the interactions between visual selective attention and visual working memory using the dual-task paradigm developed by Woodman et al. (2001). They compared selective attention with both a spatial (Experiment 1) and nonspatial (Experiment 2) working memory task during visual search. Participants completed a change-detection task which required them to determine whether there was a change to the location or colour of the memory test probe, from the initial memory array. Interestingly, they found that distractor interference varied based on the nature of the working memory task. In the spatial working memory task, visual search performance was affected by the spatial working memory task, and spatial working memory load impaired the visual search process. Oh and Kim suggested that the same limited-capacity mechanisms appeared to be shared by both the visual search process and spatial working memory storage. In contrast, the nonspatial working memory task did not appear to interfere with visual search efficiency and the search process did not interfere with the maintenance of nonspatial information in working memory. Taken together, these results suggested that spatial and nonspatial working memory loads interacted differently with the visual search process.

In a follow-up study Woodman and Luck (2004) also examined the possibility that maintaining spatial information in working memory would interfere with visual search processes. They also used an experimental procedure similar to Woodman et al. (2001) in which they slightly modified the working memory task but kept the visual search task identical. For the working memory task, they used a location change detection task which required participants to remember the spatial locations of two objects. Each trial began with the sequential presentation of two white dots which participants were asked to remember and was followed by a test array in which both dots were presented simultaneously. In the dual-task condition, participants were provided with a search task (described previously; Woodman et al) during the retention interval of the memory task. They found that remembering a relatively modest number of spatial locations affected the efficiency of the search process. Consistent with Oh and Kim (2004), they found that as set size in the search task increased, memory accuracy became progressively more impaired and vice versa. Woodman and Luck proposed that maintaining spatial representations in working memory may interfere with visual search which supported the hypothesis for the existence of separate working memory systems. In addition, these separate working memory systems may be linked to the dorsal and ventral pathways in the posterior visual cortex which are specialized in processing 'where' and 'what' information, respectively (Woodman & Luck).

A number of studies have suggested that visual search efficiency is determined by the nature of the working memory task (D'Esposito & Postle, 1998; Han & Kim; 2004; Owen, Evans, & Petrides, 1996; Petrides, 1989). Previous experimental designs have used dual-task paradigms in which participants were asked to complete a visual attention task in addition to a memory task with either a recognition format (Lavie et al., 2004) or a memory test array (Oh & Kim, 2004). However, these studies typically examined the temporary storage of information. In contrast, Han and Kim (2004) argued that working memory encompassed more than just the temporary storage of information (i.e. object representation). They suggested that working memory included a number of different processes such as multiple-task coordination, distractor interference prevention, memory updating, set-shifting, and manipulation/transposition of information (see also D'Esposito Postle, Ballard, & Lease, 1999).

In their series of studies, Han and Kim (2004) investigated the difference between the ability to purely maintain information temporarily in working memory and the ability to manipulate it in some way. They also used the same dual-task paradigm employed by

Woodman et al. (2001). During the maintenance condition, participants were required to remember either a number or a letter, while during the manipulation condition, they were either asked to count backwards by three's from a specified number or to reorder letters into alphabetical sequence. Performance in the single-task condition was compared to performance in the dual-task condition. Results showed that the 'manipulation' working memory task produced significantly steeper search slopes in the dual-task condition compared to the single-task condition. This suggested that performing a working memory task which required the use of higher-order processes impaired efficiency of visual search. In contrast, the simple 'maintenance' working memory task did not appear to affect visual search efficiency; the search slopes in both the single- and dual-task conditions were nearly identical. These results indicated that visual search efficiency was not impaired when simple maintenance of information in verbal working memory was required. Thus, Han and Kim proposed that while higher-order processes are implicated in working memory tasks which require the manipulation of information, these same processes may be inactive when simple maintenance of information is only required. These studies highlight that the nature of the working memory task may determine the extent of efficient visual attention and distractor interference.

1.6.4. Neural Substrates of Working Memory

The distinction between the ability to maintain information and the ability to manipulate information has been extensively investigated (D'Esposito & Postle, 1998; Owen et al., 1996; Petrides, 1989). Furthermore, it has been suggested that prefrontal cortex is involved during these tasks (D'Esposito et al., 1999). Specifically, ventrolateral prefrontal cortex is believed to initially receive information from posterior association areas and actively maintained to direct or guide behaviour. Dorsolateral prefrontal cortex is thought to be involved with information in working memory that requires 'monitoring' or 'manipulation'. D'Esposito and colleagues (1999) examined this distinction further using an event related functional magnetic resonance imaging technique which allowed them to compare a working memory task that required retention of information (maintenance) during a delay, with a task that required the transposition (manipulation) of information being held in working memory during a delay.

Participants were presented with a set of five letters simultaneously and were then provided with an instruction cue, either *forward* or *alphabetize*. This was followed with a probe which required participants to respond either yes or no. In the maintenance condition, participants were asked to remember a sequence of letters during the delay in order to respond correctly to the probe, while in the manipulation condition, they were asked to transpose this information during the delay. In the test phase, participants were asked to respond whether the letter was previously presented during the memory set at trial onset (maintenance condition). In the test phase of the manipulate condition, participants were presented with a letter and a number. They were asked to determine whether that letter would have appeared in the ordinal position represented by the number if the items in the memory set were rearranged into alphabetical order.

D'Esposito et al. (1999) found that during the delay period of the maintenance task, all participants showed increased activation in both dorsolateral and ventrolateral prefrontal cortex regions while during the manipulation task, significantly greater activation was found in the dorsolateral prefrontal cortex in the majority of participants. Thus, they proposed that dorsolateral prefrontal cortex may be implicated to a greater extent during behavioural conditions that required transformation of information held in working memory. In addition, that dorsolateral prefrontal cortex may subserve an additional and distinctively different function than ventrolateral prefrontal cortex. These findings were also consistent with the functional organization model of prefrontal cortex of memory function proposed by Petrides (1989).

In summary, the relationship between visual attention and working memory is unclear. This may be due to differences in the operationalization of working memory across studies. The current series of experiments will examine two possible mechanisms of working memory; Lavie's (Lavie et al., 2004) conceptualisation of working memory compared to Baddeley's model (Baddeley, 2003). Importantly, the manipulation of working memory will disambiguate between the notion of task difficulty and working memory as it is more generally understood (i.e. the ability to manipulate information on-line). Furthermore, an important line of inquiry comprises the exploration of working memory in tasks which require 'manipulation' and 'maintenance' of information while simultaneously performing a visual selective attention task.

1.7. Rationale for the Current Study

Despite the extensive literature on the nature of visual attention, there is still very little consensus regarding the processes which assist with efficient selective attention and rejection of distracting information. Recently, Lavie and colleagues (Lavie, 1995; Lavie et al., 2004) suggested that the amount of attentional resources available determines the ability to process relevant information and prevent distractor interference. In distractor interference tasks, distractors and targets are generally presented simultaneously. A limited amount of research has examined distractor interference when the presentation of distractor and target items are temporally separated. These studies have generally shown that there is a crucial temporal interval in which individuals are able to prevent the presentation of old distractors from producing interference effects on subsequently presented targets (Kahneman et al., 1983; Kritikos et al., 2008; Watson & Humphreys, 1997). Temporally separating the presentation of distractors and targets potentially provides greater information about the internal representation of a target item on subsequent goal-directed responses over time. This internal representation, which is also a feature of working memory, may be able to assist selective attention by preventing distractor interference through a process of maintaining the prioritization of relevant information (de Fockert et al., 2001). Experiment 1 will address the extent of distractor processing under different perceptual load conditions when distractor and target items are temporally separated. In addition to providing information about how visual information is processed across time, it will also extend knowledge regarding how the internal representation of an item (by temporally separating distractors and targets) influences distractor processing.

Studies have shown that working memory mechanisms are also implicated in visual selective attention. Lavie's cognitive load theory of selective attention suggests that the ability to reject irrelevant distractors and focus attention was a result of two dissociable mechanisms; a perceptual selection mechanism which assists distractor rejection when perceptual load is high and an active control mechanism which ensures that attention is allocated accordingly, even when working memory load is low (Lavie et al., 2004). However, other studies have shown that the nature of the working memory task determines distractor interference in visual attention (D'Esposito & Postle, 1998; Han & Kim; 2004; Owen et al., 1996; Petrides, 1989). Experiment 2 will examine the cognitive load theory using tasks which require both 'maintenance' and 'manipulation' of information. The exploration of working memory, through tasks which require both 'manipulation' and 'maintenance' of information, will help to determine how visual attention and working memory may be interrelated.

The current research will help to identify key mechanisms involved in visual selective attention and it will highlight how distracting irrelevant information is processed under different levels of perceptual and working memory load. Whilst this research is based on a young, healthy population, the information gained will help to determine how models of visual selective attention can be applied to clinical populations including anarchic hand syndrome, visual neglect, and attentional disorders (Kumanda & Humphreys, 2002; Lavie & Robertson, 2001). Furthermore, understanding how different parts of the brain work to influence attention could ultimately lead to a better understanding of conditions such as Attention Deficit Hyperactivity Disorder and Dyslexia (Vidyasagar, 2005; Vidyasagar & Pigarev, 2007).

1.7.1. Aims and Hypotheses

The present series of experiments aimed to examine further the perceptual load and cognitive load theories of selective visual attention. This thesis aimed to integrate and test theories of selective attention, by implementing established as well as modified paradigms. The overall objective was to describe the relationship between perceptual task demands, working memory, and the timing of stimulus presentation on the ability to process relevant and filter out irrelevant information. Specific aims and hypotheses for the individual experiments are elaborated in the introductory sections of the following two chapters.

EXPERIMENT 1

The aim of Experiment 1 was to test Lavie's (1995) perceptual load theory in the context of temporal separation between distractor information and efficient target selection. This was achieved by manipulating the processing demands for visual displays that were identical in appearance. The manipulation of perceptual load was adapted from feature integration theory (Treisman & Gelade, 1980). According to feature integration theory, perception of features is load free while a conjunction of features requires focussed attention and therefore imposes perceptual load. As Lavie (1995) suggested, manipulating the requirements to process features versus conjunctions provides the advantage of implementing a well-established operational formulation of perceptual load.

2.1 Experiment 1A

Experiment 1A attempted to examine the efficacy of the proposed manipulation of low and high perceptual load using feature and conjunction search, respectively. Based on previous literature (Lavie, 1995), it was expected that when distractors and targets appeared simultaneously, reaction times would be slower and accuracy (measured by number of errors) would be reduced compared to when the target was presented alone. It was also hypothesised that RTs would be significantly faster in the feature demand low perceptual load condition compared to the conjunction demand high perceptual load condition

2.1.1 Method

2.1.1.1 Participants

Nineteen individuals (12 females, 7 males; age range 21-35 years; *M*=27.58, *SD*=2.76) participated in Experiment 1A. They were undergraduate and postgraduate students from Victoria University who gave informed consent and volunteered their time. The criteria for inclusion in the present study required that participants were right-handed and had normal or corrected-to-normal vision.

2.1.1.2. Design

In Experiment 1A**,** a 3-way within-subjects repeated measures design was used. There were three levels of perceptual load (target alone; TA, low perceptual load and high perceptual load), and congruence measured at one level (incongruent). The two dependent variables were reaction time (measured in milliseconds; ms) and accuracy (number of errors).

2.1.1.3. Apparatus

The experiment was conducted in a sound and light attenuated room. All experimental stimuli were presented on an IBM Personal Computer attached to a VGA colour monitor set to 1024 x 768 pixels. The experiment was run using the Presentation (Version 9.9) software developed by Neurobehavioral Systems. Accuracy and latency of responses were recorded for analysis; reaction times were collected in milliseconds (ms). Participants made their choice responses using a Personal Computer gaming control pad (Thrustmaster Firestorm Digital 3; Appendix C).

2.1.1.4. Stimuli

The experimental display is presented in Figure 1. The display consisted of a letter, a shape, and an additional letter appearing either above or below the target. The target letter was either **x** or **o** and appeared in the centre of each display and subtended a visual angle of 0.2^o vertically and 0.2^o horizontally on the x and y axes (positions on screen in terms of visual angles). The target letter was always designated by an underscore and could be flanked on either the left or right side by a coloured shape, with 0.80^o of contour-to-contour separation between them against a black screen. The target letter could be flanked by a circle or a square which could either be red or green. Each of these stimuli appeared with equal probability and in random arrangement either to the left or right of fixation. The circle and square both subtended a visual angle of 0.2^o vertically and horizontally on the x and y axes. To assist participants focus their attention at the centre of the computer screen, each trial was preceded by two cues, a larger white circle followed by a smaller white circle measuring 1.02^o and 0.50^o contour to contour, respectively.

An incongruent distractor letter subtending a visual angle of 0.30^o vertically and 0.30^o horizontally, appeared randomly and equiprobably either above or below the centre, separated by 1.0^o of visual angle from the nearest contour of the central fixation point. The distractor letter was always incongruent to the target (the letter **x** when the target was **o** and the letter **o** when the target letter was **x**). Both the target and distractor letters were white (in Times New Roman font) against a black background and presented in lowercase.

2.1.1.5. Procedure

Participants were given a plain language statement outlining the purpose of the experiment and asked to sign a consent form. They were then provided with standardised verbal instructions and tested individually in a single session lasting 15-20 minutes. Participants were seated in front of a computer screen at a distance of 57cm with their head placed in an adjustable chin rest to ensure their line of vision was at the centre of the computer screen.

Before each display, a white circle appeared for 300ms at the centre of the display, acting as a fixation point. This was followed by the presentation of a smaller circle for 200ms to assist participants focus attention to the visual display. Stimulus display onset occurred 200ms after fixation point offset (see Figure 1). The duration of the stimulus onset asynchrony (between distractor offset and target onset) was also randomly determined at between 93 and 200ms to reduce the potential for predicting target onset and therefore motor preparation when responding. Nine values (93,100, 139, 145, 153, 180, 185, 193, and 200) were randomly assigned to each trial within a block. Stimuli remained on screen for 3000ms or until participants made their choice response.

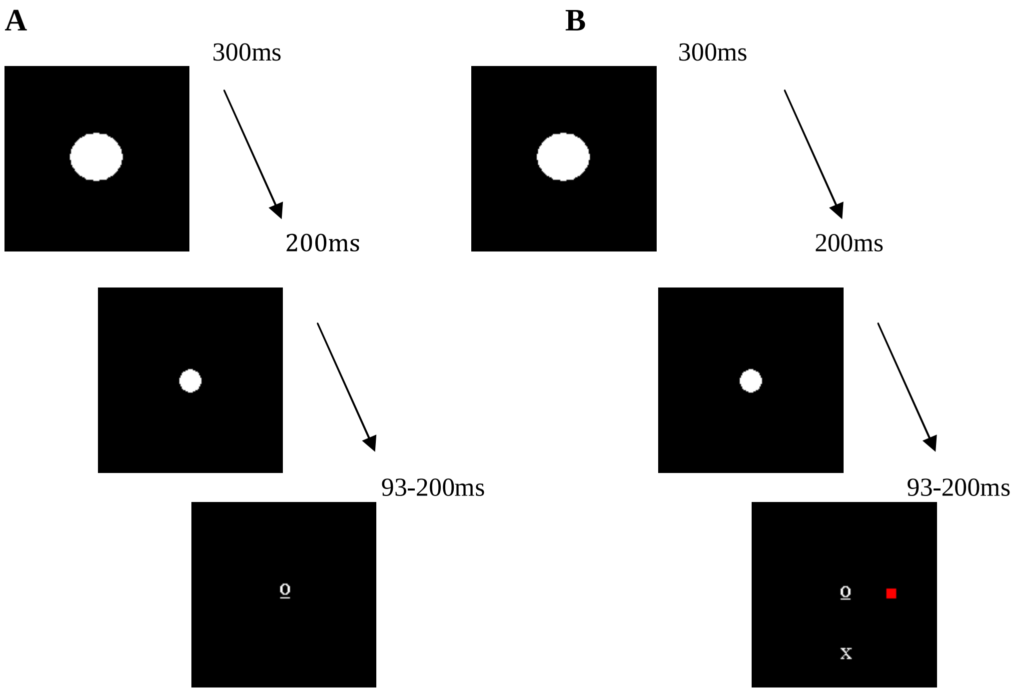

Figure 1. Sample experimental sequences for Experiment 1A (not to scale): **A** Target alone condition **B** Target presented with additional item and incongruent distractor item. Two cues were presented to assist participants focus at the centre of the screen prior to the onset of the target alone (A) or the target with additional item and distractor (B)

The experiment consisted of three conditions: target alone, low perceptual load (feature demand condition), and high perceptual load (conjunction demand condition). In the target alone condition, following the fixation point offset a blank screen appeared and remained for a randomly varied interval (93-200ms) followed by the presentation of the target alone (see Figure 1). In the low and high perceptual load conditions, following the fixation point offset a blank screen appeared and remained for a randomly varied interval (93-200ms) followed by the simultaneous presentation of the target and distractor letters (see Figure 1). The participants were advised that the experiment used a go/no-go procedure that required them to make their choice response to the target letter based on the presence of an additional item that was presented simultaneously with the target. Each perceptual load condition consisted of four instructional manipulations which are described below.

In the feature demand condition, in 25% of the trials, participants were required to respond to the target letter when the additional shape was green and to withhold their response when it was red, regardless of whether the item was a circle or a square. In 25% of the trials, participants were asked to respond to the target letter when the additional item was red and to withhold their response when it was green, regardless of whether the shape was a circle or a square. In 25% of the trials participants were asked to respond to the target letter when the additional item was a circle and to withhold their response when it was a square, no matter whether the colour was red or green. In 25% of the trials, participants were asked to respond to the target letter when the additional item was a square and to withhold their response when it was a circle, irrespective of whether the colour was green or red.

In the conjunction demand condition, in 25% of the trials, participants were required to respond to the target letter when it was flanked by a green square and to withhold their response when a green circle, red square, or red circle was presented. In 25% of the trials, participants were required to respond to the target letter when a green circle was presented with it and to withhold their response when a green square, red square, or red circle was presented. In 25% of trials, participants were required to respond to the target letter when it appeared with a red square and to withhold their response when a red circle, green circle, or green square was presented. In 25% of trials, participants were required to respond to the target letter only when a red circle was presented alongside it and to withhold their response when a red square, green circle, or green square was presented. Therefore, participants were asked to attend to the colour or shape (in the feature demand condition) or to the relevant combination of colour and shape (in the conjunction demand condition) and to respond to the target letter only when the appropriate feature or conjunction of features appeared. Participants were also advised that a distractor letter would appear either above or below the central target display during certain blocks of trials and they were emphatically instructed to ignore it.

Participants were presented with instructions on the computer screen prior to the beginning of each trial block. The instructions advised which feature or conjunction of features needed to appear with the target in order for a response to be made. Participants were instructed to respond as quickly as possible by pressing the left or right button on the gaming control pad; the left index finger for target **x** and right index finger for target **o**, and vice versa depending on task requirements. Participants were advised of the importance of both fast reaction times and accuracy when responding. Following the presentation of instructions, participants were required to press the space bar on the keyboard to begin the trial.

There were three block types: target alone, low perceptual load, and high perceptual load. The order of the trials according to distractor/target spatial positions was randomised within each block. Blocks were administered twice, once in forward and once in reverse order. The three conditions were presented in 18 separate blocks and were counterbalanced across all participants. The initial forward order of the blocks was counterbalanced across participants. For example, participant 1: LPL, HPL, TA, then TA, HPL, LPL, participant 2: HPL, LPL, TA, TA, LPL, HPL. Hand-to-response key mapping order was counterbalanced across participants. For the first eight blocks of trials, half of the participants used their left hand to respond to target letter **x** and their right hand to respond to target letter **o**, while for the other participants hand-to-target mapping was reversed. For the remaining eight blocks of trials, participants were asked to swap hands corresponding to the opposite target type. Participants were given practice trials prior to the experimental trials. Participants who began with the low perceptual load (feature demand) condition were given a block of 12 practice trials, while those who began with the high perceptual load (conjunction demand) condition were given a block of 24 practice trials followed by the experiment. The decision to use different amounts of practice trials between the feature and conjunction conditions was based on Lavie's (1995) methodology. Lavie's participants completed double the number of practice trials in the high perceptual load condition compared to the low perceptual load condition. This was adopted in the current study to ensure results could be as comparable as possible to Lavie's results. In total, Experiment 1A consisted of 576 experimental trials (18 blocks of 32 trials) and 72 practice trials (two blocks of 12 trials and two blocks of 24 trials). The duration of experiment 1A was around 20 minutes.

2.1.2 Results 1A

Mean reaction times (RTs) and mean number of errors were calculated for each participant in all experiments. The data analysis was conducted using the computer program SPSS version 15.0. Various repeated measures Analysis of Variances (ANOVAs) were conducted on the data. Dependent t-tests, using Bonferroni correction, were also conducted to further investigate significant interaction effects. The assumption of sphericity was measured using Mauchley's test. The Huynh-Feldt correction was used as it is a more conservative measure of significance (Field, 2005). Effect sizes were calculated for the pairwise comparisons using Pearson's correlation coefficient (r); effect sizes were not calculated for main effects (see Field, for full discussion). These principles applied to all experiments.

2.1.2.1 Analysis of Reaction Times

The means of the RTs were computed for each participant of Experiment 1A as a function of low perceptual load (feature demand), high perceptual load (conjunction demand), and target alone (Table 1). Paired-sample t-tests were conducted to determine the effects of perceptual load (low perceptual load, high perceptual load, and target alone) on RTs. Reaction times of error trials were excluded from analysis.

Pairwise comparisons revealed significantly faster mean RTs in the low perceptual load condition than in the high perceptual load condition, $t_{(18)}=-5.09$, $p<.001$, $r=.8$. Overall, mean RTs in the target alone condition were significantly faster than the other conditions. Mean RTs in the target alone condition were significantly faster than mean RTs in the low perceptual load condition $t_{(18)}=6.21$, $p<.001$, $r=.8$ and also significantly faster than mean RTs in the high perceptual load condition $t_{(18)}=8.36$, $p<.001$, $r=.9$. Given the statistically significant findings and large effect size for mean reaction times in the target alone condition, further analyses were not conducted for this condition in the subsequent experiments.

2.1.2.2 Analysis of Errors

Paired samples t-test revealed that there was a significant difference in mean errors between the low perceptual load and target alone conditions $t_{(18)}=7.26$, $p<.001$, $r=.9$. There was also a significant difference in mean number of errors between the high perceptual load and target alone conditions $t_{(18)}=7.30$, $p<.001$, $r=.9$. In contrast, paired samples t-test revealed no significant difference in mean number of errors between the low perceptual load and high perceptual load conditions $t_{(18)}=1.14$, $p>.05$, $r=.3$.

Table 1
Means and Standard Deviations of Reaction Times and Means and Standard Deviations of Errors as a function of Task Load in Experiment 1A

	Reaction Time		**Error**	
Task Load	**M**	**SD**	**M**	**SD**
Target Alone	268	92	2.95	1.71
Low Load (Feature Demand)	421	55	16.11	8.37
High Load (Conjunction demand	458	53	14.11	6.72

The results showed that perceptual load was effectively manipulated; mean reaction times were significantly faster in the low perceptual load versus the high perceptual load condition. Furthermore, mean reaction times were significantly faster when the target appeared alone compared to the other conditions. The pattern was not, however, as clear for accuracy: as load increased accuracy remained constant.

2.2 Experiment 1B

In Experiment 1B, perceptual load was manipulated in the context of temporal separation and distractor-target compatibility. Based on previous literature (Lavie, 1995), it was expected that when distractors and targets appeared simultaneously, reaction times would be slower and accuracy would be reduced, that is the number of errors should increase, compared to when the target appeared alone.

In the feature demand low perceptual load condition, when distractors and targets were presented simultaneously, it was hypothesised that the basic feature would be detected with little or no increase in the load of relevant processing, leaving spare capacity to spill over automatically to the critical distractor. Reaction times should therefore be faster in the presence of congruent compared to the neutral distractors and significantly slower overall with incongruent distractors. A decrease in the accuracy of the choice responses was expected when incongruent distractors were presented in the feature demand low perceptual load condition but not in the conjunction demand high perceptual load condition.

In the conjunction demand high perceptual load condition, when distractors and targets were presented simultaneously, it was predicted that reaction times would be greater than in the feature demand low perceptual load condition (Lavie, 1995). Under the conjunction demand high perceptual load condition, the task of recognizing the appropriate conjunctions in the very same displays should impose greater demand on attentional capacity, leaving considerably less for the irrelevant distractor and hence reducing interference effects. Further, it was expected that the conjunction demand high perceptual load condition would impose a greater demand on attentional capacity, leaving considerably less capacity for the irrelevant distractor and reduce interference effects. That is, incongruent distractor should result in faster reaction times, followed by neutral and congruent distractors in the conjunction demand high perceptual load condition.

Based on previous literature (Kritikos et al., 2008), it was expected that when distractors preceded the presentation of targets by 200ms, the distractor interference effect would be significant though attenuated compared to the simultaneous condition. That is, reaction times would be slower and accuracy would be reduced in the simultaneous condition compared to the preceding condition.

Temporal separation of distractors and targets by 93-200ms in the feature demand low perceptual load condition should produce distractor interference effects. Specifically, it was hypothesised that reaction times would be slower in the incongruent than the neutral conditions and slower in the neutral compared to the congruent conditions. Temporal separation of distractors and targets in the conjunction demand high perceptual load condition, conversely, should abolish the already attenuated distractor congruence effect seen under a temporal interval of 93-200ms.

2.2.1 Method

2.2.1.1 Participants

Twenty individuals (13 females, 7 males; age range: 21-35 years; *M*=27.05, *SD*=3.70) participated in Experiment 1B. They were undergraduate and postgraduate students from Victoria University and fulfilled the same inclusion criteria stipulated for Experiment 1A. The same participants were used in Experiment 1 with the exception of one new participant. All participants completed Experiment 1A prior to completing Experiment 1B.

2.2.1.2 Design

In Experiment 1B, a 3x3x2 within-subjects repeated measures design was used. There were three levels of perceptual load (target alone, low perceptual load and high perceptual load), three levels of congruence (congruent, incongruent, and neutral), and two levels of temporal separation (preceding and simultaneous). The dependent variables were reaction time and accuracy.

2.2.1.3. Stimuli and Procedure

The stimuli, design, and procedure were identical to Experiment 1A except for the following alterations. In Experiment 1B, a neutral distractor letter **z** was introduced. The distractor letter was equally likely to be congruent (the letter **x** when the target was **x**, or the letter **o** when the target was **o**), incongruent (the letter **x** when the target was **o**, and vice versa), or neutral in relation to the target letter (the letter **z** which had no defined response in the experiment). The paradigm also consisted of two temporal separation conditions: preceding and simultaneous.

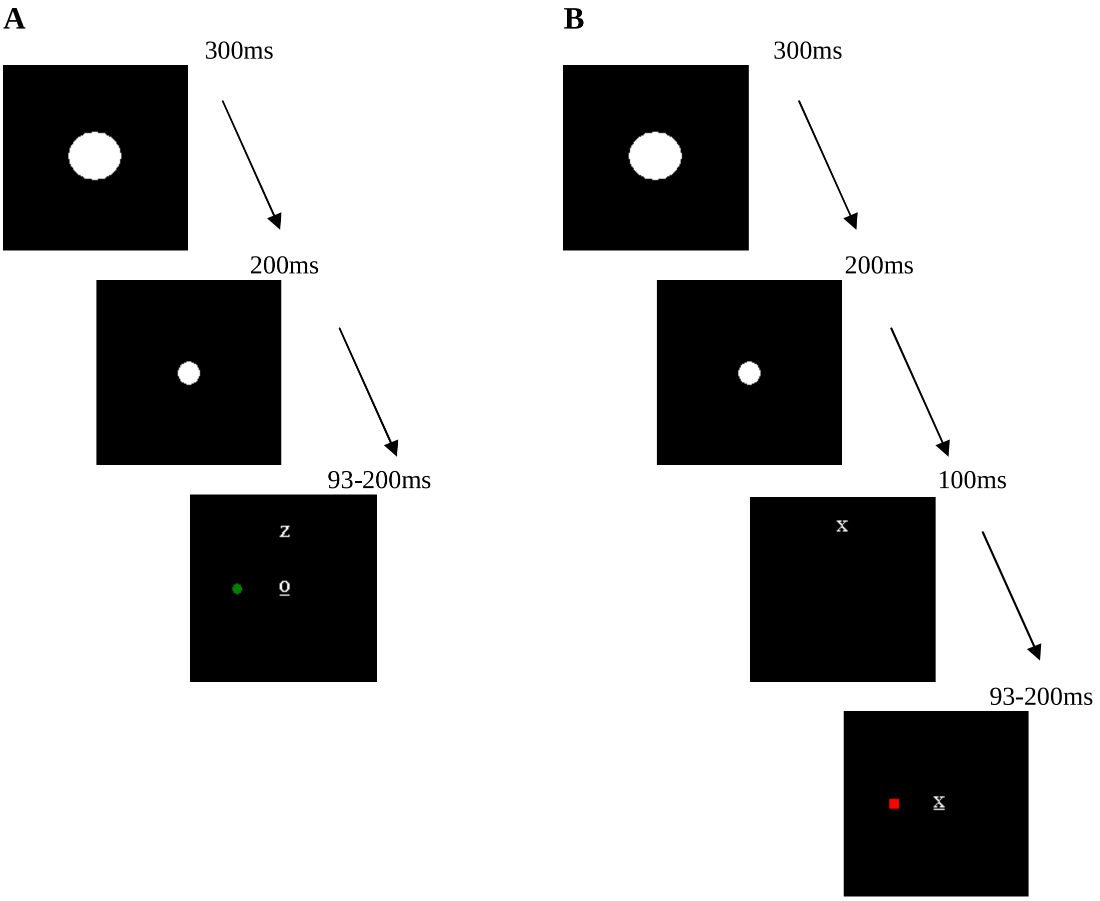

Figure 2. Example of experimental sequence for Experiment 1B (not to scale): **A** Target, additional item, and neutral distractor presented simultaneously **B** Congruent distractor presented between 93-200ms in advance of the target letter and additional item.

In the preceding condition, the distractor was presented immediately after the fixation point offset for a period of 100ms. A blank screen appeared and remained for a randomly varied interval between 93-200ms, followed by the target flanked by the additional item (as in Experiment 1A), which remained on the screen until a response was made or after 3000ms. In the simultaneous condition, following the fixation point offset and a randomly varied blank screen interval (93-200ms), the target, flanking object, and distractor appeared simultaneously and remained on the screen until a response was made or after 3000ms.

The three perceptual load conditions were identical to those presented in Experiment 1A. In the target alone condition, following the fixation point offset a blank screen appeared and remained for a randomly varied interval (93-200ms) followed by the presentation of the target alone. The three perceptual load conditions were presented across both temporal separation conditions in separate blocks, the order of which was counterbalanced across all participants. The order of the trials according to distractor/target spatial positions and temporal intervals were also randomised within each block. Blocks were administered twice, once in forward and once in reverse order. For example, participant 1: LPL, HPL, TA, then TA, HPL, LPL, participant 2: HPL, LPL, TA, TA, LPL, HPL. This sequence of trials occurred for both the simultaneous and preceding conditions. The three perceptual load conditions were presented in 20 separate blocks and were counterbalanced across participants, with repetition of the target alone trials within both of the temporal separation conditions.

Hand-to-response key mapping response order was counterbalanced across participants. For 50% of all trials, half of the participants used their left hand to respond to target letter **x** and their right hand to respond to target letter **o**. As in experiment 1A, for the other participants hand-to-response key mapping was reversed. For the remaining 50% of trials, participants were asked to swap hands corresponding to the opposite target type. Participants were given practice trials prior to the presentation of the experimental trials. Participants who began with the Feature demand condition were given a block of 12 practice trials, while those who began with the Conjunction demand condition were given a block of 24 practice trials followed by the experiment. In total, Experiment 1B consisted of 1152 experimental trials (36 blocks of 32 trials) and 144 practice trials (four blocks of 12 trials and four blocks of 24 trials). This experiment lasted approximately 40 minutes. Participants were given rest breaks between blocks of trials to avoid fatigue.

2.2.2 Results 1B

2.2.2.1. Analysis of Reaction Times

The means of the RTs were computed for each participant of Experiment 1B as a function of perceptual load (low perceptual load, high perceptual load), congruence (congruent, incongruent, neutral), and temporal separation (simultaneous, preceding). A 2x3x2 repeated measures ANOVA was conducted for mean RTs and mean number of errors. Pairwise comparisons were conducted using Bonferroni corrections. Table 2 shows the mean RTs and standard deviations as a function of perceptual load, distractor congruence, and temporal separation and Table 3 shows the mean number of errors as a function of perceptual load, distractor congruence, and temporal separation.

There was a significant main effect of perceptual load on mean RTs, $F_{(1,19)}=24.47$, $p<.001$, such that mean RTs to targets in the high perceptual load condition were significantly faster than in the low perceptual load condition. There was a significant main effect of congruence on RTs $F_{(2,38)}=15.69$, $p<.001$, such that RTs to targets in the presence of either congruent and neutral distractors were significantly faster than RTs to incongruent distractors.

There was also a significant interaction between temporal separation and perceptual load, $F_{(1,19)}=5.21$, $p<.05$. Pairwise comparisons revealed that mean RTs were significantly faster in the simultaneous high perceptual load condition (M=415, SD=53) than in the simultaneous low perceptual load condition (M=434, SD=65, $t_{(19)}=2.22$, $p<.05$, r=.5). Similarly, pairwise comparisons revealed that mean RTs were significantly faster in the preceding high perceptual load condition (M=414, SD=61) than in the preceding low perceptual load condition (M=451, SD=52, $t_{(19)}=7.84$, $p<.001$, r=.9).

A significant interaction was found between temporal separation and congruence $F_{(2,38)}=7.00$, $p<.01$. Pairwise comparisons revealed that mean RTs were significantly faster in the simultaneous congruent condition (M=419, SD=53) than in the simultaneous incongruent condition (M=438, SD=62, $t_{(19)}=-4.70$, $p<.001$, r=.7), when collapsed across perceptual load. Pairwise comparisons further revealed that mean RTs were significantly faster in the simultaneous neutral condition (M=416, SD=54) compared to the simultaneous incongruent condition (M=438, SD=62, $t_{(19)}=4.76$, $p<.001$, r=.7) when collapsed across perceptual load. Paired comparisons did not reveal a significant difference in RTs between congruent, incongruent, and neutral distractors in the preceding condition. These results showed that each of these factors separately influenced RTs; however there was no interaction amongst all three factors. Whilst Temporal Separation interacted with both Perceptual Load and Congruence, the pattern of results does not support the Perceptual Load theory.

Table 2
Mean Reaction Times and Standard Deviations as a Function of Distractor Congruence, Task Load, and Distractor Presentation in Experiment 1B

	LPL		**HPL**	
	M	**SD**	**M**	**SD**
Simultaneous DI				
C	431	65	407	47
I	449	74	427	61
N	422	62	410	53
Preceding DI				
C	447	52	414	62
I	455	46	415	61
N	452	60	412	61

Note. LPL= Low Perceptual Load. HPL= High Perceptual Load. DI=Distractor Interference. C=Congruent. I=Incongruent. N=Neutral

2.2.2.2 Analysis of Errors

Response accuracy did not significantly differ across congruence, perceptual load, or temporal separation. This suggested that none of these factors influenced errors.

Table 3

Means and Standard Deviations of Errors as a Function of Distractor Congruence, Task Load, and Distractor Presentation in Experiment 1B

	LPL		**HPL**	
	M	**SD**	**M**	**SD**
Simultaneous DI				
C	2.15	2.94	1.50	2.35
I	2.75	3.73	2.20	3.81
N	1.90	3.06	1.90	3.95
Preceding DI				
C	1.80	2.69	2.05	3.85
I	2.20	2.84	1.95	3.90
N	2.00	3.09	2.20	4.06

Note. LPL= Low Perceptual Load. HPL= High Perceptual Load. DI=Distractor Interference. C=Congruent. I=Incongruent. N=Neutral.

EXPERIMENT 2

The aim of Experiment 2 was to directly contrast the effects of selective visual attention, perceptual load, and working memory load. Working memory was defined as the ability to maintain information across a delay, and also to manipulate information, such that it had to be reorganized (Kerns, McInerney, & Wilde, 2001). This experiment aimed to examine the effects of both perceptual load and working memory load on distractor interference through the use of a dual-task paradigm.

3.1 Experiment 2A

The first part of Experiment 2 (2A) sought to test the efficacy of the paradigm described by Lavie et al. (2004) as a manipulation of low and high perceptual load using display set size. In Experiment 2A, it was expected that high perceptual load should decrease distractor interference while low perceptual load should increase distractor interference (Lavie, 1995).

3.1.1 Method

3.1.1.1 Participants

Twenty individuals (15 females; 5 males; age range: 21-35; *M*= 27.05, *SD*=3.60) participated in Experiment 2A. Participants fulfilled the same inclusion criteria as per Experiments 1A and 1B.

3.1.1.2 Design

This experiment used a 3x3 within-subjects repeated measures design. The first within-subjects factor was perceptual load (target alone, low perceptual load and high perceptual load) and the second within-subjects factor was congruence (congruent, incongruent, and neutral). The dependent variables were reaction time and accuracy.

3.1.1.3 Stimuli

The target letter in the selective attention task subtended a visual angle of 0.2^{o} horizontally and 0.2^{o} vertically and was equally likely to be either an **x** or **o**, presented in lowercase equiprobably in any of the six possible positions along a central horizontal row subtending 4.2^{o}. The target letter appeared alone in the low perceptual load or presented with five nontarget letters (S K V J and R) in the high perceptual load condition. These five nontarget letters occupied the other positions in the central row equally often in a random order. The nontarget letters appeared in uppercase and at a viewing distance of 57cm, they subtended a visual angle of 0.3^{o} vertically and 0.3^{o} horizontally and were separated by 0.8^{o} from closest edge to edge.

A distractor letter subtending a visual angle of 0.2^{o} horizontally and 0.2^{o} vertically appeared either above or below the central position and was equally likely to be congruent (that is, an **o** when the target was an **o** and an **x** when the target was **x**), incongruent (that is, an **o** when the target was an **x** and vice versa), or neutral (that is, the letter **z**) to the target.

The distance between the distractor edge and the fixation point was 0.9^o so that the separation between the distractor and the central row letters (from edge to edge) varied from 1.0^o of distance for the two central letters to 1.8^o and 2.6^o of separation for the two intermediate and two end letters, respectively (see Figure 3). All of the letters were presented in white against a black background. Each of the distractor categories appeared equally often with each of the target positions.

The combinations of target identities, target positions, distractor identities, distractor positions, nontarget identities and nontarget positions were counterbalanced so that each target letter in any given position was equally likely to be presented with any distractor in either of the two distractor positions.

3.1.1.4. Procedure

Seating and informed consent procedures were identical to those used for Experiment 1A and 1B. Experiment 2A consisted of the following alterations.

Perceptual load in this selective attention task was manipulated by varying the relevant set size. Thus, in the target alone condition, following fixation point offset of between 93 and 200ms a target letter was displayed alone. In the low perceptual load condition, following a fixation point offset of 93-200ms, a target letter appeared in one of six locations in a central row subtending 4.2^o together with a distractor letter which appeared either above or below the central row.

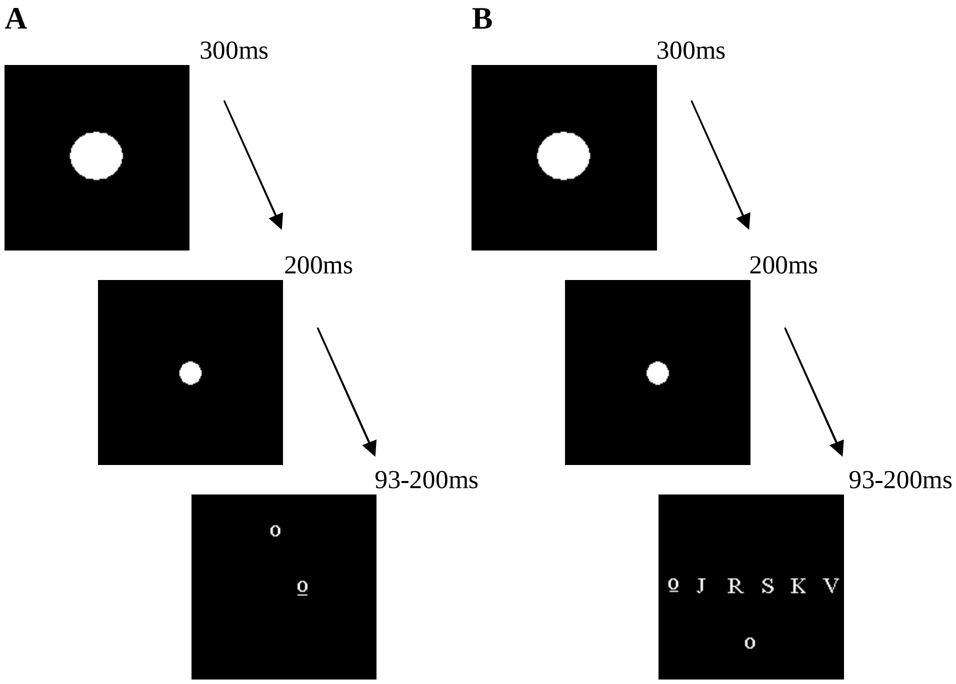

Figure 3**.** Example of experimental trial sequence for Experiment 2A (not to scale): **A** Low perceptual load condition; the target appeared along the central horizontal axis with one distractor letter above it. **B** High perceptual load condition; the target appeared among six non-targets letters along the central horizontal axis and one distractor letter below it.

Figure 3 shows the sequence of events for the high perceptual load condition. Following a fixation point offset of 93-200ms, the visual array consisted of a target letter, distractor letter (either above or below the central row), and 5 nontarget letters. The target letter appeared among five nontarget letters which were equally spaced in a central row subtending 4.2^o. The nontarget letters were S K V J and R, (Lavie et al., 2004) and presented in uppercase. The nontarget letters were all response neutral (that is, letters that were not associated with any response in the task) and only served to force participants to search for the target letter among them. Targets were presented equally often in each of the six central locations, and each nontarget was randomly allocated to one of the five remaining locations on each trial. This manipulation of relevant set size has previously been used successfully to demonstrate the effect of perceptual load on selective attention in a number of experiments (Lavie, 1995; Lavie & Cox, 1997; Lavie & Fox, 2000). The selective attention task used the distractor response-competition paradigm (Eriksen & Eriksen, 1974).

Instructions about hand-to-response key mapping were provided on the computer screen before the beginning of each trial. Participants were instructed to respond to target letters by pressing one of two buttons on a gaming control pad; participants were instructed to respond as fast as they could while avoiding errors. They were also instructed to ignore the distractor letters presented either above or below the central horizontal line. The participants commenced the blocks of trials after pressing the space bar on the keyboard. Before each display, a white circle (pre-cue) appeared for 300ms at the centre of the display acting as a fixation point. This was followed by the presentation of a smaller white circle (cue) for 200ms to assist participants focus their attention to the visual display on the screen. Following a delay ranging between 93 and 200ms, the fixation point was replaced by the stimulus display, as described above. The duration of the stimulus onset asynchrony (between fixation point offset and target onset) was randomly determined at between 93ms and 200ms to reduce the possibility of target onset predictability and therefore motor preparation in responding. All stimuli remained on screen for 3000ms or until a response was made.

There were six separate blocks of 72 trials, and the order of block presentation was counterbalanced across all participants. For the first three blocks, participants were required to respond to **x** with their right hand and to **o** with their left; this was reversed for the subsequent three blocks. For example, participant 1: LPL, HPL, TA, then TA, HPL, LPL, participant 2: HPL, LPL, TA, TA, LPL, HPL. Hand response order was counterbalanced across participants. The order of the trials according to distractor-target spatial positions was randomised within each block. The order of distractor-target congruence was also randomised within each block. Participants who began with the low perceptual load condition performed 12 practice trials, while participants who began with the high perceptual load condition received 24 practice trials. In total, Experiment 2A consisted of 432 experimental trials (6 blocks of 72 trials) and 36 practice trials (one block of 12 trials and one block of 24 trials). The duration of the experiment was around 15 minutes.

3.1.2 Results 2A

The means of the RTs were computed for each participant of Experiment 2A as a function of perceptual load (low perceptual load, high perceptual load) and congruence (congruent, incongruent, neutral). A 2x3 repeated measures ANOVA was conducted for the RTs and errors. Pairwise comparisons were conducted using Bonferroni corrections.

Table 4 shows the mean RTs and standard deviations and Table 5 displays the mean number of errors as a function of perceptual load and distractor congruence.

3.1.2.1 Analysis of Reaction Times

There was a significant main effect of perceptual load on RTs $F_{(1,19)}=101.47$, $p<.001$, such that mean RTs to targets in the low perceptual load condition were significantly faster than in the high perceptual load condition (M=921, SE=29 and M=698, SE=25, respectively). There was a significant main effect of congruence on RTs $F_{(2,38)}=5.45$, $p<.01$, such that mean RTs to targets in the presence of congruent compared with incongruent distractors were significantly faster (M=798, SE=27 and M=822, SE=24, respectively). There was no significant difference in RTs between incongruent and neutral distractors.

There was a significant interaction between perceptual load and congruence $F_{(2,38)}=8.88$, $p<.01$. Pairwise comparisons revealed that mean RTs to targets were significantly faster in the low perceptual load congruent condition (M=673, SD=119) than in the low perceptual load incongruent condition (M=733, SD=113, $t_{(19)}=-7.89$, $p<.001$, r=.9). Pairwise comparisons further revealed that mean RTs to targets were significantly faster in the low perceptual load neutral condition (M=688, SD=112) than in the low perceptual load incongruent condition (M=733, SD=113, $t_{(19)}=4.57$, $p<.001$, r=.7). Mean RTs were also significantly faster in the low perceptual load congruent condition (M=673, SD=119) than in the high perceptual load congruent condition (M=922, SD=13, $t_{(19)}=10.96$, $p<.001$, r=.9). Pairwise comparisons revealed mean RTs were significantly faster in the low perceptual load incongruent condition (M=733, SD=113), than in the high perceptual load incongruent condition (M=912, SD=119, $t_{(19)}$=8.14, $p<.001$, r=.8). Finally, pairwise comparisons revealed mean RTs were significantly faster in the low perceptual load neutral condition (M=688, SD=112) than in the high perceptual load neutral condition (M=928, SD=148, $t_{(19)}$=8.52, $p<.001$, r=.9*)*. Paired comparisons did not reveal a significant difference in RTs between congruent, incongruent, and neutral distractors in the high perceptual load condition.

These results demonstrated that perceptual load was effectively manipulated in the current experiment. Furthermore, mean RTs were also determined by the interaction between perceptual and congruence.

3.1.2.2 Analysis of Errors

There was a significant main effect of congruence on mean number of errors $F_{(2,38)}$=5.70, $p<.01$, such that the mean number of errors was significantly greater when the target letter appeared with incongruent distractors compared to congruent distractors $F_{(1,19)}$=10.68, $p<.01$, r=.6. There was also a significant interaction between perceptual load and congruence on response accuracy $F_{(2,38)}$=5.12, $p<.05$. Pairwise comparisons revealed that the mean number of errors was significantly greater in the low perceptual load incongruent distractor condition (M=5.00, SD=3.14) than in the low perceptual load congruent distractor condition (M=2.65, SD=2.81, $t_{(19)}$=-5.70, $p<.01$, r=.8). Further, there were significantly more errors in the low perceptual load neutral distractor condition (M=4.45, SD=2.96) compared to the low perceptual load congruent distractor condition (M=2.65, SD=2.81, $t_{(19)}$=-3.36, p<.01, r=.7). Finally, the mean number of errors were significantly greater in the high perceptual load congruent distractor condition (M=4.55, SD=3.95) compared to the low perceptual load congruent distractor condition (M=2.65, SD=2.81, $t_{(19)}$=2.97, p<.01, r=.4). This data showed that response accuracy to the target letter varied in the low perceptual load condition according to target-distractor relationship.

Table 4
Means and Standard Deviations of Reaction Times and Means and Standard Deviations of Errors as a Function of Distractor Compatibility and Task Load in Experiment 2A

	Reaction Time		**Errors**	
Task Load	**M**	**SD**	**M**	**SD**
Low				
C	673	119	2.65	2.81
I	733	113	5.00	3.15
N	688	112	4.45	2.96
High				
C	922	139	4.55	3.95
I	912	119	4.50	3.99
N	928	148	4.50	2.70

Note. LPL= Low Perceptual Load. HPL= High Perceptual Load. DI=Distractor Interference. C=Congruent. I=Incongruent. N=Neutral.

3.2 Experiment 2B

The second part of Experiment 2 manipulated distractor-target compatibility, perceptual load, and working memory load. It was predicted that high working memory load conditions should increase distractor interference, as the reduced availability of control mechanisms for attention should reduce the ability to control attention in accordance with current processing priorities and thus increase intrusions of irrelevant distractors.

In the low working memory load and high perceptual load condition, it was expected that distractor interference should be reduced because working memory would actively maintain current processing priorities to ensure that low-priority stimuli did not gain control of behaviour. In the high working memory load and high perceptual load condition, it was expected that there would be an increase in the processing of distractors as a result of the limited capacity available for active control.

Based on the predictions of the cognitive load theory (Lavie et al., 2004), it was hypothesised that in the low working memory load condition and low perceptual load condition, reaction times to targets should be faster when they appeared with congruent distractors and significantly slower with incongruent distractors.

In the low working memory and high perceptual load condition, reaction times were expected to be significantly faster when presented with congruent versus incongruent distractors. Based on the predictions of the cognitive load theory (Lavie et al., 2004), it was predicted that in the high working memory load condition, low perceptual load would result in faster reaction times to targets when presented with congruent versus incongruent distractors. In the high working memory and high perceptual load conditions, it was hypothesised that reaction times would be significantly faster in the congruent versus incongruent distractor conditions.

3.2.1 Method

3.2.1.1. Participants

The same twenty individuals that had participated in experiment 2A were used in Experiment 2B. All participants completed Experiment 2A prior to completing 2B.

3.2.1.2. Stimuli

The stimuli used for Experiment 2B were identical to those used in Experiment 2A except for the appearance of 0, 1, 2, or 3 horizontal lines placed under the target letters.

3.2.1.3. Design

Experiment 2B used a 3x3x2 within-subjects repeated measures design. There were three levels of perceptual load (target alone, low perceptual load, and high perpetual load). There were three levels of congruence: congruent, incongruent, and neutral. There were also two working memory load conditions (low working memory load; LWML, and high working memory load; HWML). The dependant variables were reaction time and accuracy.

3.2.1.3.1 Manipulation of Working Memory

In both working memory load conditions, the visual display consisted of the relevant target letter (either **x** or **o**), a distractor letter (which was congruent, incongruent, or neutral to the target letter), and nontarget letters (S, K, V, J, and R) as described in Experiment 2A. In addition, the visual array consisted of symbols placed directly below the target letter. The symbols included 1, 2, or 3 horizontal lines (see Figure 4). In 25%

of the trials, 1 line was presented directly below the target letter. In 25% of trials, 2 lines were presented directly below the target letter. In 25% of the trials, 3 lines were presented directly below the target letter. In 25% of the trials, no lines were presented. In the low working memory load condition, participants were required to count the number of times 2 lines appeared beneath the target letter. In the high working memory load condition, they were required to add together the total number of lines presented throughout the entire block trial.

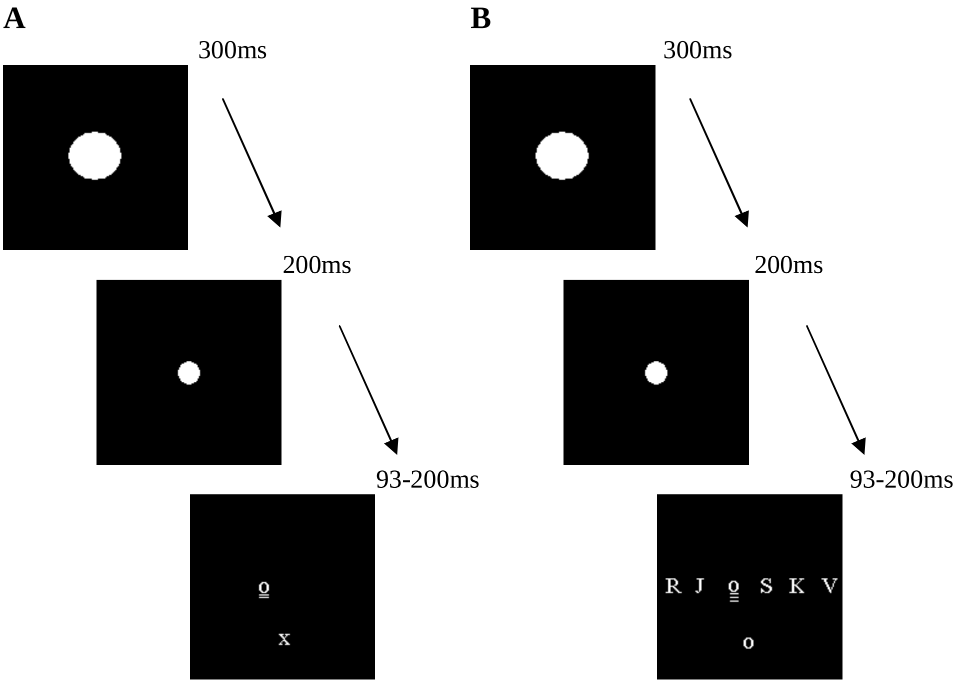

Figure 4. Example experimental trial sequence for Experiment 2B (not to scale): **A** Low perceptual load low working memory load condition in which the target item (along the central horizontal axis) has two underline symbols beneath it **B** High perceptual load high working memory load condition in which the target item has three underline symbols beneath it.

3.2.1.4. Procedure

Seating, informed consent, and experimental procedures were identical to those used for Experiment 2A except for the following alterations. Prior to the beginning of each block trial, participants were provided with instructions about the nature of the task. Participants were advised that they were required to respond to a target letter (either **x** or **o** as in the selective attention task performed in 2A) as fast as they could while performing an additional task. In the low working memory load trials, participants were asked to count the number of times the target letter appeared with 2 lines under it in the visual array and provide their answer at the end of each blocked trial. In the high working memory load condition, participants were instructed to add together the number of lines presented during each block of trials and to provide their answer at the end of each trial.

Before each display, a white circle (pre-cue) appeared for 300ms at the centre of the display acting as a fixation point. This was followed by the presentation of a smaller white circle for 200ms to assist participants focus their attention to the visual display on the screen. Following a delay ranging between 93 and 200ms, the fixation point was replaced by the stimulus display as described in Experiment 2A with the addition of the symbols under the target letters.

There were five block types: target alone (TA), high working memory load and high perceptual load (HWM/HPL), high working memory load and low perceptual load (HWM/LPL), low working memory load and high perceptual load (LWM/HPL), low working memory load and low perceptual load (LWM/LPL). As with experiment 2A, the order of the trials according to distractor-target spatial positions was randomised within each block as was the order of distractor-target congruence. Blocks were administered twice, once in forward and once in reverse order. The initial forward order of the blocks was counterbalanced across subjects (for example, participant 1: TA, HWM/HPL, HWM/LPL, LWM/HPL, LWM/LPL then LWM/LPL, LWM/HPL, HWM/LPL, HWM/HPL, TA; participant 2: HWM/HPL, HWM/LPL, LWM/HPL, LWM/LPL, TA then TA, LWM/LPL, LWM/HPL, HWM/LPL, HWM/HPL, etc).

For the first five blocks, participants responded to **x** with their right hand and to **o** with their left; this was reversed for the subsequent five blocks. Hand response order was counterbalanced across participants. Participants performed a total of 720 (ten blocks of 72) experimental trials each. At the beginning of each block, each participant completed 12 practice trials for the low working memory load conditions and 24 practice trials for the high working memory load conditions (total of 144 practice trials). The duration of Experiment 2B was 30-40 minutes.

3.2.2 Results 2B

The means of the RTs were computed for each participant of Experiment 2B as a function of perceptual load (low perceptual load, high perceptual load), congruence (congruent, incongruent, neutral), and working memory load (low working memory load, high working memory load). A 2x3x2 repeated measures ANOVA was conducted for the RTs and errors. Pairwise comparisons were conducted using Bonferroni corrections. Table 6 shows the mean RTs and standard deviations and Table 7 displays the mean number of errors as a function of perceptual load, distractor congruence, and working memory load.

3.2.2.1 Analysis of Reaction Times

There was a significant main effect of working memory load on RTs $F_{(1,19)}=20.44$, $p<.001$, such that RTs to the target were significantly faster in the low working memory load (M=1072, SE=46) condition compared with the high working memory load condition (M=1190, SE=58). There was also significant main effect of perceptual load on RTs $F_{(1,19)}=28.25$, $p<.001$, such that RTs were significantly slower in the high perceptual load condition (M=1200, SE=49) compared with the low perceptual load condition (M=1062, SE=55). There was no significant main effect of congruence ($p>.05$); however, there was a significant interaction between working memory load and congruence $F_{(2,38)}=4.53$, $p<.05$.

Pairwise comparisons revealed that mean RTs to the target letter were significantly faster in the high working memory congruent distractor condition (M=1190, SD=268) than in the high working memory neutral distractor condition (M=1212, SD=261 , $t_{(19)}=-2.75$, $p<.05$, r=.5). Mean RTs were also significantly faster in the high working memory load incongruent distractor condition (M=1168, SD=258) than in the high working memory load neutral distractor condition (M=1212, SD=261, $t_{(19)}=-2.39$, $p<.05$, r=.5), when perceptual load was collapsed across conditions. However, there was no significant difference in mean RTs to targets between the high working memory load congruent distractor condition and the high working memory load incongruent distractor condition ($p>.05$).

Mean RTs to the target did not differ significantly between the low working memory load congruent distractor condition and the low working memory load incongruent distractor condition when perceptual load was collapsed. However, mean RTs were significantly faster in the low working memory load neutral distractor condition (M=1057, SD=205) than in the low working memory load congruent distractor condition (M=1084, SD=210, $t_{(19)}= 2.10$, $p<.05$, $r=.4$). The results showed a trend of faster RTs in the low working memory load neutral distractor condition (M=1057, SD=205) than in the low working memory load incongruent distractor condition (M=1076, SD=212, $t_{(19)}= 2.05$, $p=.054$, $r=.4$).

Overall, there was a significant difference in mean RTs to target letters between working memory load conditions and distractor congruence when collapsed across perceptual load. Mean RTs to the target letter were significantly faster in the low working memory load congruent distractor condition (M=1084, SD=210) than in the high working memory congruent distractor condition (M=1190, SD=268, $t_{(19)}=3.84$, $p<.01$, $r=.7$). Mean RTs were also significantly faster in the low working memory incongruent distractor condition (M=1076, SD=212) than in the high working memory load incongruent distractor condition (M=1168, SD=258, $t_{(19)}=2.86$, $p<.05$, $r=.6$). Mean RTs were significantly faster in the low working memory load neutral distractor condition (M=1057, SD=205), than in the high working memory load neutral distractor condition (M=1212, SD=261, $t_{(19)}$= 5.87, p<.001, r=.8).

Although not significant, there was an interaction between working memory load and perceptual load $F_{(1,19)}$=4.24**,** p=.054, r=.4, when collapsed across congruence; this showed a trend towards working memory load having differential effects on reaction times depending upon the perceptual load of the task. It is possible that with a larger sample size, this trend would have reached a statistical difference.

Overall, these results showed that both perceptual load and working memory load were effectively manipulated such that there was a significant difference in mean RTs across the different levels of load. Distractor congruence was found to interact with working memory load.

Table 5

Means and Standard Deviations of Reaction Times as a Function of Distractor Congruence, Perceptual Load, and Working Memory in Experiment 2B

	LPL		HPL	
	M	SD	M	SD
LWM				
C	1021	234	1146	207
I	1007	257	1144	185
N	1011	241	1103	192
HWM				
C	1101	279	1279	270
I	1095	281	1241	260
N	1136	286	1289	256

Note. LPL= Low Perceptual Load. HPL= High Perceptual Load. LWM= Low Working Memory. HWM= High Working Memory. DI=Distractor Interference. C=Congruent. I= Incongruent. N= Neutral.

3.2.2.2 Analysis of Errors

There was a significant main effect of congruence on mean number of errors $F_{(2,38)}=4.41$, $p<.05$, such that the mean number of errors to the target letter were significantly greater when the target appeared with incongruent than with congruent distractors $F_{(1,19)}=5.58$, $p<.05$, $r=.5$. There were also significantly more response errors to the target letter when it appeared with incongruent rather than in the presence of neutral distractors $F_{(1,19)}=6.84$, $p<.05$, $r=.5$.

There was a significant interaction between working memory and congruence on the mean number of response errors $F_{(2,38)}=5.86$, $p<.01$. Pairwise comparisons revealed that the mean number of errors in the high working memory load congruent distractor condition (M=6.68, SD=3.77) were significantly less than the mean number of errors in the high working memory load incongruent distractor condition, (M=7.83, SD=4.11, $t_{(19)}$=-2.20, p<.05, r=.4). Mean errors in the high working memory load incongruent distractor condition (M=7.83, SD=4.11) were significantly greater than the number of mean errors in the low working memory load incongruent distractor condition, (M=5.80, SD=3.65, $t_{(19)}$=2.13, p<.05, r=.4). Pairwise comparisons also revealed that errors in the high working memory incongruent distractor condition (M=7.83, SD=4.11) were significantly greater than errors in the high working memory neutral distractor condition, (M=5.80, SD=3.65, $t_{(19)}$=4.51, p<.01, r=.7).

Table 6

Means and Standard Deviations of Errors as a Function of Distractor Congruence, Perceptual Load, and Working Memory in Experiment 2B

	LPL		HPL	
	M	**SD**	**M**	**SD**
LWM				
C	5.35	4.88	5.60	3.99
I	6.45	4.52	5.95	4.51
N	6.45	3.46	5.85	3.88
HWM				
C	6.40	4.42	6.95	4.31
I	7.85	4.17	7.80	5.06
N	5.80	4.10	5.80	4.11

Note. LPL= Low Perceptual Load. HPL= High Perceptual Load. LWM= Low Working Memory. HWM= High Working Memory. DI= Distractor Interference. C= Congruent. I= Incongruent. N= Neutral.

These results suggest that distractor congruence influenced response accuracy and also interacted with working memory load.

DISCUSSION

4.1 Experiment 1 Perceptual Load and Distractor Interference in a Go/No-Go Visual Attention Task

The overarching aim of the first experiment was to examine the relationship between perceptual task demands and the timing of stimulus presentation on the ability to process relevant and filter out irrelevant information. The objective of Experiment 1A was to test Lavie's (1995) perceptual load postulation that all information is processed automatically until attentional capacity is exhausted. Perceptual load was adapted from the feature integration theory (Treisman & Gelade, 1980). Perception of basic features in a visual display (low perceptual load condition), such as shape ("square") or colour ("red"), was expected to occur fast and preattentively, while the perception of a conjunction of features (high perceptual load condition), such as a "red square", was expected to occur in a slow, serial manner. Using features and a conjunction of features in a visual attention task enabled the implementation of a well-established, operational formulation of perceptual load (Lavie). Experiment 1B used the same manipulation of perceptual load as Experiment 1A, but compared distractor interference when distractor and target items were presented simultaneously to when they were temporally separated. Both Experiment 1A and 1B employed a go/no-go procedure in which participants used only one response button to either respond or inhibit a response to the target letter. Thus, changes in reaction times to the target when they were presented with other items in the visual display could be attributed to competition for attention rather than response competition (Kahneman & Treisman, 1979).

4.1.1. Experiment 1A

4.1.1.1. Distractor Interference when Distractor and Targets Items are Presented Simultaneously

Based on previous research (Folk & Remington, 1998; Kahneman et al., 1983), it was expected that when distractors and targets were presented simultaneously, reaction times would be slower and the number of response errors would increase. Results supported this prediction; when a target item was simultaneously presented with irrelevant distracting information, there was a reaction time cost such that reaction times were at least 153ms slower (low perceptual load condition) compared to reaction times to the target when it appeared alone. This pattern of findings is consistent with previous reports in the literature. Kahneman and colleagues demonstrated that when a visual display consisted of both a target and an irrelevant distractor, both of these objects would ‘pop out’ and compete for attention. This subsequently led to an increase in reaction times as the system determined where attention should be allocated. In contrast, visual displays with only a single target item resulted in faster response times because no other items competed with it for attention. Folk and Remington also found that response times to targets in the presence of other items increased compared to response times when the target item was presented alone.

In addition, in Experiment 1A of this study there were more response errors to the target when the target and distractor items were presented simultaneously, compared with when the target appeared alone. This suggested that the presence of the irrelevant distractor item interfered with processing of the relevant information. Taken together, these findings indicated that the visual processing system was unable to exclude completely irrelevant distracting information from perceptual processing. Hence, both the number of errors and response times to target items increased when the target appeared simultaneously with distractor items in the visual display. The nature of these 'cost' effects was further examined to determine whether the systematic manipulation of perceptual load would determine the extent of distractor interference.

4.1.1.2. Perceptual Load Modulates Reaction Times: Faster Reaction ` Times in Low Perceptual Load than High Perceptual Load Visual Displays

The extent of distractor interference was subsequently explored within the context of the perceptual load theory. Lavie (1995) suggested that the perceptual load of the visual display determines the level of distractor processing (as revealed through changes in reaction time). Based on the perceptual load theory (Lavie, 1995; 2000; 2005), it was predicted that reaction times would be significantly faster in the feature demand low perceptual load condition compared to the conjunction demand high perceptual load condition. The current study found support for this hypothesis. Specifically, participants responded significantly faster to targets in the feature demand low perceptual load condition compared to the conjunction demand high perceptual load condition. In the feature demand low perceptual load condition, basic features (e.g. shape or colour), which are assumed to cause little or no increase in perceptual load compared to search for a conjunction of features, resulted in faster reaction times.

In contrast, during the conjunction demand high perceptual load condition, the task of recognizing the conjunctions in the same displays imposed more of a demand on attentional capacity which resulted in slower reaction times. These results support the idea that search for a feature can occur relatively quickly and may elicit parallel processing while a conjunction search requires focused attention and search occurs in a serial manner (i.e. slower reactions times; Treisman, 1988; Treisman & Gelade, 1980; Treisman, Sykes, & Gelade, 1977). Overall, reaction times in the target alone conditions were significantly faster than both the high and low perceptual load conditions. The accuracy data revealed a different pattern, however. The mean number of errors committed by participants did not vary across the feature demand low perceptual load and conjunction demand high perceptual load conditions; this suggested that participants made the same amount of errors irrespective of whether perceptual load was high or low. However, significantly fewer response errors were committed when the target item was presented alone. Thus, the number of errors did not appear to be related to the perceptual load of the visual display, but rather the mere presence of other items in the array interfered with accurate response selection.

The findings from Experiment 1A provided preliminary support for the perceptual load theory (Lavie, 1995; 2000; 2005). The current experiment employed a similar methodological design to Lavie (1995) to establish a baseline distractor interference effect. This also enabled distractor interference to be attributed to the systematic manipulation of perceptual load. The main difference between Lavie's work and Experiment 1A was the manipulation of the target-distractor relationship. While Lavie used distractor letters that were congruent, incongruent, or neutral to the target letter, the current experiment used distractor letters that were always incongruent to the target letter. Lavie argued that whilst specific predictions could be made regarding the presence of incongruent distractors on target processing, such predictions were not possible for congruent distractors. Therefore, using only incongruent distractors in the present experiment provided a relatively unambiguous measure of the contribution of perceptual load in visual attention. One of the goals of the subsequent experiment (Experiment 1B) was to examine the precise nature of the distractor interference effect by using distractor letters that were congruent, incongruent, and neutral to the target letter. It was expected that reaction times would vary as a consequence of the target-distractor relationship.

4.1.2. Experiment 1B

The second part of Experiment 1 extended the previous findings by manipulating perceptual load in the context of distractor-target congruence. This was expected to clarify whether distractor letters identical to the target would produce either facilitation (i.e. faster reaction times; Eriksen & Eriksen, 1974) or feature-specific inhibition (i.e.

slower reaction times; Bjork & Murray, 1977). In addition, this experiment examined the time-course of distractor interference effects by temporally separating the presentation of the distractor and target letters. The aim was to determine how the internal representation of the distractor letter interacted with the processing of relevant information. Thus, target letters were presented alone, presented simultaneously with the distractor letter, or presented up to 200ms following the presentation of the distractor letter. This interaction was examined with distractor letters that were congruent, incongruent, and neutral to the target letter.

4.1.2.1. Simultaneous Presentation of Distractor and Target Items Slows Reaction Times and Reduces Accuracy

The initial hypothesis predicted that when the target and distractor letters were presented simultaneously, reaction times would be slower and accuracy would be reduced compared with the target appearing alone. Consistent with predictions, reaction times were slower when the distractor and target were presented simultaneously, compared with when they were presented alone. This finding supported results from Experiment 1A and demonstrated that the mere presence of an additional item resulted in a reaction time ‘cost’. Interestingly, the results did not reveal a significant difference in the number of errors when the target and distractor appeared simultaneously.

4.1.2.2. Distractor Processing When Perceptual Load is Low: Reaction Times and Accuracy

Target-distractor congruence was subsequently investigated to determine the level of processing that occurred under different levels of perceptual load. To re-cap briefly, Lavie's (1995) theory predicts that under conditions of low perceptual load, attention is not able to remain focused and consequently spills over to the rest of the visual display. Therefore, irrelevant information is also processed, resulting in greater distractor interference manifesting as longer reaction times and reduced accuracy. In contrast, in conditions of high perceptual load, attentional resources are exhausted and thus irrelevant information is not processed (reduced distractor interference compared to low load conditions). In the present study, it was predicted that in the feature demand low perceptual load condition, when distractors and targets appeared simultaneously, the feature (either shape or colour) would be detected with little or no increase in the load of relevant processing. This would lead spare attentional capacity to spill over automatically to the distractor item (Lavie, 1995; 2000; 2005). As a result, reaction times to targets should be significantly faster in the congruent compared with the neutral distractor condition and significantly slower overall in the incongruent distractor condition.

Consistent with previous research (Lavie, 1995; Yantis & Johnston, 1990; Theeuwes et al., 2004), in the feature demand low perceptual load condition, there was evidence of distractor processing. Reaction times to the target letter when either congruent or neutral distractors appeared were significantly faster compared with when an incongruent distractor was presented with the target. The current results were consistent with a number of studies (Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979) which showed a decrease in interference effects, if not actual facilitation of reaction times, when the distractor and the target were identical or were associated with the same response category. As expected, the presence of incongruent distractors slowed reaction times to the target letter suggesting possible response competition effects (Lavie, 1995).

Although it was predicted that response times to the target letter would be significantly faster when presented with a congruent distractor letter compared to a neutral distractor letter, this was not the case. There was no significant difference between reaction times to the target when either of these distractors was presented simultaneously with the target. It is possible that interference and facilitation effects to target response could not be accurately quantified due to the selection of the baseline condition (Flowers & Wilcox, 1982). Flowers and Wilcox proposed that a neutral baseline item should be a distinctly different character compared to the target and incongruent distractor items (e.g. a non-alphanumeric character when the target is an alphanumeric character). Using a distinctly different distractor item may have provided greater information about distractor interference mechanisms during visual search.

It could be argued that the current non-significant results between the neutral and congruent distractor conditions may be attributed to a lack of response mapping for the neutral distractor letter. In the present experiment, the target letter was counterbalanced across blocks of trials and was either an ‘x’ or ‘o’. Both letters were mapped onto a particular response button; however the neutral distractor letter ‘z’ did not have a mapped response. Distractor letters of the opposite response set would be expected to produce significantly slower reaction times compared to same response set distractor letters (Eriksen & Eriksen, 1974). Furthermore, distractor interference effects are said to occur because at least some of the irrelevant information is processed together with the target until they are identified sufficiently to elicit an appropriate response (Eriksen & Eriksen). Thus, response competition effects may have occurred when an incongruent distractor was presented with the target letter but not when a neutral distractor was presented with it. Alternatively, it is possible that some expectancy for incongruent distractors was built up from the previous experiment (1A) and consequently the new distractor types added in the current experiment were treated as ‘non-congruent’.

The current experiment also investigated the number of response errors that were produced under different perceptual load conditions and also as a variance of the target-distractor relationship. A decrease in accuracy was expected when incongruent distractors were presented in the feature demand condition but not in the conjunction demand condition. Surprisingly, there was no significant difference in accuracy across both low and high perceptual load conditions. However, significantly more response errors to the target were made when an incongruent distractor was presented compared with when either a congruent or neutral distractor letter was presented. This suggested that response accuracy was not determined by the level of perceptual load of the visual display but by the distractor-target relationship.

4.1.2.3. Distractor Processing when Perceptual Load is High: Reaction Times and Accuracy

Based on perceptual load theory (Lavie, 1995), it was expected that target response would be significantly slower in the conjunction demand high perceptual load condition compared with the feature demand low perceptual load condition. In the conjunction demand condition, the additional task requirement to form the appropriate conjunctions, holding the visual display constant, was expected to impose a greater demand on attentional capacity. Therefore, less attentional capacity would be available for distractor processing. This hypothesis was not supported. In contrast, the results showed that reactions times were significantly slower in the feature demand low perceptual load condition compared to the conjunction demand high perceptual load condition. This finding was particularly surprising given that in the previous experiment (Experiment 1A) the typical perceptual load effect was found using the same experimental manipulation.

Previous research (Theeuwes, 1992; 1996) demonstrated that attention could be captured automatically by the most salient item in the display regardless of whether that item was relevant to the task. In the current experiment, the distractor letter was physically bigger than both the target letter and the additional object in the visual display, and thus arguably more salient than the target. It is possible that the distractor captured attention due to its salience relative to the other items in the visual display, particularly in the low perceptual load condition and consequently produced slower reaction times (Eltiti et al., 2005).

A relatively recent model of visual selective attention was proposed by Theeuwes and colleagues (Theeuwes et al., 2000) which suggested that both bottom-up and top-down processing mechanisms occur at different stages of visual attention processing. During early preattentive processing, selection is driven by bottom-up processes, such that attention is captured by the most salient stimulus present in the visual field. After attention is captured by the location of the salient distractor, ‘attentive’ processing exerts top-down activation which allows attention to be shifted elsewhere (Theeuwes et al., 2000). Theeuwes’ postulation is in fact similar to Lavie’s formulation of visual attention in displays where perceptual load is low (Lavie et al., 2004). Specifically, there is an active mechanism of attentional control which is required for rejecting irrelevant distractors even when they are perceived (i.e. low perceptual load displays; Lavie et al). This active mechanism ensures that low-priority stimuli do not gain control of behaviour. The present results are consistent with this interpretation; attention may have been captured initially by the irrelevant distractor letter (bottom up processing), which resulted in increased reaction times. However the attentional control mechanism (top-down processing) may have been able to reorient attention back onto task requirements and ensure response selection.

The surprisingly faster reaction times in the conjunction demand high perceptual load condition compared with the feature demand low perceptual load condition were also in contrast to the assumptions of feature integration theory. Treisman and colleagues (Treisman & Gelade, 1980; Treisman & Schmidt, 1982) reported linear search slopes during a conjunction search task which suggested that attention was directed serially to each item in the visual display until the correct item was located (Treisman & Gelade; Treisman & Schmidt). Similarly, Lavie (1995) argued that an increase in perceptual load, such as a conjunction search, slowed reaction times because the system performed additional operations compared to a feature search. In contrast to these expectations, a number of investigators have found evidence for parallel processing during a high perceptual load condition such as a conjunction search task (Nakayama & Silverman, 1986a; 1986b; Treisman & Sato, 1990; Wolfe et al., 1989).

Based on their series of experiments, Wolfe et al. (1989) suggested that visual search is guided by information at an early parallel processing stage. During the parallel stage of processing, information about the feature is used to guide attention in the search for conjunctions. Each time the 'spotlight' moves, it is directed to the most likely target location, as identified by the parallel processes. Continuous updating of the input from the parallel processes increases the likelihood that those processes will accurately identify the target. Under some conditions, this produces flat search slopes because early selection processes guide the 'spotlight' towards the target prior to the target entering into the slower, serial stage of processing (Wolfe et al). In contrast, Treisman and Sato (1990) argued that there are 'conjunction detectors' for specific features which operate at the early parallel processing stage of attention. Emerging properties of specific features are 'sensed' and a conjunction of features can be coded early

(Pomeranzt et al., 1977). Therefore, shallower search slopes can occur during conjunction search because items are checked within subgroups in a parallel manner. The current results support the finding that a conjunction search can be just as efficient, and even more efficient, as feature search. However, the precise mechanisms which enable such efficient response selection under this condition require further exploration. It is possible that one of the abovementioned postulations regarding conjunction search could apply to the current findings. This is analysed in detail below.

The current experiment provided the opportunity to explore the idea that there may be ‘conjunction detectors’ which produce efficient search. Specifically, participants were provided with four different feature search conditions (circle, square, green, red) and four conjunction search conditions (red circle, red square, green circle, and green square). In contrast, Lavie’s (1995) participants were asked to pay attention only to the colour of the shape in the feature demand condition (i.e. blue) or to the relevant conjunction of colour and shape in the conjunction demand condition (i.e. blue square or red circle). It is possible that in the current experiment, participants became faster at processing the relevant conjunctions because the emerging properties of the features could be ‘sensed’ and the conjunctions could be coded early (Pomeranzt et al., 1977). Given the number of search conditions in the current experiment, it is possible that certain items mapped onto object files which accrued information about an object and allowed access to meaningful information at an early stage (Treisman, 1993). Thus, shallower search slopes were found in conjunction search conditions because items were checked within subgroups in a parallel manner.

In summary, the current findings show that in contrast to the perceptual load theory (Lavie, 1995) reaction times can be faster during a high perceptual load conjunction demand condition. However, the current experimental design required participants to search for a greater number of features and conjunction of features compared to Lavie. This difference may have influenced the efficiency of search during the conjunction demand condition. Indeed, previous studies support the current findings (Nakayama & Silverman, 1986a; 1986b; Treisman & Sato, 1990; Wolfe et al., 1989). Collectively, these results suggest that feature and conjunction search may not be the best manipulation of perceptual load as Lavie initially proposed.

4.1.2.4. High Perceptual Load and Distractor Interference

It was predicted that the conjunction demand high perceptual load condition would impose greater demand on attentional capacity, leaving considerably less time for irrelevant distractor processing and reduce interference effects (Lavie, 1995; 2000; 2005). Specifically, the presence of incongruent distractors was expected to produce faster reaction times, followed by neutral and congruent distractors in the high perceptual load condition (Lavie). This hypothesis was not supported. Reaction times to the target were faster when congruent and neutral distractors appeared simultaneously with the target compared to the presence of incongruent distractors; the congruence effect was not eliminated in the high perceptual load condition suggesting that visual processing occurred in a parallel manner (Nakayama & Silverman, 1986; Treisman & Sato, 1990; Wolfe et al., 1989). Thus, all items in the visual display were processed and interfered with efficient target selection in the high perceptual load condition.

Consistent with previous findings (Eriksen & Eriksen, 1974; Flowers & Wilcox, 1982; Santee & Egeth, 1982), the current experiment showed that distractors identical to the target produced facilitation effects, rather than feature-specific interference (Bjork & Murray, 1977; Lavie, 1995). These results demonstrate that the ability to ignore irrelevant information may not be directly related to the perceptual load of the visual display and that processing irrelevant information may be inevitable even under high perceptual load conditions.

In summary, the perceptual load theory (Lavie, 1995) proposes that distractor interference is reduced or eliminated when perceptual load is high because cognitive resources are fully utilized and there is no attentional spill over to irrelevant information. The findings from the current experiment show that perceptual load may not be able to consistently explain distractor interference effects in visual attention. Indeed, when distractor and target items were presented simultaneously, distractor interference occurred across both the high and low perceptual load conditions. A closer inspection of Lavie's results from her third experiment revealed a trend of facilitation effects (when a target was presented with a congruent distractor) under a high perceptual load condition. This facilitation effect was completely eliminated only when certain data were excluded from analysis (See Lavie, 1995; Experiment 3) suggesting that some experimental paradigms elicit faster reaction times to targets presented with congruent distractors. Overall, the current findings indicate that specific predictions regarding the pattern of distractor interference effects in a high perceptual load display may not be possible.

4.1.2.5. Temporal Separation of Irrelevant and Relevant Information: The Time Course of Distractor interference

A number of studies have shown that distractor letters can produce either interference or facilitation effects depending on the temporal presentation of distractors and target letters (Eriksen & Schultz, 1979; Flowers & Wilcox, 1982; Kritikos et al., 2008). Therefore, the systematic manipulation of the stimulus onset asynchrony, relative to manipulation of distractor stimuli, represented another potentially useful approach for isolating interactions occurring at different stages (Taylor, 1997).

4.1.2.6. The Temporal Separation of Distractor and Target Items in a Visual Display Influences Distractor Interference

In the preceding distractor condition, a distractor letter was presented up to 200ms in advance of the target letter and the additional item. Based on previous research (Kritikos et al., 2008; Watson & Humphreys, 1998), it was expected that distractor interference would be significant, though attenuated when the distractor preceded the target letter by 200ms compared with simultaneous presentation. The results did not support this hypothesis. Specifically, significant distractor interference occurred when the distractor letter appeared simultaneously with the target and also when it was presented 200ms in advance of the target. Furthermore, the results did not support the hypothesis that accuracy would be reduced when the distractor item was presented in advance of the target letter. Overall, these findings suggested that the temporal separation of distractor and target items did not influence distractor interference.

Compared with previous designs, however, (e.g. Kahneman et al., 1983; Kritikos et al., 2008) this paradigm used a go-no/go procedure (to follow Lavie et al) in which either a response was made to the target or a response was inhibited depending on the additional item that was also presented. Given this difference, it is likely that the internal representation of the preceding distractor in the go-no/go task was suppressed efficiently (processed and discarded prior to the presentation of the target). Alternatively, it is possible that the temporal interval between the distractor and target was *not* large enough in such a task to interfere significantly with visual processing, thus the distractor item may not have been processed as a separate event. Irrespective of the reason, these results highlight the possibility that different mechanisms occur in a go-no/go experimental design and that these may not be generalised to the present theory of temporal separation (e.g. Kritikos et al).

4.1.2.7. Temporal Separation of Distractors and Target: Distractor Interference when Perceptual Load is Low

The effect of temporal separation on distractor interference across different perceptual load conditions was also examined. Based on the perceptual load theory, greater distractor interference was predicted in the low perceptual load condition when the distractor preceded the target by 200ms (Lavie, 1995). Slower reaction times to the target letter were expected when incongruent distractors were presented compared to neutral distractors. Furthermore, reaction times to targets were expected to be significantly slower when neutral distractors were presented in advance of the target compared to congruent distractors. In contrast, reaction times to the target letter were comparable across the distractor types in the low perceptual load condition when distractors appeared 200ms prior to the target.

These results were opposite to findings by Kritikos and colleagues (Kritikos et al., 2008) who demonstrated a congruence effect both when the target and distractor appeared simultaneously and when they were temporally separated; reaction times to the target letter were slower when presented with an incongruent compared to a neutral distractor and faster overall when presented with a congruent distractor. This suggested that there was some attentional spill over to the distractor letters which resulted in facilitation and interference effects at the level of response selection (Kritikos et al). Kritikos and associates proposed that the same (or similar) processes occurred both when distracting information was presented simultaneously with the target item and when it preceded it. In contrast, the results of this experiment suggest that different processes may occur in visual attention when a target item is preceded by distracting information. Based on these results, it could be argued that the temporal separation between the distractor and target may have been sufficient to enable the distractor to be semantically processed and discarded prior to the presentation of the target.

Interestingly, reaction times were significantly slower in the low perceptual load compared with the high perceptual load condition when the target was preceded by the distractor. This is the same pattern that was found when distractor and target items were presented simultaneously, suggesting that the temporal separation of items in the visual display did not alter the pattern of distractor interference. Although the presence of the distractors produced costs in the form of slower reaction times, the distractor compatibility effect was eliminated in the low perceptual load condition. These results cannot be explained within the framework of the perceptual load theory; however there are a number of theories which can accommodate these findings.

The results can be explained by the phenomenon of attentional capture (Folk & Remington, 1998). Numerous experiments (Folk & Remington; Theeuwes, 1996; Yantis & Jonides, 1990) have shown that under some conditions, irrelevant (distracting) information or irrelevant stimulus events involuntarily receive attentional priority. The contentious issue revolves around whether the effects of attentional capture are due to top-down or bottom-up processes. Proponents of top-down processing (Folk & Remington; Folk et al., 1992) suggest that attentional capture is contingent on the match between the properties of the stimulus and the top-down set of the observer. When attention is focussed in advance of a spatial location, abrupt onsets elsewhere in the visual display do not capture attention. In contrast, the bottom-up approach suggests that regardless of stimulus properties, an irrelevant singleton, if salient enough, will produce attentional capture (Forster & Lavie, 2008; Theeuwes, 1992, 1996). Abrupt onsets in a visual display have also been shown to produce attentional capture (Jonides & Yantis, 1988) in a stimulus driven manner, because of their inherent salience. Relevant to the present thesis, it could be argued that when the distractor was presented in advance of the target letter, it appeared as an abrupt onset which captured attention and produced a generalized interference effect. This ‘attentional capture’ resulted in significantly longer reaction times to the target letter in the low perceptual load condition irrespective of the type of distractor letter presented.

The current findings lend more support, however, to the predictions of the salience hypothesis (Eltiti et al., 2005). This proposes that distractor salience determines the extent of distractor interference. Perceptual load may not be responsible for determining the capacity resources available to prevent distractor processing, but it may change the relative salience of the distractor items. The salience hypothesis predicts that distractor onsets produce significant interference effects under low perceptual load conditions. In contrast, distractor offsets reduce the saliency of the distractor item, thereby enabling participants to engage in selective attention because the distractor is no longer interfering with selective attention (e.g. Theeuwes, 1991). Thus, the magnitude of the distractor interference will be significantly reduced or eliminated during the distractor-offset condition in both high and low perceptual load displays.

In their series of experiments, Eltiti et al. (2005) found reduced distractor interference in the low perceptual load condition during the distractor offset / target onset condition suggesting that perceived distractors did not capture attention. Similarly, the current experiment revealed that, although distractors were perceived and processed to some extent, reaction times were comparable across distractor types; there was no evidence of a congruence effect in the low perceptual load condition when distractors were presented 200ms prior to the target. Thus, it could be argued that distractor processing was determined by the salience of items in the visual display and not perceptual load.

4.1.2.8. Temporal Separation of Distractors and Target: Distractor Interference when Perceptual Load is High

The distractor interference effect was examined under the high perceptual load condition, when irrelevant information was presented 200ms prior to the target. It was predicted that the distractor congruence effect would be abolished. The results supported this hypothesis such that there was no significant difference in reaction times between the three types of distractor letters. This converges with the perceptual load theory which asserts that a high perceptual load visual display consumes attentional resources (Lavie, 1995). Therefore distractors are not processed to the same extent as they are in a low perceptual load display (Lavie) and do not produce a congruence effect. However, the current results also converge with the predictions of the salience hypothesis. This states that distractor interference is attenuated in a high perceptual load display because of reduced salience of the irrelevant stimuli. Indeed, the distractor in a high perceptual load display is less likely to capture attention when there is less available capacity to process irrelevant information (Eltiti et al., 2005).

Kahneman and colleagues (Kahneman et al., 1983) offered a different explanation for efficient target selection when distractors and target items were temporally separated. They found that the advance presentation of irrelevant objects eliminated or greatly reduced filtering costs. In their ‘removed early’ condition (see section 1.5), distractor duration was 300ms, followed by a blank interval of 500ms and then target onset. Using the ‘object file’ analogy, Kahneman and colleagues showed that there was less interference when a pre-existing file required updating compared to when a new file was created. Furthermore, the presentation of the distractor letter ahead of the target allowed sufficient time for the object files to be created which reduced interference from the distractor. The temporal separation condition in the current experiment was similar to Kahneman and colleagues: distractor duration was 200ms, followed by a blank screen of 200ms, and then target onset. The current results supported those of Kahneman and colleagues. The elimination of distractor congruence effects suggested that the gap between the distractor and target was large enough to enable the pre-existing file to be updated.

Overall, the current findings suggest that perceptual load did not modulate distractor interference. Indeed, the perceptual load theory cannot account for efficient target selection in the high perceptual load condition compared to the low perceptual load condition. The manipulation of temporal separation between the distractor and target further revealed the limitations of the perceptual load theory in its ability to explain distractor interference effects when irrelevant information preceded relevant stimuli by up to 200ms. A number of theorists have suggested that distractor interference is reduced or eliminated due to working memory processes (Duncan & Humphreys, 1989; Luck & Vogel, 1997; Watson & Humphreys, 1997). It has been proposed that the generation of an inhibitory template may actually prevent irrelevant distracting information from interfering with visual attention (Watson & Humphreys). This reportedly occurs through the creation of an internal template (i.e. a memory representation) which is thought to be a feature of working memory (Duncan & Humphreys). Changes in working memory load may actually modulate distractor interference (Lavie et al., 2004). The subsequent experiment examined how working memory load interacts with visual selective attention processes. This was done by testing the cognitive load theory of visual attention proposed by Lavie and colleagues (Lavie et al., 2004).

4.2. Experiment 2 Cognitive Load Theory of Visual Attention

Working memory processes may be closely implicated in visual attention and may assist with reducing distractor interference. One of the main challenges in this field is the way working memory processes are defined and tested. In this series of experiments, working memory was defined both as the ability to maintain information across a delay and the ability to manipulate and reorganise information (Kerns et al., 2001). In contrast, Lavie and colleagues (2004) examined working memory using a short-term recognition memory task in which they manipulated working memory load by varying the memory set size. Thus, working memory load was determined by task difficulty (Lavie et al).

The main purpose of Experiment 2 was to examine the contributions of perceptual and working memory loads to distractor interference effects. The aim was to examine whether the cognitive load theory of visual attention could be supported using a more traditional definition of working memory (Kerns et al., 2001). Thus, working memory load was determined by tasks which required participants to maintain and manipulate information over a short period of time. Perceptual load was determined by changing the relevant display set size (Lavie, 1995; Lavie et al., 2004). In the low perceptual load condition, the target letter was displayed in one of six locations along an imaginary horizontal line together with a distractor letter which appeared either above or beneath it. In the high perceptual load display, the target letter was surrounded by five nontarget letters along the imaginary horizontal line together with the distractor letter, presented either above or below the target. Distractor interference was determined by target-distractor relationship in which distractors could either be congruent, incongruent, or neutral to the target. The explanatory power of the cognitive load theory of visual attention proposed by Lavie and colleagues (Lavie et al) was tested using a dual-task paradigm. In Experiment 2A, the efficacy of the perceptual load theory (Lavie) was examined using a visual search task. This was done to establish a baseline distractor interference effect by manipulating only perceptual load (display set size) and target-distractor congruence in a single-task paradigm. In Experiment 2B, a working memory task was incorporated in the same visual search task. Target-distractor congruence was used as a measure of distractor interference in addition to reaction times to the target and response accuracy.

4.2.1. Experiment 2A

4.2.1.1 Perceptual Load: Display Set Size and Distractor Interference

Based on the assumption that perceptual load (Lavie, 1995; Lavie et al., 2004) determines the extent of distractor interference during visual attention, it was predicted that high perceptual load would decrease distractor interference relative to low perceptual load. Unlike the findings from the simultaneous condition in Experiment 1B, the current findings supported this hypothesis. Participants responded significantly faster to the target in the low perceptual load condition. In addition, the presentation of a distractor letter either above or below the target letter in a low perceptual load display produced greater distractor interference than in a high perceptual load visual display. When a distractor was identical to the target, reaction times to the target were faster compared with an incongruent distractor. A similar pattern was found when a neutral distractor letter (that is, one with no designated response) was presented with the target compared with an incongruent distractor.

In addition, the results showed that perceptual load impacted upon response accuracy. In the low perceptual load condition, more response errors were made when an incongruent distractor appeared with the target compared with a congruent distractor. In addition, more response errors were made when a neutral compared with a congruent distractor appeared with the target. When load was high, the number of response errors to the target was consistent across the three distractor types. Accuracy across both perceptual load conditions supported Lavie's findings (1995). Overall, the current results were consistent with previous research (Lavie, 1995; Lavie & Cox, 1997) and showed that perceptual load was successfully manipulated using visual display set size. Firstly, reaction times to the target were significantly faster in the low perceptual load condition; secondly, there was evidence of greater distractor interference; and lastly, there were also more response errors to the target.

4.2.2. Experiment 2B The Relationship Between Working Memory Load and Perceptual Load on Distractor Interference

As outlined in section 1.6.2. of the introduction, Lavie and colleagues (2004) proposed the existence of two dissociable mechanisms in visual selective attention which reduce distractor interference. Focussed visual attention occurs with high perceptual load because attentional capacity is exhausted. In contrast, in low perceptual load, a cognitive control mechanism helps to maintain task priorities and eliminate distractor interference effects. Distractor interference is predicted to occur during a visual selective attention task when working memory load is high, for example, when completing multiple tasks (Lavie et al). The findings from Experiment 2A of the present thesis provided a foundation on which the subsequent experiment could be based: the same visual selective attention task was used but a working memory task was embedded within it. Perceptual load was manipulated in the context of working memory load and distractor-target compatibility. This experiment aimed to test the cognitive load theory of visual attention (Lavie et al., 2004).

4.2.2.1. Working Memory Load Modulates Distractor Interference

Based on the predictions of the cognitive load theory (Lavie et al., 2004), increased distractor interference was expected when working memory load was high. Specifically, during this condition there should be reduced cognitive control to maintain task priorities and prevent perceptual processing of irrelevant information. The current results were consistent with the assumptions of the cognitive load theory (Lavie et al). There was an interaction between working memory load and the level of distractor interference during the selective attention task. Firstly, reaction times to the target letter in the attention task were slower when working memory load was high. Secondly, there was greater distractor interference to target processing during the attention task when working memory load was high.

The manipulation of working memory in Experiment 2B was expected to disambiguate between two possible working memory mechanisms as highlighted in section 1.6. of the introduction. Models of working memory suggest that only a finite amount of information can be maintained simultaneously (Luck & Vogel, 1997; Sperling, 1960). Thus, efficient cognitive processing depends on the ability to select among relevant and irrelevant information and to allocate processing resources accordingly (Hay et al., 2006). During a visual selective attention task, the storage of an internal representation of relevant information may assist with accurate response selection. Indeed, Awh and colleagues (2006) suggested that there may be an interaction between working memory and top-down attentional control such that capacity limits in working memory are assisted by goal-driven selection before visual information is perceived. Consequently, when attentional resources are at capacity, such as when working memory load is high, only a select number of relevant items may be held in the internal attentional template (Desimone & Duncan, 1995; Watson & Humphreys, 1997). This could explain the nature of distractor interference during the visual attention task when working memory load was high in the current experiment.

In Experiment 2B of this thesis, when working memory load was high, reaction times to the target letter during the visual selective attention task were faster when either a congruent or an incongruent distractor was presented compared with a neutral distractor. These results suggest that currently relevant information directed attention and subsequent encoding of information towards those items (Desimone & Duncan, 1995; Szabo et al., 2004). In addition, participants may have created a memory representation for both target letters which assisted response selection when either congruent or incongruent distractor letters were presented. This representation may have been further strengthened because both target letters were mapped onto two different response buttons during this experiment. In contrast, the neutral distractor never acted as a target and therefore participants may not have created an internal template for that item. Consequently, the presence of the neutral distractor may have interfered with response selection because it did not match the mental representations created for the target letters. Furthermore, it is possible that when working memory load was high, cognitive control resources were fully utilized and therefore the processing system relied more heavily on the internal template of the target letters to ensure efficient selective attention. These factors may have contributed to the slower reaction times when neutral distractors were presented with the targets.

The pattern of distractor interference during the visual selective attention task in the low working memory load condition was opposite to that observed in the high working memory load condition. In particular, reaction times to the target were faster when a neutral distractor appeared compared with a congruent or incongruent distractor. Both the congruent and incongruent distractors appeared to have captured attention and produced slower reaction times. It could be argued that when working memory load was low, cognitive resources were not fully exhausted and therefore there was greater distractor interference during the visual attention task. The presence of the congruent distractor may have produced feature-specific interference effects (Bjork & Murray, 1977) while the presence of the incongruent distractor letters elicited the typical response-incongruent interference effects found in such tasks (Lavie, 1995).

The results suggest that working memory load may have modulated distractor processing. When working memory load was low, there may have been capacity for the further creation and storage on the internal attentional template for additional items, such as the neutral distractor. It is possible that when working memory load was low, the presence of the neutral distractor could be suppressed efficiently because there was no mapped response button for it. In this case, the presence of the neutral distractor was actually facilitatory. Indeed, Woodman and Luck (2002) suggested that when a stored item was never the search target, participants may have used the memory item (that is, the neutral distractor) to guide attention away from certain distractors. The current results suggest that objects stored in working memory can produce attentional capture, that is, slower reaction times). However, this effect may have been suppressed when neutral distractors were presented by competitive interactions within working memory (Awh et al., 2006).

4.2.2.2. Distractor Interference in High Perceptual Load Visual Displays when Working Memory Load is Varied

One of the objectives of the current experiment was to test further the claim made by Lavie et al. (2004) that there are two separate mechanisms which reduce or prevent distractor interference during selective attention. During a high perceptual load task, a passive perceptual mechanism is able to prevent distractor interference purely because there is insufficient availability for their processing. An active mechanism of attentional control can prevent irrelevant information from being processed in situations of low perceptual load, even when there are sufficient resources for them to be processed. This form of attentional control requires the activation of higher order functions, such as working memory, to ensure that irrelevant (low priority) information is not processed (Lavie et al). Thus, the extent of distractor interference was investigated using different manipulations of perceptual and working memory loads.

It was hypothesised that when working memory load is low but perceptual load is high, distractor interference should be reduced because working memory would actively maintain current processing priorities to ensure that low-priority stimuli did not gain control of behaviour. Furthermore, it was predicted that when both working memory load and perceptual load are high, distractor interference would increase because of the limited capacity available for active control. Neither of these hypotheses were supported by the current findings. These findings suggested that the abovementioned combinations of working memory and perceptual load did not modulate the effect of congruence on distractor interference; distractor processing remained comparable across the different distractor types. Instead, these findings demonstrate that efficient selective attention may not involve two dissociable mechanisms of control against distractor interference (Lavie et al., 2004).

Recently it was proposed that working memory and visual selective attention tasks may use the same cognitive resources (Awh et al., 2006). In addition, limited working memory resources, as seen during a high working memory load task, may limit the ability to use controlled processing (Tuholski et al., 2001). Controlled processing is required when information in memory must become or remain activated, particularly when irrelevant distractor information competes for attention and needs to be inhibited from perceptual processing; essentially, it involves the processes of activating and maintaining goal or task relevant information (Engle et al., 1999). It is possible that during the abovementioned conditions, distractor information was not attended to, or was inhibited, because of limited working memory resources. Indeed, neuroimaging studies have shown that semantic processing of irrelevant information may be reduced during high working memory load tasks (de Focket et al., 2001). de Fockert and colleagues found that high working memory load in the prefrontal cortex was associated with reduced distractor-related activity in posterior visual cortices. It is possible that in the current study, distractors were never semantically processed given the elimination of congruence in both the high working memory high perceptual load condition and in the low working memory high perceptual load condition.

4.2.2.3. Working Memory Load and Perceptual Load: Evidence for Reduced Distractor Processing

A number of hypotheses were made regarding distractor processing under various combinations of perceptual and cognitive load. In particular, it was predicted that reaction times to targets would be faster when accompanied by congruent versus incongruent distractors. This was predicted for the low perceptual load/low working memory load condition, the low working memory/high perceptual load condition, the high working memory/low perceptual load condition, and the high working memory/high perceptual load condition. In all of these conditions, reaction times were not modulated by congruence; the distractor letters did not produce the facilitation or interference effects previously reported (Experiment 2A; Lavie et al., 2004). These findings instead suggest a generalised interference effect, as demonstrated by the relatively slow reaction times across all conditions.

One of the main objectives of the current experiment was to examine the different operationalizations of working memory. The dual-task design used by Lavie and colleagues (Lavie et al., 2004) examined working memory load by presenting participants with a memory set which consisted of one digit (in the low working memory load condition) or six digits (in the high working memory load condition). This was interleaved with a visual search task and followed by a memory probe display. Participants were required to determine whether the probe digit had appeared in the initial memory set. The crucial difference between their study and the current experiment was the way in which working memory was examined. Lavie and associates used a short-term recognition memory task, such that information had to be maintained over a short delay. It could be argued that while Lavie and colleagues assessed short-term *maintenance* of information, they did not examine how the *manipulation* of information in working memory influenced selective attention. This is an important distinction in defining the mechanisms contributing to interference effects. This issue is expanded upon below.

4.2.2.4. The Operationalization of Working Memory

Working memory has been traditionally defined as both the ability to maintain information across a delay and the ability to manipulate (or reorganize) information (Kerns et al., 2001). In contrast to Lavie and colleagues' (2004) study, the current experiment examined distractor interference during a visual search task which required participants to primarily *maintain* (low working memory load) or primarily *manipulate* (high working memory load) information in working memory. A number of models of cognition (e.g. ACT-R, Anderson, 1993; EPIC, Meyer & Kieras, 1997) have suggested that when higher level cognitive processes are utilised, such as during a high working memory load task, working memory allows a rapidly accessible and easily updated memory system. However, the mechanisms regarding how information in working memory is accessed, updated, and manipulated have yet to be clearly delineated. Previous studies have suggested that these higher-order cognitive processes may rely on different neural substrates from those that merely maintain information in working memory (e.g. D'Esposito et al., 1999; Han & Kim, 2004; Owen et al., 1996).

The current study investigated distractor interference effects in conditions of working memory that required both *maintenance* and *manipulation* of information while performing a concurrent visual attention task. Participants were asked to respond to a target letter while also counting the number of times two underline symbols appeared beneath the target letter in a given block of trials (low working memory load condition) or by adding together the number of lines that appeared beneath the target letter in a block of trials (high working memory load condition). Both working memory load conditions required a number of attention demanding processes, including switching attention from item to item, summing the number of items, and maintaining a running total of the numbers. However, the high working memory load task required information to be constantly manipulated and updated using a more demanding addition task. It is possible that both levels of working memory load in the current experiment engaged a higher level of cognitive control processes compared to Lavie's experiment (Lavie et al., 2004).

The results, however, showed that working memory load *was* effectively manipulated in the current experiment, such that there was a significant difference in response times between the two working memory load conditions. Reaction times in the visual search task were significantly slower when working memory load was high compared to when it was low. Consequently, greater distractor processing (i.e. congruence effects) during the search task was expected (Lavie et al., 2004). Instead, the results demonstrated that distractors were processed in both working memory load conditions. These findings suggest that the cognitive load theory may require some modification in order to explain distractor processing when higher order cognitive processes are enlisted.

Higher order cognitive processes are typically required during working memory tasks in which information needs to be manipulated in some way (Han & Kim, 2004; Oh & Kim, 2004). Consistent with previous findings (Han & Kim; Oh & Kim), the present results suggest that efficient visual search was related to working memory load. Han and Kim used a dual-task paradigm in which participants performed a visual search task while either manipulating or maintaining information in working memory. They found that reaction times in the visual search task were significantly slower when the working memory task required manipulation of information compared to when the visual search task was performed alone; performing a higher-order working memory task impaired search efficiency. In contrast, simple maintenance of verbal information in working memory did not impair visual search. These results demonstrated a difference between simply maintaining information in working memory compared to manipulating information while performing a concurrent visual search task (Han & Kim). Thus, the nature of processing required may determine the extent to which visual attention can remain efficient.

The current results showed that perceptual load was also manipulated effectively in Experiment 2B. Reaction times during the visual search task were slower when perceptual load of the visual display was high compared to when it was low. This was consistent with previous research (Han & Kim, 2004; Lavie et al., 2004; Lavie & Cox, 1997; Lavie, 1995) in which perceptual load was operationalized by visual display set size. Although both working memory load and perceptual load were effectively manipulated, congruence did not play a significant role during the attention task, suggesting that distractors were not semantically processed. Efficient visual attention is expected when perceptual load is high and working memory load is low (Lavie et al). Under these conditions, distractor interference effects have been shown to be lower compared to any other condition (Lavie et al). In contrast, the current results showed that distractor congruence effects were eliminated under all possible combinations of working memory and perceptual load.

The present findings provided very little support for the hypothesis that different conditions of working memory load and perceptual load determine the extent of distractor processing. In addition, there was very little evidence that there are two dissociable mechanisms in visual attention which prevent irrelevant information from interfering with processing of relevant information. Instead, the results suggest that working memory and attention may actually utilise the same capacity resources. It is possible that the impact of congruence on distractor interference was eliminated in the present experiment because these shared resources were fully exhausted. Maintaining information about the targets for the visual search task and information to perform the working memory task eliminated distractor processing.

4.3. General Discussion, Limitations, and Future Directions

The current series of experiments examined the effect of stimulus onset, perceptual load, and working memory demand on distractor interference. In Experiment 1A, perceptual load was effectively manipulated such that reaction times were faster in the low perceptual load condition versus the high perceptual load condition. In the subsequent experiment (1B), distractor interference was examined under high and low perceptual load conditions when distractors were presented 200ms in advance of, or simultaneously with, the target. Unlike Experiment 1A, reaction times were actually slower in the low perceptual load condition compared with the high perceptual load condition. Although the additional demands of the conjunction search task were expected to prevent irrelevant items from consuming capacity, distractor processing occurred in both high and low perceptual load conditions. In contrast to perceptual load theory, these results suggest that the ability to ignore irrelevant information was not directly related to the perceptual load of the visual display. Furthermore, temporally separating the presentation of distractors and targets eliminated the congruence effect, such that reaction times were comparable across distractor types. These findings suggested that the 200ms gap between the distractor and target was sufficient to allow the image of the distractor to be processed and discarded prior to response selection.

In these experiments, perceptual load was manipulated by changing the processing demands for visual displays that were identical in their appearance. Participants were required to process either a colour alone or conjunction of shape and colour in addition to the target item. Surprisingly, faster reaction times were found in the high perceptual load condition compared to the low perceptual load condition. However, it is possible that these results were related to the number of feature and conjunction search conditions that participants completed across both experiments. Indeed, the number and type of searches performed differed significantly from Lavie's (1995) experiment. It is possible that the change in methodology resulted in the divergent findings. This then begs the question: can feature integration theory be used as an appropriate manipulation of perceptual load in a visual attention task? Future research may investigate this further by changing the amount and type of conjunction search conditions participants perform. This would help determine whether processing efficiency during conjunction search increases as individuals become more familiar with identifying task relevant conjunctions in a visual display. Future research interested in feature integration theory as a viable manipulation of perceptual load may examine the processing mechanisms implicit in feature and conjunction search. This could include investigation of the proposal that early selection processes guide a 'spotlight' of attention towards the target prior to the target entering into the slower serial stage of processing (Wolfe et al., 1998). In addition, it may include testing whether the existence of 'conjunction detectors' for specific pairs of features operate at the early stage of attention (Treisman & Sato, 1990).

The temporal separation data showed significant distractor interference both when the target and distractor were presented simultaneously and when the distractor preceded the target by 200ms. In addition, presenting the distractor in advance of the target eliminated the distractor congruence effect across both high and low perceptual load conditions. Based on the perceptual load theory, this result was expected in the high perceptual load condition but not in the low perceptual load condition. It is possible that the current results diverged from previous findings (Kritikos et al., 2008) due to the experimental design employed. Although the perceptual load theory has found support across a number of different attention tasks, including go-no/go and visual search, the same pattern of distractor processing was not found when distractors preceded the targets by 200ms. It could be argued that a go-no/go task may have utilised different mechanisms compared to a visual search task, such as inhibition and suppression of response selection. Indeed Chelazzi and colleagues (1993) suggested that there is a critical period during which distractor processing and inhibition of responses alter the response to the target. It is possible that these inhibitory mechanisms may have interfered with efficient response selection when the distractor and target letters were temporally separated. Future research regarding the time-course of distractor interference could investigate interference effects using a purely visual search task. In addition, the current results suggest that it may be beneficial to both reduce and increase the gap between distractors and targets to further elucidate the time-course of distractor interference under different perceptual load conditions.

The second part of this thesis examined whether distractor interference during a visual attention task was influenced by working memory processes (Duncan & Humphreys, 1989; Luck & Vogel, 1997; Watson & Humphreys, 1997). Specifically, whether changes in working memory load could modulate distractor interference (Lavie et al., 2004). However, one of the main challenges in this field of research is that interpretations of working memory vary. This series of experiments aimed to examine both the traditional view of working memory and Lavie's operationalization of working memory (Lavie et al). Working memory, as it is more generally understood, is said to involve both maintaining and manipulating information over a short delay. In contrast, Lavie used a short-term recognition memory task which required participants to merely maintain information over a short delay. The current experiment found little support for the cognitive load theory of attention when tasks requiring both maintenance and manipulation of information were used. This suggests that the cognitive load theory can only account for one type of working memory, namely the maintenance of information in short-term memory.

It could be argued that the present results did not support the cognitive load theory because the overall demands on cognitive capacity may have been too high across both working memory load conditions. However, working memory load was successfully manipulated, such that reaction times were significantly faster in the low working memory load condition compared to the high working memory condition. Future research may examine distractor interference using another type of working memory task (e.g. Han & Kim, 2004), together with manipulations of perceptual load to examine further the cognitive load theory of selective attention.

The elimination of congruence effects suggested that the irrelevant distractor letter may not have been processed during the visual attention task. One way to test distractor processing under different manipulations of perceptual and working memory loads would be to increase the size of the distractor letter. Making the distractor letter more salient in the visual display may actually produce greater distractor interference (Eliti et al., 2005). Such an experiment would be highly beneficial as it would be able to test both the salience hypothesis and the cognitive load theory of visual attention.

The current research has highlighted how distracting irrelevant information is processed under different levels of perceptual and working memory load. Although this body of work was based on healthy individuals, the information gained could, in future studies, be applied to clinical populations. This would enable us to better understand the mechanisms which are disrupted in syndromes such as anarchic hand, visual neglect, and attentional disorders (Kumanda & Humphreys, 2002; Lavie &Robertson, 2001; Vidyasagar, 2005; Vidyasagar & Pigarev, 2007).

In summary, the present series of experiments have examined various mechanisms believed to be involved in visual selective attention. Specifically, this research demonstrated that perceptual load may not be the only factor that determines the extent of distractor processing. Indeed, distractors can be processed in both high and low perceptual load conditions. Furthermore, presenting distractors in advance of targets eliminated the congruence effect across both high and low perceptual load conditions. This suggested that distractors were processed and discarded prior to response selection irrespective of load. The current study showed that working memory is implicated in visual attention and that distractor interference is modulated by the nature of the working memory task. Finally, the results suggest that working memory and attention may actually utilize the same cognitive resources. The current body of work has extended knowledge of the processes implicated in visual selective attention, the time-course of distractor processing, and the way in which working memory modulates distractor interference.

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Appendix A: Recruitment Notice

Participants Wanted for Research Study

You are invited to participate in a research project of visual selective attention. The aim of this research is to gain a greater understanding of how distracting information can influence the way we respond to events in our environments. The results of these findings will extend knowledge about visual selective attention processes.

Participants are required whose ages range between 18-35 years and who have normal or corrected-to-normal vision. The experiment will require you to complete a computer based visual task and make responses to certain stimuli. It is anticipated that the computer tasks will require about 90 minutes depending on the number of experiments you are willing to complete.

Please feel free to contact me by email or by phone ########## for additional information about participating in this study.

Appendix B: Participant Information and Consent Form

Visual selective attention: the effects of stimulus onset, perceptual load and working memory demand on distractor interference

INFORMATION TO PARTICIPANTS:

You have been invited to be a part of a study on the nature of visual selective attention. The aim of this research is to gain a greater understanding of how distracting information can influence the way we respond to events in our environment. It is anticipated that findings will provide the neuropsychological communities a greater understanding into the role of selective attention processes.

I require participants whose ages range between 18-35 years who have normal or corrected-to-normal vision. The participants will be requested to complete a computer based visual task which will require them to make responses to certain stimuli. It is anticipated that the computer task will require 45-minutes to complete. Participants will be allowed to have short breaks during testing sessions if they are thought to be fatigued by the tasks.

No findings which could identify any individual will be published. The anonymity of your participation will be protected by our procedure in which no names will be attached to any of the data collected; names will be replaced by code numbers. Only my supervisor and I will have access to this data which will be stored for five years as prescribed by the university regulations.

If you agree to participate you may withdraw at any time. If you decide to withdraw during the course of the research you may advise the researcher to cease. If after having completed the experiment you decide you no longer wish to be included in the research you may contact me and all your results will be removed.

Any queries about your participation in this project may be directed to the researchers Eleftheria Kotsopoulos on ######### or Dr. Ada Kritikos on ##########.

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, University Human Research Ethics Committee, Victoria University of Technology, PO Box 14428 MCMC, Melbourne, 8001 (telephone no: 03-9688 4710).

Consent Form for Subjects Involved in Research

CERTIFICATION BY SUBJECT

I,……………………………………………………………………………………………………
.

of
……………………………………………………………………………………………………

……………………………………………………………………………………………………
…

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study entitled:

Temporal separation between distractors and targets: The impact of perceptual and cognitive load on distractor interference

being conducted at Victoria University of Technology by: **Ms Eleftheria Kotsopoulos**

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Ms Eleftheria Kotsopoulos

and that I freely consent to participation involving the use on me of these procedures.

Procedures:

- Use a computer to complete a visual attention task

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.
I have been informed that the information I provide will be kept confidential.

Signature (Participant): **...** **Date: ....**

Witness to Signature: **……………………………………….** **Date: ....**

Signature (Researcher): .... Date: ....

[*please note: where the subject/s is aged under 18, separate parental consent is required; where the subject is unable to answer for themselves due to mental illness or disability, parental or guardian consent may be required.]

Appendix C: Diagram of the Response Control Pad

Thrustmaster Firestorm Digital 3 Gamepad

Arrows indicate response buttons used by participants

Appendix D: Results for Experiment 1A

Appendix D1

Reaction Time data indicating mean reaction times, standard deviations, and t-statistics for Experiment 1A

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Feature Demand LOW Perceptual Load Mean Reaction Time	421.3021	19	55.20979	12.66600
	Conjunction Demand HIGH Perceptual Load Mean Reaction Time	457.9200	19	53.32602	12.23383
Pair 2	Feature Demand LOW Perceptual Load Mean Reaction Time	421.3021	19	55.20979	12.66600
	Target Alone Mean Reaction Time	267.8659	19	91.69116	21.03539
Pair 3	Conjunction Demand HIGH Perceptual Load Mean Reaction Time	457.9200	19	53.32602	12.23383
	Target Alone Mean Reaction Time	267.8659	19	91.69116	21.03539

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Feature Demand LOW Perceptual Load Mean Reaction Time - Conjunction Demand HIGH Perceptual Load Mean Reaction Time	-36.61785	31.34914	7.19199	-51.72765	-21.50805	-5.091	18	.000
Pair 2	Feature Demand LOW Perceptual Load Mean Reaction Time - Target Alone Mean Reaction Time	153.43627	107.69079	24.70596	101.53097	205.34157	6.210	18	.000
Pair 3	Conjunction Demand HIGH Perceptual Load Mean Reaction Time - Target Alone Mean Reaction Time	190.05412	99.07042	22.72831	142.30371	237.80453	8.362	18	.000

Appendix D2

Accuracy data indicating mean number of errors, standard deviations, and t-statistics for Experiment 1A

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Feature Demand LOW Perceptual Load Errors	16.1053	19	8.37917	1.92231
	Conjunction Demand HIGH Perceptual Load Errors	14.1053	19	6.61559	1.51772
Pair 2	Feature Demand LOW Perceptual Load Errors	16.1053	19	8.37917	1.92231
	Target Alone errors	2.9474	19	1.71509	.39347
Pair 3	Conjunction Demand HIGH Perceptual Load Errors	14.1053	19	6.61559	1.51772
	Target Alone errors	2.9474	19	1.71509	.39347

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Feature Demand LOW Perceptual Load Errors - Conjunction Demand HIGH Perceptual Load Errors	2.00000	7.62306	1.74885	-1.67420	5.67420	1.144	18	.268
Pair 2	Feature Demand LOW Perceptual Load Errors - Target Alone errors	13.15789	7.89700	1.81170	9.35166	16.96413	7.263	18	.000
Pair 3	Conjunction Demand HIGH Perceptual Load Errors - Target Alone errors	11.15789	6.66052	1.52803	7.94763	14.36816	7.302	18	.000

Appendix E: Results for Experiment 1B

Appendix E1

Reaction Time data indicating mean reaction times, standard deviations, F-statistics, and within-subjects contrasts for Experiment 1B

Descriptive Statistics

	Mean	Std. Deviation	N
sum of odd and even simultaneous FEATURE congruent RT's	431.0769	64.87198	20
sum of odd and even simultaneous FEATURE incongruent RT's	448.9727	74.39878	20
sum of odd and even simultaneous FEATURE neutral RT's	421.7058	61.84889	20
sum of odd and even simultaneous CONJUNCTION congruent RT's	407.2822	47.04295	20
sum of odd and even simultaneous CONJUNCTION incongruent RT's	426.6134	61.05032	20
sum of odd and even simultaneous CONJUNCTION neutral RT's	409.7839	53.35205	20
sum of odd and even preceeding FEATURE congruent RT's	446.9472	51.95758	20
sum of odd and even preceeding FEATURE incongruent RT'ts	454.7948	46.41122	20
sum of odd and even preceeding FEATURE neutral DI RT's	452.2664	60.23688	20
sum of odd and even preceeding CONJUNCTION congruent DI RT's	414.4894	61.85879	20
sum of odd and even preceeding CONJUNCTION incongruent DI RT's	414.5809	60.91687	20
sum of odd and even preceeding CONJUNCTION neutral DI RT's	411.7167	60.76881	20

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
TemporalSeparation	Sphericity Assumed	4060.772	1	4060.772	.678	.421	.034
	Greenhouse-Geisser	4060.772	1.000	4060.772	.678	.421	.034
	Huynh-Feldt	4060.772	1.000	4060.772	.678	.421	.034
	Lower-bound	4060.772	1.000	4060.772	.678	.421	.034
Error(Temporal Separation)	Sphericity Assumed	113862.591	19	5992.768			
	Greenhouse-Geisser	113862.591	19.000	5992.768			
	Huynh-Feldt	113862.591	19.000	5992.768			
	Lower-bound	113862.591	19.000	5992.768			
PerceptualLoad	Sphericity Assumed	48904.640	1	48904.640	24.470	.000	.563
	Greenhouse-Geisser	48904.640	1.000	48904.640	24.470	.000	.563
	Huynh-Feldt	48904.640	1.000	48904.640	24.470	.000	.563
	Lower-bound	48904.640	1.000	48904.640	24.470	.000	.563
Error(PerceptualLoad)	Sphericity Assumed	37973.085	19	1998.583			
	Greenhouse-Geisser	37973.085	19.000	1998.583			
	Huynh-Feldt	37973.085	19.000	1998.583			
	Lower-bound	37973.085	19.000	1998.583			
Congruence	Sphericity Assumed	7513.071	2	3756.536	15.692	.000	.452
	Greenhouse-Geisser	7513.071	1.630	4608.864	15.692	.000	.452
	Huynh-Feldt	7513.071	1.762	4264.363	15.692	.000	.452
	Lower-bound	7513.071	1.000	7513.071	15.692	.001	.452
Error(Congruence)	Sphericity Assumed	9096.924	38	239.393			
	Greenhouse-Geisser	9096.924	30.973	293.709			
	Huynh-Feldt	9096.924	33.475	271.755			
	Lower-bound	9096.924	19.000	478.785			
TemporalSeparation * PerceptualLoad	Sphericity Assumed	5068.385	1	5068.385	5.212	.034	.215
	Greenhouse-Geisser	5068.385	1.000	5068.385	5.212	.034	.215
	Huynh-Feldt	5068.385	1.000	5068.385	5.212	.034	.215
	Lower-bound	5068.385	1.000	5068.385	5.212	.034	.215
Error(Temporal Separation*Perceptual Load)	Sphericity Assumed	18476.932	19	972.470			
	Greenhouse-Geisser	18476.932	19.000	972.470			
	Huynh-Feldt	18476.932	19.000	972.470			
	Lower-bound	18476.932	19.000	972.470			
TemporalSeparation * Congruence	Sphericity Assumed	4074.007	2	2037.004	7.003	.003	.269
	Greenhouse-Geisser	4074.007	1.666	2445.822	7.003	.005	.269
	Huynh-Feldt	4074.007	1.806	2255.223	7.003	.004	.269
	Lower-bound	4074.007	1.000	4074.007	7.003	.016	.269
Error(Temporal Separation*Congruence)	Sphericity Assumed	11053.718	38	290.887			
	Greenhouse-Geisser	11053.718	31.648	349.267			
	Huynh-Feldt	11053.718	34.323	322.049			
	Lower-bound	11053.718	19.000	581.775			
PerceptualLoad * Congruence	Sphericity Assumed	260.485	2	130.243	.489	.617	.025
	Greenhouse-Geisser	260.485	1.949	133.618	.489	.612	.025
	Huynh-Feldt	260.485	2.000	130.243	.489	.617	.025
	Lower-bound	260.485	1.000	260.485	.489	.493	.025
Error(PerceptualLoad* Congruence)	Sphericity Assumed	10121.769	38	266.362			
	Greenhouse-Geisser	10121.769	37.040	273.265			
	Huynh-Feldt	10121.769	38.000	266.362			
	Lower-bound	10121.769	19.000	532.725			
TemporalSeparation * PerceptualLoad * Congruence	Sphericity Assumed	998.555	2	499.278	1.381	.264	.068
	Greenhouse-Geisser	998.555	1.939	514.872	1.381	.264	.068
	Huynh-Feldt	998.555	2.000	499.278	1.381	.264	.068
	Lower-bound	998.555	1.000	998.555	1.381	.254	.068
Error(Temporal Separation*Perceptual Load*Congruence)	Sphericity Assumed	13736.738	38	361.493			
	Greenhouse-Geisser	13736.738	36.849	372.784			
	Huynh-Feldt	13736.738	38.000	361.493			
	Lower-bound	13736.738	19.000	722.986			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TemporalSeparation	PerceptualLoad	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
TemporalSeparation	Level 1 vs. Level 2		1353.591	1	1353.591	.678	.421	.034
Error(Temporal	Level 1 vs. Level 2		37954.197	19	1997.589			
PerceptualLoad		Level 1 vs. Level 2	16301.547	1	16301.547	24.470	.000	.563
Error(PerceptualLoad)		Level 1 vs. Level 2	12657.695	19	666.194			
Congruence			2549.977	1	2549.977	15.519	.001	.450
			3061.466	1	3061.466	23.894	.000	.557
Error(Congruence)			3121.961	19	164.314			
			2434.448	19	128.129			
TemporalSeparation *	Level 1 vs. Level 2	Level 1 vs. Level 2	6757.847	1	6757.847	5.212	.034	.215
Error(Temporal	Level 1 vs. Level 2	Level 1 vs. Level 2	24635.910	19	1296.627			
TemporalSeparation * Congruence	Level 1 vs. Level 2		4288.882	1	4288.882	6.822	.017	.264
			7489.853	1	7489.853	9.598	.006	.336
Error(Temporal Separation*Congruence)	Level 1 vs. Level 2		11944.289	19	628.647			
			14827.041	19	780.371			
PerceptualLoad * Congruence		Level 1 vs. Level 2	199.760	1	199.760	.337	.568	.017
			510.220	1	510.220	1.134	.300	.056
Error(PerceptualLoad* Congruence)		Level 1 vs. Level 2	11267.950	19	593.050			
			8545.783	19	449.778			
TemporalSeparation * PerceptualLoad *	Level 1 vs. Level 2	Level 1 vs. Level 2	1689.645	1	1689.645	.624	.439	.032
			2321.258	1	2321.258	.683	.419	.035
Error(Temporal Separation*Perceptual	Level 1 vs. Level 2	Level 1 vs. Level 2	51479.544	19	2709.450			
			64535.966	19	3396.630			

Appendix E2

Reaction Time data indicating t-statistics for pairwise comparisons

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	MEAN RT for Simultaneous Feature CIN DI total	433.9185	20	64.69299	14.46579
	MEAN RT for Simultaneous Conjunction CIN DI total	414.5598	20	52.59928	11.76156
Pair 2	MEAN RT Preceding Feature CIN DI total	451.3361	20	51.25018	11.45989
	MEAN RT Preceding Conjunction CIN DI total	413.5957	20	60.59742	13.55000
Pair 3	MEAN RT for Simultaneous Feature CIN DI total	433.9185	20	64.69299	14.46579
	MEAN RT Preceding Feature CIN DI total	451.3361	20	51.25018	11.45989
Pair 4	MEAN RT for Simultaneous Conjunction CIN DI total	414.5598	20	52.59928	11.76156
	MEAN RT Preceding Conjunction CIN DI total	413.5957	20	60.59742	13.55000
Pair 5	MEAN RT Simultaneous Congruent DI Total across PL	419.1795	20	53.00006	11.85117
	MEAN RT Simultaneous Incongruent DI total across PL	437.7930	20	61.97823	13.85875
Pair 6	MEAN RT Simultaneous Congruent DI Total across PL	419.1795	20	53.00006	11.85117
	MEAN RT Simultaneous Neutral DI total across PL	415.7448	20	54.22510	12.12510
Pair 7	MEAN RT Simultaneous Incongruent DI total across PL	437.7930	20	61.97823	13.85875
	MEAN RT Simultaneous Neutral DI total across PL	415.7448	20	54.22510	12.12510
Pair 8	MEAN RT Preceding Congruent DI total across PL	430.7183	20	55.59417	12.43124
	MEAN RT Preceding Incongruent DI across PL	434.6879	20	52.49601	11.73846
Pair 9	MEAN RT Preceding Congruent DI total across PL	430.7183	20	55.59417	12.43124
	MEAN RT Preceding Neutral DI across PL	431.9915	20	59.01935	13.19713
Pair 10	MEAN RT Preceding Incongruent DI across PL	434.6879	20	52.49601	11.73846
	MEAN RT Preceding Neutral DI across PL	431.9915	20	59.01935	13.19713
Pair 11	MEAN RT Simultaneous Congruent DI Total across PL	419.1795	20	53.00006	11.85117
	MEAN RT Preceding Congruent DI total across PL	430.7183	20	55.59417	12.43124
Pair 12	MEAN RT Simultaneous Incongruent DI total across PL	437.7930	20	61.97823	13.85875
	MEAN RT Preceding Incongruent DI across PL	434.6879	20	52.49601	11.73846
Pair 13	MEAN RT Simultaneous Neutral DI total across PL	415.7448	20	54.22510	12.12510
	MEAN RT Preceding Neutral DI across PL	431.9915	20	59.01935	13.19713

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	MEAN RT for Simultaneous Feature CIN DI total - MEAN RT for Simultaneous Conjunction CIN DI total	19.35864	38.95019	8.70953	1.12938	37.58789	2.223	19	.039
Pair 2	MEAN RT Preceding Feature CIN DI total - MEAN RT Preceding Conjunction CIN DI total	37.74048	21.53102	4.81448	27.66366	47.81731	7.839	19	.000
Pair 3	MEAN RT for Simultaneous Feature CIN DI total - MEAN RT Preceding Feature CIN DI total	-17.41768	52.69206	11.78230	-42.07832	7.24296	-1.478	19	.156
Pair 4	MEAN RT for Simultaneous Conjunction CIN DI total - MEAN RT Preceding Conjunction CIN DI total	.96417	43.20925	9.66188	-19.25838	21.18672	.100	19	.922
Pair 5	MEAN RT Simultaneous Congruent DI Total across PL - MEAN RT Simultaneous Incongruent DI total across PL	-18.61349	17.73161	3.96491	-26.91214	-10.31484	-4.695	19	.000
Pair 6	MEAN RT Simultaneous Congruent DI Total across PL - MEAN RT Simultaneous Neutral DI total across PL	3.43469	12.59706	2.81679	-2.46091	9.33030	1.219	19	.238
Pair 7	MEAN RT Simultaneous Incongruent DI total across PL - MEAN RT Simultaneous Neutral DI total across PL	22.04819	20.71296	4.63156	12.35422	31.74215	4.760	19	.000
Pair 8	MEAN RT Preceding Congruent DI total across PL - MEAN RT Preceding Incongruent DI across PL	-3.96958	18.12570	4.05303	-12.45267	4.51350	-.979	19	.340
Pair 9	MEAN RT Preceding Congruent DI total across PL - MEAN RT Preceding Neutral DI across PL	-1.27321	11.94824	2.67171	-6.86516	4.31874	-.477	19	.639
Pair 10	MEAN RT Preceding Incongruent DI across PL - MEAN RT Preceding Neutral DI across PL	2.69637	14.74505	3.29709	-4.20452	9.59727	.818	19	.424
Pair 11	MEAN RT Simultaneous Congruent DI Total across PL - MEAN RT Preceding Congruent DI total across PL	-11.53876	47.10055	10.53200	-33.58249	10.50498	-1.096	19	.287
Pair 12	MEAN RT Simultaneous Incongruent DI total across PL - MEAN RT Preceding Incongruent DI across PL	3.10515	44.90748	10.04162	-17.91220	24.12250	.309	19	.761
Pair 13	MEAN RT Simultaneous Neutral DI total across PL - MEAN RT Preceding Neutral DI across PL	-16.24666	48.36733	10.81526	-38.88327	6.38995	-1.502	19	.149

Appendix E3

Accuracy data indicating mean number of errors, standard deviations, F-statistics, and within subjects contrasts for Experiment 1B

Descriptive Statistics

	Mean	Std. Deviation	N
sum of odd and even simultaneous FEATURE congruent errors	2.1500	2.94288	20
sum of odd and even simultaneous FEATURE incongruent errors	2.7500	3.72580	20
sum of odd and even simultaneous FEATURE neutral errors	1.9000	3.05907	20
sum of odd and even simultaneous CONJUNCTION congruent errors	1.5000	2.35081	20
sum of odd and even sumultaneous CONJUNCTION Incongruent errors	2.2000	3.80581	20
sum of odd and even simultaneous CONJUNCTION neutral errors	1.9000	3.95900	20
sum of odd and even preceding FEATURE Congruent Errors	1.8000	2.68720	20
sum of odd and even preceding Feature Incongruent errors	2.2000	2.83957	20
sum of odd and even preceding FeatureNeutral errors	2.0000	3.09499	20
sum of odd and even preceding conjunction congruent errors	2.0500	3.84537	20
sum of odd and even preceding conjunctionIncongruent errors	1.9500	3.89973	20
sum of odd and even preceding Conjunction Neutral errors	2.2000	4.06008	20

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
simpre	Sphericity Assumed	.067	1	.067	.010	.920	.010	.051
	Greenhouse-Geisser	.067	1.000	.067	.010	.920	.010	.051
	Huynh-Feldt	.067	1.000	.067	.010	.920	.010	.051
	Lower-bound	.067	1.000	.067	.010	.920	.010	.051
Error(simpre)	Sphericity Assumed	121.100	19	6.374				
	Greenhouse-Geisser	121.100	19.000	6.374				
	Huynh-Feldt	121.100	19.000	6.374				
	Lower-bound	121.100	19.000	6.374				
perceptload	Sphericity Assumed	1.667	1	1.667	.266	.612	.266	.078
	Greenhouse-Geisser	1.667	1.000	1.667	.266	.612	.266	.078
	Huynh-Feldt	1.667	1.000	1.667	.266	.612	.266	.078
	Lower-bound	1.667	1.000	1.667	.266	.612	.266	.078
Error(perceptload)	Sphericity Assumed	118.833	19	6.254				
	Greenhouse-Geisser	118.833	19.000	6.254				
	Huynh-Feldt	118.833	19.000	6.254				
	Lower-bound	118.833	19.000	6.254				
disttype	Sphericity Assumed	6.700	2	3.350	1.901	.163	3.802	.370
	Greenhouse-Geisser	6.700	1.528	4.384	1.901	.175	2.905	.320
	Huynh-Feldt	6.700	1.635	4.098	1.901	.172	3.108	.332
	Lower-bound	6.700	1.000	6.700	1.901	.184	1.901	.258
Error(disttype)	Sphericity Assumed	66.967	38	1.762				
	Greenhouse-Geisser	66.967	29.037	2.306				
	Huynh-Feldt	66.967	31.064	2.156				
	Lower-bound	66.967	19.000	3.525				
simpre * perceptload	Sphericity Assumed	3.267	1	3.267	.421	.524	.421	.095
	Greenhouse-Geisser	3.267	1.000	3.267	.421	.524	.421	.095
	Huynh-Feldt	3.267	1.000	3.267	.421	.524	.421	.095
	Lower-bound	3.267	1.000	3.267	.421	.524	.421	.095
Error(simpre*perceptload)	Sphericity Assumed	147.567	19	7.767				
	Greenhouse-Geisser	147.567	19.000	7.767				
	Huynh-Feldt	147.567	19.000	7.767				
	Lower-bound	147.567	19.000	7.767				
simpre * disttype	Sphericity Assumed	4.133	2	2.067	2.111	.135	4.222	.406
	Greenhouse-Geisser	4.133	1.811	2.283	2.111	.141	3.823	.384
	Huynh-Feldt	4.133	1.991	2.076	2.111	.135	4.202	.405
	Lower-bound	4.133	1.000	4.133	2.111	.163	2.111	.281
Error(simpre*disttype)	Sphericity Assumed	37.200	38	.979				
	Greenhouse-Geisser	37.200	34.406	1.081				
	Huynh-Feldt	37.200	37.821	.984				
	Lower-bound	37.200	19.000	1.958				
perceptload * disttype	Sphericity Assumed	2.533	2	1.267	1.752	.187	3.505	.344
	Greenhouse-Geisser	2.533	1.816	1.395	1.752	.191	3.182	.327
	Huynh-Feldt	2.533	1.997	1.269	1.752	.187	3.500	.344
	Lower-bound	2.533	1.000	2.533	1.752	.201	1.752	.242
Error(perceptload*disttype)	Sphericity Assumed	27.467	38	.723				
	Greenhouse-Geisser	27.467	34.502	.796				
	Huynh-Feldt	27.467	37.945	.724				
	Lower-bound	27.467	19.000	1.446				
simpre * perceptload * disttype	Sphericity Assumed	1.433	2	.717	1.124	.336	2.248	.233
	Greenhouse-Geisser	1.433	1.716	.836	1.124	.330	1.928	.217
	Huynh-Feldt	1.433	1.869	.767	1.124	.333	2.101	.225
	Lower-bound	1.433	1.000	1.433	1.124	.302	1.124	.172
Error(simpre*perceptload*disttype)	Sphericity Assumed	24.233	38	.638				
	Greenhouse-Geisser	24.233	32.595	.743				
	Huynh-Feldt	24.233	35.517	.682				
	Lower-bound	24.233	19.000	1.275				

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	simpre	perceptload	disttype	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
simpre	Level 1 vs. Level 2			.022	1	.022	.010	.920	.010	.051
Error(simpre)	Level 1 vs. Level 2			40.367	19	2.125				
perceptload		Level 1 vs. Level 2		.556	1	.556	.266	.612	.266	.078
Error(perceptload)		Level 1 vs. Level 2		39.611	19	2.085				
disttype			Level 1 vs. Level 3	.313	1	.313	.247	.625	.247	.076
			Level 2 vs. Level 3	1.513	1	1.513	3.542	.075	3.542	.431
Error(disttype)			Level 1 vs. Level 3	24.063	19	1.266				
			Level 2 vs. Level 3	8.113	19	.427				
simpre * perceptload	Level 1 vs. Level 2	Level 1 vs. Level 2		4.356	1	4.356	.421	.524	.421	.095
Error(simpre*perceptl	Level 1 vs. Level 2	Level 1 vs. Level 2		196.756	19	10.356				
simpre * disttype	Level 1 vs. Level 2		Level 1 vs. Level 3	.200	1	.200	.114	.739	.114	.062
			Level 2 vs. Level 3	7.200	1	7.200	4.669	.044	4.669	.536
Error(simpre*disttype)	Level 1 vs. Level 2		Level 1 vs. Level 3	33.300	19	1.753				
			Level 2 vs. Level 3	29.300	19	1.542				
perceptload * disttype		Level 1 vs. Level 2	Level 1 vs. Level 3	1.800	1	1.800	1.507	.235	1.507	.214
			Level 2 vs. Level 3	5.000	1	5.000	4.043	.059	4.043	.480
Error(perceptload*dist type)		Level 1 vs. Level 2	Level 1 vs. Level 3	22.700	19	1.195				
			Level 2 vs. Level 3	23.500	19	1.237				
simpre * perceptload * disttype	Level 1 vs. Level 2	Level 1 vs. Level 2	Level 1 vs. Level 3	9.800	1	9.800	1.367	.257	1.367	.199
			Level 2 vs. Level 3	.200	1	.200	.051	.823	.051	.055
Error(simpre*perceptl oad*disttype)	Level 1 vs. Level 2	Level 1 vs. Level 2	Level 1 vs. Level 3	136.200	19	7.168				
			Level 2 vs. Level 3	73.800	19	3.884				

a. Computed using alpha = .05

Appendix F: Results for Experiment 2A

Appendix F1

Reaction Time data indicating mean reaction times, standard deviations, F-statistics, and within-subjects contrasts for Experiment 2A

Descriptive Statistics

	Mean	Std. Deviation	N
HLCRT	922.4255	139.11676	20
HLIRT	911.8273	119.26227	20
HLNRT	928.0626	147.70853	20
LLCRT	673.0461	119.25859	20
LLIRT	732.6899	113.46433	20
LLNRT	688.2354	111.76258	20

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
PerceptualLoad	Sphericity Assumed	1488945.928	1	1488945.928	101.473	.000	.842
	Greenhouse-Geisser	1488945.928	1.000	1488945.928	101.473	.000	.842
	Huynh-Feldt	1488945.928	1.000	1488945.928	101.473	.000	.842
	Lower-bound	1488945.928	1.000	1488945.928	101.473	.000	.842
Error(PerceptualLoad)	Sphericity Assumed	278793.256	19	14673.329			
	Greenhouse-Geisser	278793.256	19.000	14673.329			
	Huynh-Feldt	278793.256	19.000	14673.329			
	Lower-bound	278793.256	19.000	14673.329			
Congruence	Sphericity Assumed	12118.449	2	6059.225	5.453	.008	.223
	Greenhouse-Geisser	12118.449	1.782	6798.779	5.453	.011	.223
	Huynh-Feldt	12118.449	1.954	6200.800	5.453	.009	.223
	Lower-bound	12118.449	1.000	12118.449	5.453	.031	.223
Error(Congruence)	Sphericity Assumed	42223.484	38	1111.144			
	Greenhouse-Geisser	42223.484	33.866	1246.764			
	Huynh-Feldt	42223.484	37.132	1137.106			
	Lower-bound	42223.484	19.000	2222.289			
PerceptualLoad * Congruence	Sphericity Assumed	29028.098	2	14514.049	8.876	.001	.318
	Greenhouse-Geisser	29028.098	1.887	15387.028	8.876	.001	.318
	Huynh-Feldt	29028.098	2.000	14514.049	8.876	.001	.318
	Lower-bound	29028.098	1.000	29028.098	8.876	.008	.318
Error(PerceptualLoad* Congruence)	Sphericity Assumed	62136.015	38	1635.158			
	Greenhouse-Geisser	62136.015	35.844	1733.508			
	Huynh-Feldt	62136.015	38.000	1635.158			
	Lower-bound	62136.015	19.000	3270.317			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	PerceptualLoad	Congruence	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
PerceptualLoad	Level 1 vs. Level 2		992630.619	1	992630.619	101.473	.000	.842
Error(PerceptualLoad)	Level 1 vs. Level 2		185862.171	19	9782.220			
Congruence		Level 1 vs. Level 2	12027.357	1	12027.357	9.117	.007	.324
		Level 2 vs. Level 3	3981.635	1	3981.635	3.084	.095	.140
Error(Congruence)		Level 1 vs. Level 2	25065.216	19	1319.222			
		Level 2 vs. Level 3	24527.386	19	1290.915			
PerceptualLoad * Congruence	Level 1 vs. Level 2	Level 1 vs. Level 2	98678.672	1	98678.672	17.491	.001	.479
		Level 2 vs. Level 3	73665.036	1	73665.036	9.049	.007	.323
Error(PerceptualLoad* Congruence)	Level 1 vs. Level 2	Level 1 vs. Level 2	107189.837	19	5641.570			
		Level 2 vs. Level 3	154672.054	19	8140.634			

Appendix F2

Reaction Time data indicating mean reaction times, standard deviations and t-statistics for pairwise comparisons

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	High Perceptual Load Congruent Mean Reaction Time	922.4255	20	139.11676	31.10745
	High Perceptual Load Incongruent Mean Reaction Time	911.8273	20	119.26227	26.66786
Pair 2	High Perceptual Load Congruent Mean Reaction Time	922.4255	20	139.11676	31.10745
	High Perceptual Load Neutral Mean Reaction Time	928.0626	20	147.70853	33.02863
Pair 3	High Perceptual Load Incongruent Mean Reaction Time	911.8273	20	119.26227	26.66786
	High Perceptual Load Neutral Mean Reaction Time	928.0626	20	147.70853	33.02863
Pair 4	Low Perceptual Load Congruent Mean Reaction Time	673.0461	20	119.25859	26.66703
	Low Perceptual Load Incongruent Mean Reaction Time	732.6899	20	113.46433	25.37139
Pair 5	Low Perceptual Load Congruent Mean Reaction Time	673.0461	20	119.25859	26.66703
	Low Perceptual Load Neutral Mean Reaction Time	688.2354	20	111.76258	24.99087
Pair 6	Low Perceptual Load Incongruent Mean Reaction Time	732.6899	20	113.46433	25.37139
	Low Perceptual Load Neutral Mean Reaction Time	688.2354	20	111.76258	24.99087
Pair 7	High Perceptual Load Congruent Mean Reaction Time	922.4255	20	139.11676	31.10745
	Low Perceptual Load Congruent Mean Reaction Time	673.0461	20	119.25859	26.66703
Pair 8	High Perceptual Load Incongruent Mean Reaction Time	911.8273	20	119.26227	26.66786
	Low Perceptual Load Incongruent Mean Reaction Time	732.6899	20	113.46433	25.37139
Pair 9	High Perceptual Load Neutral Mean Reaction Time	928.0626	20	147.70853	33.02863
	Low Perceptual Load Neutral Mean Reaction Time	688.2354	20	111.76258	24.99087

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	High Perceptual Load Congruent Mean Reaction Time - High Perceptual Load Incongruent Mean Reaction Time	10.59818	65.68808	14.68830	-20.14479	41.34115	.722	19	.479
Pair 2	High Perceptual Load Congruent Mean Reaction Time - High Perceptual Load Neutral Mean Reaction Time	-5.63709	55.71127	12.45742	-31.71076	20.43659	-.453	19	.656
Pair 3	High Perceptual Load Incongruent Mean Reaction Time - High Perceptual Load Neutral Mean Reaction Time	-16.23527	68.95963	15.41984	-48.50937	16.03883	-1.053	19	.306
Pair 4	Low Perceptual Load Congruent Mean Reaction Time - Low Perceptual Load Incongruent Mean Reaction Time	-59.64379	33.82757	7.56407	-75.47558	-43.81199	-7.885	19	.000
Pair 5	Low Perceptual Load Congruent Mean Reaction Time - Low Perceptual Load Neutral Mean Reaction Time	-15.18925	35.53440	7.94573	-31.81986	1.44136	-1.912	19	.071
Pair 6	Low Perceptual Load Incongruent Mean Reaction Time - Low Perceptual Load Neutral Mean Reaction Time	44.45453	43.55131	9.73837	24.07189	64.83717	4.565	19	.000
Pair 7	High Perceptual Load Congruent Mean Reaction Time - Low Perceptual Load Congruent Mean Reaction Time	249.37940	101.77652	22.75792	201.74652	297.01227	10.958	19	.000
Pair 8	High Perceptual Load Incongruent Mean Reaction Time - Low Perceptual Load Incongruent Mean Reaction Time	179.13743	98.41658	22.00662	133.07705	225.19781	8.140	19	.000
Pair 9	High Perceptual Load Neutral Mean Reaction Time - Low Perceptual Load Neutral Mean Reaction Time	239.82723	125.86901	28.14517	180.91872	298.73574	8.521	19	.000

Appendix F3

Accuracy data indicating mean number of errors, standard deviations, F-statistics, and within subjects contrasts for Experiment 2A

Descriptive Statistics

	Mean	Std. Deviation	N
HLCERR	4.5500	3.95335	20
HLIERR	4.5000	3.99342	20
HLNERR	4.5000	2.70477	20
LLCERR	2.6500	2.81490	20
LLIERR	5.0000	3.14559	20
LLNERR	4.4500	2.96426	20

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
PerceptualLoad	Sphericity Assumed	7.008	1	7.008	.998	.330	.050
	Greenhouse-Geisser	7.008	1.000	7.008	.998	.330	.050
	Huynh-Feldt	7.008	1.000	7.008	.998	.330	.050
	Lower-bound	7.008	1.000	7.008	.998	.330	.050
Error(PerceptualLoad)	Sphericity Assumed	133.492	19	7.026			
	Greenhouse-Geisser	133.492	19.000	7.026			
	Huynh-Feldt	133.492	19.000	7.026			
	Lower-bound	133.492	19.000	7.026			
Congruence	Sphericity Assumed	28.850	2	14.425	5.701	.007	.231
	Greenhouse-Geisser	28.850	1.998	14.438	5.701	.007	.231
	Huynh-Feldt	28.850	2.000	14.425	5.701	.007	.231
	Lower-bound	28.850	1.000	28.850	5.701	.028	.231
Error(Congruence)	Sphericity Assumed	96.150	38	2.530			
	Greenhouse-Geisser	96.150	37.967	2.532			
	Huynh-Feldt	96.150	38.000	2.530			
	Lower-bound	96.150	19.000	5.061			
PerceptualLoad * Congruence	Sphericity Assumed	31.617	2	15.808	5.118	.011	.212
	Greenhouse-Geisser	31.617	1.961	16.125	5.118	.011	.212
	Huynh-Feldt	31.617	2.000	15.808	5.118	.011	.212
	Lower-bound	31.617	1.000	31.617	5.118	.036	.212
Error(PerceptualLoad* Congruence)	Sphericity Assumed	117.383	38	3.089			
	Greenhouse-Geisser	117.383	37.254	3.151			
	Huynh-Feldt	117.383	38.000	3.089			
	Lower-bound	117.383	19.000	6.178			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	PerceptualLoad	Congruence	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
PerceptualLoad	Level 1 vs. Level 2		4.672	1	4.672	.998	.330	.050
Error(PerceptualLoad)	Level 1 vs. Level 2		88.994	19	4.684			
Congruence		Level 1 vs. Level 2	26.450	1	26.450	10.681	.004	.360
		Level 2 vs. Level 3	1.512	1	1.512	.602	.447	.031
Error(Congruence)		Level 1 vs. Level 2	47.050	19	2.476			
		Level 2 vs. Level 3	47.738	19	2.513			
PerceptualLoad * Congruence	Level 1 vs. Level 2	Level 1 vs. Level 2	115.200	1	115.200	10.793	.004	.362
		Level 2 vs. Level 3	6.050	1	6.050	.473	.500	.024
Error(PerceptualLoad* Congruence)	Level 1 vs. Level 2	Level 1 vs. Level 2	202.800	19	10.674			
		Level 2 vs. Level 3	242.950	19	12.787			

Appendix F4

Accuracy data indicating mean number or errors, standard deviations, and t-statistics for pairwise comparisons

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	High Perceptual Load Congruent errors	4.5500	20	3.95335	.88400
	High Perceptual Load Incongruent errors	4.5000	20	3.99342	.89295
Pair 2	High Perceptual Load Congruent errors	4.5500	20	3.95335	.88400
	High Perceptual Load Neutral errors	4.5000	20	2.70477	.60481
Pair 3	High Perceptual Load Incongruent errors	4.5000	20	3.99342	.89295
	High Perceptual Load Neutral errors	4.5000	20	2.70477	.60481
Pair 4	Low Perceptual Load Congruent errors	2.6500	20	2.81490	.62943
	Low Perceptual Load Incongruent errors	5.0000	20	3.14559	.70338
Pair 5	Low Perceptual Load Congruent errors	2.6500	20	2.81490	.62943
	Low Perceptual Load Neutral errors	4.4500	20	2.96426	.66283
Pair 6	Low Perceptual Load Incongruent errors	5.0000	20	3.14559	.70338
	Low Perceptual Load Neutral errors	4.4500	20	2.96426	.66283
Pair 7	High Perceptual Load Congruent errors	4.5500	20	3.95335	.88400
	Low Perceptual Load Congruent errors	2.6500	20	2.81490	.62943
Pair 8	High Perceptual Load Incongruent errors	4.5000	20	3.99342	.89295
	Low Perceptual Load Incongruent errors	5.0000	20	3.14559	.70338
Pair 9	High Perceptual Load Neutral errors	4.5000	20	2.70477	.60481
	Low Perceptual Load Neutral errors	4.4500	20	2.96426	.66283

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	High Perceptual Load Congruent errors - High Perceptual Load Incongruent errors	.05000	2.62528	.58703	-1.17867	1.27867	.085	19	.933
Pair 2	High Perceptual Load Congruent errors - High Perceptual Load Neutral errors	.05000	2.50210	.55949	-1.12102	1.22102	.089	19	.930
Pair 3	High Perceptual Load Incongruent errors - High Perceptual Load Neutral errors	.00000	2.63579	.58938	-1.23359	1.23359	.000	19	1.000
Pair 4	Low Perceptual Load Congruent errors - Low Perceptual Load Incongruent errors	-2.35000	1.84320	.41215	-3.21264	-1.48736	-5.702	19	.000
Pair 5	Low Perceptual Load Congruent errors - Low Perceptual Load Neutral errors	-1.80000	2.39737	.53607	-2.92200	-.67800	-3.358	19	.003
Pair 6	Low Perceptual Load Incongruent errors - Low Perceptual Load Neutral errors	.55000	2.11449	.47281	-.43961	1.53961	1.163	19	.259
Pair 7	High Perceptual Load Congruent errors - Low Perceptual Load Congruent errors	1.90000	2.86356	.64031	.55981	3.24019	2.967	19	.008
Pair 8	High Perceptual Load Incongruent errors - Low Perceptual Load Incongruent errors	-.50000	3.10348	.69396	-1.95247	.95247	-.721	19	.480
Pair 9	High Perceptual Load Neutral errors - Low Perceptual Load Neutral errors	.05000	2.92853	.65484	-1.32060	1.42060	.076	19	.940

Appendix G: Results for Experiment 2B

Appendix G1

Reaction Time data indicating mean reaction times, standard deviations, F-statistics, and within-subjects contrasts for Experiment 2B

Within-Subjects Factors

Measure: MEASURE_1

WorkingMemory	PerceptualLoad	Congruence	Dependent Variable
1	1	1	HWMHPLcongRT
		2	HWMHPLincongRT
		3	HWMHPLneutralRT
	2	1	HWMLPLcongruentRT
		2	HWMLPLincongruentRT
		3	HWMLPLneutralRT
2	1	1	LWMHPLcongruentRT
		2	LWMHPLincongruentRT
		3	LWMHPLneutralRT
	2	1	LWMLPLcongruentRT
		2	LWMLPLincongruentRT
		3	LWMLPLneutralRT

Descriptive Statistics

	Mean	Std. Deviation	N
High Working Memory High Perceptual Load Congruent Mean Reaction TImes	1278.7402	270.17663	20
High Working Memory High Perceptual Load Incongruent Reaction Times	1241.1799	260.45413	20
High WOrking Memory High Perceptual Load Neutral Mean Reaction TIme	1288.8516	256.00582	20
High Working Memory Low Perceptual Load Congruent Mean Reaction Time	1101.2671	279.05233	20
High Working Memory Low Perceptual Load Incongruent Mean Reaction Time	1095.3621	281.19465	20
High Working Memory Low Perceptual Load Neutral Mean Reaction Time	1135.5343	286.15081	20
Low Wokring Memory High Perceptual Load Congruent Mean Reaction Time	1146.2617	206.74240	20
Low Working Memory High Perceptual Load Incongruent Mean Reaction Time	1143.6513	184.86876	20
Low Working Memory High Perceptual Load Neutral Mean Reaction Time	1103.3971	192.18344	20
Low Working Memory Low Perceptual Load Congruent Mean Reaction Time	1021.0475	234.08222	20
Low Working Memory Low Perceptual Load Incongruent Mean Reaction Time	1007.4477	256.82366	20
Low Working Memory Low Perceptual Load Neutral Mean Reaction Time	1011.4385	241.44767	20

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
WorkingMemory	Sphericity Assumed	834712.251	1	834712.251	20.440	.000	.518
	Greenhouse-Geisser	834712.251	1.000	834712.251	20.440	.000	.518
	Huynh-Feldt	834712.251	1.000	834712.251	20.440	.000	.518
	Lower-bound	834712.251	1.000	834712.251	20.440	.000	.518
Error(WorkingMemory)	Sphericity Assumed	775892.131	19	40836.428			
	Greenhouse-Geisser	775892.131	19.000	40836.428			
	Huynh-Feldt	775892.131	19.000	40836.428			
	Lower-bound	775892.131	19.000	40836.428			
PerceptualLoad	Sphericity Assumed	1148124.170	1	1148124.170	28.254	.000	.598
	Greenhouse-Geisser	1148124.170	1.000	1148124.170	28.254	.000	.598
	Huynh-Feldt	1148124.170	1.000	1148124.170	28.254	.000	.598
	Lower-bound	1148124.170	1.000	1148124.170	28.254	.000	.598
Error(PerceptualLoad)	Sphericity Assumed	772088.555	19	40636.240			
	Greenhouse-Geisser	772088.555	19.000	40636.240			
	Huynh-Feldt	772088.555	19.000	40636.240			
	Lower-bound	772088.555	19.000	40636.240			
Congruence	Sphericity Assumed	10478.753	2	5239.376	1.958	.155	.093
	Greenhouse-Geisser	10478.753	1.668	6282.739	1.958	.164	.093
	Huynh-Feldt	10478.753	1.809	5791.931	1.958	.160	.093
	Lower-bound	10478.753	1.000	10478.753	1.958	.178	.093
Error(Congruence)	Sphericity Assumed	101684.925	38	2675.919			
	Greenhouse-Geisser	101684.925	31.689	3208.798			
	Huynh-Feldt	101684.925	34.375	2958.127			
	Lower-bound	101684.925	19.000	5351.838			
WorkingMemory * PerceptualLoad	Sphericity Assumed	25310.155	1	25310.155	4.235	.054	.182
	Greenhouse-Geisser	25310.155	1.000	25310.155	4.235	.054	.182
	Huynh-Feldt	25310.155	1.000	25310.155	4.235	.054	.182
	Lower-bound	25310.155	1.000	25310.155	4.235	.054	.182
Error(WorkingMemory* PerceptualLoad)	Sphericity Assumed	113552.337	19	5976.439			
	Greenhouse-Geisser	113552.337	19.000	5976.439			
	Huynh-Feldt	113552.337	19.000	5976.439			
	Lower-bound	113552.337	19.000	5976.439			
WorkingMemory * Congruence	Sphericity Assumed	42542.966	2	21271.483	4.531	.017	.193
	Greenhouse-Geisser	42542.966	1.585	26840.715	4.531	.026	.193
	Huynh-Feldt	42542.966	1.705	24945.355	4.531	.023	.193
	Lower-bound	42542.966	1.000	42542.966	4.531	.047	.193
Error(WorkingMemory* Congruence)	Sphericity Assumed	178393.779	38	4694.573			
	Greenhouse-Geisser	178393.779	30.115	5923.691			
	Huynh-Feldt	178393.779	32.403	5505.389			
	Lower-bound	178393.779	19.000	9389.146			
PerceptualLoad * Congruence	Sphericity Assumed	8455.609	2	4227.805	1.197	.313	.059
	Greenhouse-Geisser	8455.609	1.962	4309.388	1.197	.313	.059
	Huynh-Feldt	8455.609	2.000	4227.805	1.197	.313	.059
	Lower-bound	8455.609	1.000	8455.609	1.197	.288	.059
Error(PerceptualLoad* Congruence)	Sphericity Assumed	134173.459	38	3530.881			
	Greenhouse-Geisser	134173.459	37.281	3599.016			
	Huynh-Feldt	134173.459	38.000	3530.881			
	Lower-bound	134173.459	19.000	7061.761			
WorkingMemory * PerceptualLoad * Congruence	Sphericity Assumed	7631.415	2	3815.708	.886	.421	.045
	Greenhouse-Geisser	7631.415	1.761	4332.861	.886	.410	.045
	Huynh-Feldt	7631.415	1.927	3959.451	.886	.417	.045
	Lower-bound	7631.415	1.000	7631.415	.886	.358	.045
Error(WorkingMemory* PerceptualLoad* Congruence)	Sphericity Assumed	163634.310	38	4306.166			
	Greenhouse-Geisser	163634.310	33.464	4889.793			
	Huynh-Feldt	163634.310	36.620	4468.386			
	Lower-bound	163634.310	19.000	8612.332			

Estimates

Measure: MEASURE_1

WorkingMemory	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1190.156	58.008	1068.745	1311.567
2	1072.207	46.304	975.293	1169.122

Estimates

Measure: MEASURE_1

PerceptualLoad	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1200.347	49.092	1097.595	1303.099
2	1062.016	55.652	945.535	1178.498

Appendix G2

Reaction Time data indicating mean reaction times, standard deviations and t-statistics for pairwise comparisons

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	MEAN RT for CIN in High Working Memory and High Perceptual Load	1269.5906	20	258.03723	57.69888
	MEAN RT for CIN di for High Working Memory and Low Perceptual Load	1110.7212	20	273.98068	61.26394
Pair 2	MEAN RT for CIN di Low Working Memory Load and HIgh Perceptual Load	1131.1034	20	190.63366	42.62698
	MEAN RT for CIN di for Low Working Memory Low Perceptual Load	1013.3112	20	240.63274	53.80712
Pair 3	MEAN RT for CIN in High Working Memory and High Perceptual Load	1269.5906	20	258.03723	57.69888
	MEAN RT for CIN di Low Working Memory Load and HIgh Perceptual Load	1131.1034	20	190.63366	42.62698
Pair 4	MEAN RT for CIN di for High Working Memory and Low Perceptual Load	1110.7212	20	273.98068	61.26394
	MEAN RT for CIN di for Low Working Memory Low Perceptual Load	1013.3112	20	240.63274	53.80712
Pair 5	MEAN RT High Working Memory + high and low perceptual load CONGRUENT di	1190.0037	20	268.37042	60.00945
	MEAN RT High Working Memory + high and low Perceptual load INCONGRUENT di	1168.2710	20	258.36821	57.77289
Pair 6	MEAN RT High Working Memory + high and low perceptual load CONGRUENT di	1190.0037	20	268.37042	60.00945
	MEAN RT High Working Memory + high and low Perceptual Load NEUTRAL di	1212.1930	20	260.52141	58.25436
Pair 7	MEAN RT High Working Memory + high and low Perceptual load INCONGRUENT di	1168.2710	20	258.36821	57.77289
	MEAN RT High Working Memory + high and low Perceptual Load NEUTRAL di	1212.1930	20	260.52141	58.25436
Pair 8	MEAN RT Low Working Memory Load + high and low perceptual Load CONGRUENT DI	1083.6546	20	210.40986	47.04908
	MEAN RT Low Working Memory + high and low Perceptual Load INCONGRUENT DI	1075.5495	20	212.29614	47.47086
Pair 9	MEAN RT Low Working Memory Load + high and low perceptual Load CONGRUENT DI	1083.6546	20	210.40986	47.04908
	MEAN RT Low Working Memory + high and low Perceptual Load NEUTRAL DI	1057.4178	20	204.73121	45.77929
Pair 10	MEAN RT Low Working Memory + high and low Perceptual Load INCONGRUENT DI	1075.5495	20	212.29614	47.47086
	MEAN RT Low Working Memory + high and low Perceptual Load NEUTRAL DI	1057.4178	20	204.73121	45.77929
Pair 11	MEAN RT High Working Memory + high and low perceptual load CONGRUENT di	1190.0037	20	268.37042	60.00945
	MEAN RT Low Working Memory Load + high and low perceptual Load CONGRUENT DI	1083.6546	20	210.40986	47.04908
Pair 12	MEAN RT High Working Memory + high and low Perceptual load INCONGRUENT di	1168.2710	20	258.36821	57.77289
	MEAN RT Low Working Memory + high and low Perceptual Load INCONGRUENT DI	1075.5495	20	212.29614	47.47086
Pair 13	MEAN RT High Working Memory + high and low Perceptual Load NEUTRAL di	1212.1930	20	260.52141	58.25436
	MEAN RT Low Working Memory + high and low Perceptual Load NEUTRAL DI	1057.4178	20	204.73121	45.77929

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	MEAN RT for CIN in High Working Memory and High Perceptual Load - MEAN RT for CIN di for High Working Memory and Low Perceptual Load	158.86942	118.77031	26.55785	103.28320	214.45563	5.982	19	.000
Pair 2	MEAN RT for CIN di Low Working Memory Load and HIgh Perceptual Load - MEAN RT for CIN di for Low Working Memory Low Perceptual Load	117.79213	130.26409	29.12794	56.82666	178.75760	4.044	19	.001
Pair 3	MEAN RT for CIN in High Working Memory and High Perceptual Load - MEAN RT for CIN di Low Working Memory Load and HIgh Perceptual Load	138.48724	114.20637	25.53732	85.03701	191.93747	5.423	19	.000
Pair 4	MEAN RT for CIN di for High Working Memory and Low Perceptual Load - MEAN RT for CIN di for Low Working Memory Low Perceptual Load	97.40995	134.77938	30.13759	34.33126	160.48864	3.232	19	.004
Pair 5	MEAN RT High Working Memory + high and low perceptual load CONGRUENT di - MEAN RT High Working Memory + high and low Perceptual load INCONGRUENT di	21.73267	78.87185	17.63628	-15.18049	58.64583	1.232	19	.233
Pair 6	MEAN RT High Working Memory + high and low perceptual load CONGRUENT di - MEAN RT High Working Memory + high and low Perceptual Load NEUTRAL di	-22.18930	36.12840	8.07856	-39.09791	-5.28069	-2.747	19	.013
Pair 7	MEAN RT High Working Memory + high and low Perceptual load INCONGRUENT di - MEAN RT High Working Memory + high and low Perceptual Load NEUTRAL di	-43.92197	82.09263	18.35647	-82.34250	-5.50143	-2.393	19	.027
Pair 8	MEAN RT Low Working Memory Load + high and low perceptual Load CONGRUENT DI - MEAN RT Low Working Memory + high and low Perceptual Load INCONGRUENT DI	8.10508	56.21879	12.57090	-18.20613	34.41628	.645	19	.527
Pair 9	MEAN RT Low Working Memory Load + high and low perceptual Load CONGRUENT DI - MEAN RT Low Working Memory + high and low Perceptual Load NEUTRAL DI	26.23674	55.92027	12.50415	.06524	52.40823	2.098	19	.049
Pair 10	MEAN RT Low Working Memory + high and low Perceptual Load INCONGRUENT DI - MEAN RT Low Working Memory + high and low Perceptual Load NEUTRAL DI	18.13166	39.47932	8.82784	-.34523	36.60855	2.054	19	.054
Pair 11	MEAN RT High Working Memory + high and low perceptual load CONGRUENT di - MEAN RT Low Working Memory Load + high and low perceptual Load CONGRUENT DI	106.34911	123.96828	27.72015	48.33017	164.36806	3.837	19	.001
Pair 12	MEAN RT High Working Memory + high and low Perceptual load INCONGRUENT di - MEAN RT Low Working Memory + high and low Perceptual Load INCONGRUENT DI	92.72152	144.77701	32.37312	24.96379	160.47925	2.864	19	.010
Pair 13	MEAN RT High Working Memory + high and low Perceptual Load NEUTRAL di - MEAN RT Low Working Memory + high and low Perceptual Load NEUTRAL DI	154.77515	117.88578	26.36006	99.60291	209.94739	5.872	19	.000

Appendix G3

Accuracy data indicating mean number of errors, standard deviations, F-statistics, and within subjects contrasts for Experiment 2B

Descriptive Statistics

	Mean	Std. Deviation	N
High Working Memory High Perceptual Load errors Congruent	6.9500	4.31003	20
High Working Memory High Perceptual Load errors InCongruent	7.8000	5.06380	20
High Working Memory High Perceptual Load errors Neutral	5.8000	4.11160	20
High Working Memory Low Perceptual Load errors Congruent	6.4000	4.41767	20
High Working Memory Low Perceptual Load errors InCongruent	7.8500	4.17102	20
High Working Memory Low Perceptual Load errors Neutral	5.8000	4.09878	20
Low Working Memory High Perceptual Load errors Congruent	5.6000	3.99210	20
Low Working Memory High Perceptual Load errors Incongruent	5.9500	4.51285	20
Low Working Memory High Perceptual Load errors Neutral	5.8500	3.88350	20
Low Working Memory low Perceptual Load errors Congruent	5.3500	4.88041	20
Low Working Memory Low Perceptual Load errors Incongruent	6.4500	4.52449	20
Low Working Memory Low Perceptual Load errors Neutral	6.4500	3.45612	20

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
WorkingMemory	Sphericity Assumed	40.838	1	40.838	1.301	.268	.064
	Greenhouse-Geisser	40.838	1.000	40.838	1.301	.268	.064
	Huynh-Feldt	40.838	1.000	40.838	1.301	.268	.064
	Lower-bound	40.838	1.000	40.838	1.301	.268	.064
Error(WorkingMemory)	Sphericity Assumed	596.579	19	31.399			
	Greenhouse-Geisser	596.579	19.000	31.399			
	Huynh-Feldt	596.579	19.000	31.399			
	Lower-bound	596.579	19.000	31.399			
PerceptualLoad	Sphericity Assumed	.204	1	.204	.014	.906	.001
	Greenhouse-Geisser	.204	1.000	.204	.014	.906	.001
	Huynh-Feldt	.204	1.000	.204	.014	.906	.001
	Lower-bound	.204	1.000	.204	.014	.906	.001
Error(PerceptualLoad)	Sphericity Assumed	272.213	19	14.327			
	Greenhouse-Geisser	272.213	19.000	14.327			
	Huynh-Feldt	272.213	19.000	14.327			
	Lower-bound	272.213	19.000	14.327			
Congruence	Sphericity Assumed	52.408	2	26.204	4.407	.019	.188
	Greenhouse-Geisser	52.408	1.972	26.571	4.407	.019	.188
	Huynh-Feldt	52.408	2.000	26.204	4.407	.019	.188
	Lower-bound	52.408	1.000	52.408	4.407	.049	.188
Error(Congruence)	Sphericity Assumed	225.925	38	5.945			
	Greenhouse-Geisser	225.925	37.476	6.029			
	Huynh-Feldt	225.925	38.000	5.945			
	Lower-bound	225.925	19.000	11.891			
WorkingMemory * PerceptualLoad	Sphericity Assumed	3.038	1	3.038	.410	.530	.021
	Greenhouse-Geisser	3.038	1.000	3.038	.410	.530	.021
	Huynh-Feldt	3.038	1.000	3.038	.410	.530	.021
	Lower-bound	3.038	1.000	3.038	.410	.530	.021
Error(WorkingMemory* PerceptualLoad)	Sphericity Assumed	140.713	19	7.406			
	Greenhouse-Geisser	140.713	19.000	7.406			
	Huynh-Feldt	140.713	19.000	7.406			
	Lower-bound	140.713	19.000	7.406			
WorkingMemory * Congruence	Sphericity Assumed	43.225	2	21.612	5.862	.006	.236
	Greenhouse-Geisser	43.225	1.989	21.732	5.862	.006	.236
	Huynh-Feldt	43.225	2.000	21.612	5.862	.006	.236
	Lower-bound	43.225	1.000	43.225	5.862	.026	.236
Error(WorkingMemory* Congruence)	Sphericity Assumed	140.108	38	3.687			
	Greenhouse-Geisser	140.108	37.791	3.707			
	Huynh-Feldt	140.108	38.000	3.687			
	Lower-bound	140.108	19.000	7.374			
PerceptualLoad * Congruence	Sphericity Assumed	6.308	2	3.154	.405	.670	.021
	Greenhouse-Geisser	6.308	1.940	3.252	.405	.664	.021
	Huynh-Feldt	6.308	2.000	3.154	.405	.670	.021
	Lower-bound	6.308	1.000	6.308	.405	.532	.021
Error(PerceptualLoad* Congruence)	Sphericity Assumed	296.025	38	7.790			
	Greenhouse-Geisser	296.025	36.853	8.032			
	Huynh-Feldt	296.025	38.000	7.790			
	Lower-bound	296.025	19.000	15.580			
WorkingMemory * PerceptualLoad * Congruence	Sphericity Assumed	.225	2	.113	.027	.973	.001
	Greenhouse-Geisser	.225	1.738	.129	.027	.960	.001
	Huynh-Feldt	.225	1.898	.119	.027	.969	.001
	Lower-bound	.225	1.000	.225	.027	.871	.001
Error(WorkingMemory* PerceptualLoad* Congruence)	Sphericity Assumed	157.775	38	4.152			
	Greenhouse-Geisser	157.775	33.022	4.778			
	Huynh-Feldt	157.775	36.058	4.376			
	Lower-bound	157.775	19.000	8.304			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	WorkingMemory	PerceptualLoad	Congruence	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
WorkingMemory	Level 1 vs. Level 2			13.613	1	13.613	1.301	.268	.064
Error(WorkingMemory)	Level 1 vs. Level 2			198.860	19	10.466			
PerceptualLoad		Level 1 vs. Level 2		.068	1	.068	.014	.906	.001
Error(PerceptualLoad)		Level 1 vs. Level 2		90.738	19	4.776			
Congruence			Level 1 vs. Level 2	17.578	1	17.578	5.579	.029	.227
			Level 2 vs. Level 3	21.528	1	21.528	6.842	.017	.265
Error(Congruence)			Level 1 vs. Level 2	59.859	19	3.150			
			Level 2 vs. Level 3	59.784	19	3.147			
WorkingMemory *	Level 1 vs. Level 2	Level 1 vs. Level 2		4.050	1	4.050	.410	.530	.021
Error(WorkingMemory*	Level 1 vs. Level 2	Level 1 vs. Level 2		187.617	19	9.875			
WorkingMemory * Congruence	Level 1 vs. Level 2		Level 1 vs. Level 2	3.612	1	3.612	.497	.489	.025
			Level 2 vs. Level 3	78.013	1	78.013	11.209	.003	.371
Error(WorkingMemory* Congruence)	Level 1 vs. Level 2		Level 1 vs. Level 2	138.137	19	7.270			
			Level 2 vs. Level 3	132.237	19	6.960			
PerceptualLoad * Congruence		Level 1 vs. Level 2	Level 1 vs. Level 2	9.113	1	9.113	.604	.447	.031
			Level 2 vs. Level 3	.013	1	.013	.001	.976	.000
Error(PerceptualLoad* Congruence)		Level 1 vs. Level 2	Level 1 vs. Level 2	286.638	19	15.086			
			Level 2 vs. Level 3	256.237	19	13.486			
WorkingMemory * PerceptualLoad *	Level 1 vs. Level 2	Level 1 vs. Level 2	Level 1 vs. Level 2	.450	1	.450	.011	.918	.001
			Level 2 vs. Level 3	.450	1	.450	.022	.884	.001
Error(WorkingMemory* PerceptualLoad*	Level 1 vs. Level 2	Level 1 vs. Level 2	Level 1 vs. Level 2	782.550	19	41.187			
			Level 2 vs. Level 3	388.550	19	20.450			

Appendix G4

Accuracy data indicating mean number or errors, standard deviations, and t-statistics for pairwise comparisons

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Mean Errors for HWM all PL Congruent distractors	6.6750	20	3.77413	.84392
	Mean Errors for HWM all PL Incongruent distractors	7.8250	20	4.11440	.92001
Pair 2	Mean Errors for HWM all PL Congruent distractors	6.6750	20	3.77413	.84392
	Mean Errors HWM neutral distractors	5.8000	20	3.65052	.81628
Pair 3	Mean Errors for HWM all PL Incongruent distractors	7.8250	20	4.11440	.92001
	Mean Errors HWM neutral distractors	5.8000	20	3.65052	.81628
Pair 4	Mean Errors LWM all PL Congruent distractors	5.4750	20	3.85417	.86182
	meanerrorsINconLWM	6.2000	20	4.22835	.94549
Pair 5	Mean Errors LWM all PL Congruent distractors	5.4750	20	3.85417	.86182
	Mean Errors LWM Neutral distractors	6.1500	20	3.34467	.74789
Pair 6	meanerrorsINconLWM	6.2000	20	4.22835	.94549
	Mean Errors LWM Neutral distractors	6.1500	20	3.34467	.74789
Pair 7	Mean Errors for HWM all PL Congruent distractors	6.6750	20	3.77413	.84392
	Mean Errors LWM all PL Congruent distractors	5.4750	20	3.85417	.86182
Pair 8	Mean Errors for HWM all PL Incongruent distractors	7.8250	20	4.11440	.92001
	meanerrorsINconLWM	6.2000	20	4.22835	.94549
Pair 9	Mean Errors HWM neutral distractors	5.8000	20	3.65052	.81628
	Mean Errors LWM Neutral distractors	6.1500	20	3.34467	.74789

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Mean Errors for HWM all PL Congruent distractors - Mean Errors for HWM all PL Incongruent distractors	-1.15000	2.34015	.52327	-2.24523	-.05477	-2.198	19	.041
Pair 2	Mean Errors for HWM all PL Congruent distractors - Mean Errors HWM neutral distractors	.87500	2.10185	.46999	-.10869	1.85869	1.862	19	.078
Pair 3	Mean Errors for HWM all PL Incongruent distractors - Mean Errors HWM neutral distractors	2.02500	2.00968	.44938	1.08444	2.96556	4.506	19	.000
Pair 4	Mean Errors LWM all PL Congruent distractors - meanerrorsINconLWM	-.72500	2.11184	.47222	-1.71337	.26337	-1.535	19	.141
Pair 5	Mean Errors LWM all PL Congruent distractors - Mean Errors LWM Neutral distractors	-.67500	2.18412	.48838	-1.69720	.34720	-1.382	19	.183
Pair 6	meanerrorsINconLWM - Mean Errors LWM Neutral distractors	.05000	2.39462	.53545	-1.07072	1.17072	.093	19	.927
Pair 7	Mean Errors for HWM all PL Congruent distractors - Mean Errors LWM all PL Congruent distractors	1.20000	3.58138	.80082	-.47614	2.87614	1.498	19	.150
Pair 8	Mean Errors for HWM all PL Incongruent distractors - meanerrorsINconLWM	1.62500	3.41774	.76423	.02545	3.22455	2.126	19	.047
Pair 9	Mean Errors HWM neutral distractors - Mean Errors LWM Neutral distractors	-.35000	3.77701	.84456	-2.11769	1.41769	-.414	19	.683