INVESTIGATING STIMULUS SALIENCE AND PERCEPTUAL LOAD INTERACTION USING A HYBRID VISUAL-SEARCH FLANKER TASK

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By

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DECLARATION

I, Gerrit Stefanus de Jager, hereby declare that this dissertation, to be submitted to the University of Pretoria for the degree Master in Research Psychology, is my own original work and has not been submitted to this University or any other tertiary institution for any degree.

Signed: ________________________

This _______ day of ________ 2015

Summary

The perceptual load theory of selective attention proposed by Tsal and Lavie (1994) and Lavie (1995) argues that selective attention is predominantly necessitated by perceptual capacity limitations. In order to account for the experimental evidence where stimuli are attentionally selected either early or late, Lavie (1995) proposed that early selection occurs when perceptual capacity has been reached, while late selection occurs when perceptual capacity has not been reached. This effect has been demonstrated with the use of hybrid visual-search flanker search tasks on numerous occasions (Lavie, 2004). However, some researchers argue that the selection of stimuli is attributable to salience and not to perceptual load. Due to the increased salience of flankers in low perceptual load trials the distractor identity is much more readily processed, thereby leading to the distractor interference. Lavie (1995) attributes the increased distractor interference in low perceptual load trails to the automatic allocation of spare perceptual resources; a process that is mediated by perceptual load levels. This study investigates the potential interaction between perceptual load and distractor salience by presenting 20 participants with a hybrid visual-search flanker task, but placing salient colour singletons distractors in half the trials. The results indicate that the compatibility effect is largely nullified in low perceptual load trials containing salient distractors. The non-salient distractor trials, however, produced a significant compatibility effect as predicted by the perceptual load theory of selective attention. The lack of a significant compatibility effect in salient distractor trials might be an indication that top-down attentional control mechanisms can capitalise on the task-irrelevant colour feature to suppress the processing or perception of the distractor. This finding problematises the hypothesis that the automatic spill-over of perceptual capacity is responsible for the distractor interference in low perceptual load trials as necessitated by perceptual load theory.

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List of acronyms

ANOVA	Analysis of Variance
GLMM	Generalized Linear Mixed Effects Model
HIS	**H**igh perceptual load trials containing **I**ncompatible and **S**alient distractors
HIN	**H**igh perceptual load trials containing **I**ncompatible and **N**on-salient distractors
HNS	**H**igh perceptual load trials containing **N**eutral and **S**alient distractors
HNN	**H**igh perceptual load trials containing **N**eutral and Non-**s**alient distractors
LIS	**L**ow perceptual load trials containing **I**ncompatible and **S**alient distractors
LIN	**L**ow perceptual load trials containing **I**ncompatible and **N**on-salient distractors
LNS	**L**ow perceptual load trials containing **N**eutral and **S**alient distractors
LNN	**L**ow perceptual load trials containing **N**eutral and **N**on-salient distractors

1. Overview of the Study

1.1 Introduction

At present the cognitive and neural mechanisms that form the basis for the selection of task-relevant stimuli -and the rejection of task-irrelevant stimuli- are still not clearly understood. According to Lavie (2010):

> A main goal of attention theory is to delineate the determinants of focused attention that allow people to ignore irrelevant distractions. This goal, however, has proved rather hard to reach, and the very question of whether attention can ever affect the perception of distractors has been controversial ever since attention research began in the late fifties (p. 143).

In recent years, evidence from numerous experiments have suggested that the degree to which our perceptual systems are loaded with task-relevant stimuli play an important role in the functioning of selective mechanisms of attention. This link between our perceptual systems and the functioning of these selective mechanisms appear to stem from the limited capacity nature of our perceptual systems; an idea known as the perceptual load theory of selective attention.

However, studies that have investigated the influence of different types of stimuli on selective attention within a load theory framework have produced largely inconclusive results (Biggs & Gibson, 2013). According to Biggs and Gibson (2014), the mixed results appear to stem from the inherent difficulty in clearly delineating these constructs within an empirical framework. For example, even slight differences in stimulus presentation or experimental conditions across studies can influence the experimental results, making it difficult to contrast and compare results across studies. The inconsistency of research findings within the load theory framework also makes it difficult to estimate the importance and impact of stimulus characteristics when evaluating the load theory of selective attention. This last point has proven to be especially problematic, since it becomes difficult to gauge how important perceptual load is in determining when, and how, selective filtering occurs if stimulus characteristics can amplify or nullify its influence. A second concern involves the nature of perceptual load itself. Deriving a simple definition of perceptual load is challenging as it is not entirely clear how the grouping of perceptual stimuli influences perceptual load within and across participants or stimuli. The naïve definition of perceptual load involves defining perceptual load as a function of the number of discrete items or grouping of items contained in the search array that have to be perceived and processed, known as set-size (Lavie, 1995). The naïve definition of perceptual load has been heavily criticised due to its vagueness and the inherent difficulty in operationalising the construct reliably within an experimental framework (Benoni & Tsal, 2013).

One of the central questions that researchers have attempted to address in the past is the extent to which stimulus salience can modify selective attention in the presence or absence of perceptual load (e.g. Biggs & Gibson, 2013; Bruce & Tsotsos, 2009; Eltiti, Wallace, & Fox, 2005). Salient stimuli are stimuli that stand out due to their distinctive perceptual characteristics in comparison to other stimuli. A red circle, for example, will clearly stand out when embedded within a group of white circles.

Elucidating the role that stimulus salience and perceptual load plays in modifying selective attention is an important stepping stone in expanding and refining the load theory of selective attention. In addition to the theoretical importance of the problem, a more nuanced understanding of the interaction between stimulus salience and perceptual load would be a crucial step in understanding how perceptual load influences selective attention outside of the laboratory.

The fact that previous studies conducted on the interaction between perceptual load and stimulus salience have yielded inconclusive results can be clarified by taking into account the research done on the influence of feature singletons (i.e. a single salient stimulus) on distractibility. Even though these studies do not normally manipulate perceptual load, the theoretical implications of these studies may prove to be informative when considering the potential effect of colourful salient stimuli within a search array when perceptual load is also manipulated. Research investigating the extent to which participants are distracted by feature singletons find that participants' attentional control strategies can shift from either top-down strategies to bottom-up strategies, or *vice versa*, depending on the experimental conditions (Connor, Egeth, & Yantis, 2004).

Top-down attentional control strategies imply that participants' allocation of attention allow them to immediately filter out irrelevant stimuli by processing only the stimuli that are relevant to the task at hand. When employing a top-down attentional control strategy it becomes possible for participants to filter out task-irrelevant stimuli regardless of their salience. On the other hand, bottom-up attentional control strategies imply that the stimulus characteristic is the main determinant of stimulus processing. It should come as no surprise then that a salient stimulus, even an irrelevant one, is rarely filtered out early when employing a bottom-up attentional control strategy (Connor, Egeth, & Yantis, 2004).

Support for both of these attentional control strategies has been demonstrated experimentally (Connor, Egeth, & Yantis, 2004). At present it is not clear how the literature on top-down and bottom-up attentional strategies can be integrated with the perceptual load theory of selective attention. The load theory of selective attention can be considered a predominantly bottom-up account of selective attention due to its reliance on the number of stimuli, or set-size, to trigger the selective filtering of stimuli. Accordingly, the top-down driven suppression of irrelevant stimuli should not be possible since a feature of the stimuli (i.e. set-size) determines whether stimuli are selected early or late. This hypothesis, however, is partially contradicted by the studies that demonstrate the top-down driven suppression of distracting stimuli (Connor, Egeth, & Yantis, 2004).

In practical terms, there are two findings that should not be possible if the perceptual load theory of selective attention is correct. First, participants should not be able to successfully suppress the processing of distracting stimuli in low perceptual load conditions. If it can be demonstrated that participants are able to successfully suppress the processing of distractors in low perceptual conditions, this may imply that top-down attentional control allows them to filter out the distractors; a finding that would be difficult to reconcile with the perceptual load account of selective attention as it currently stands. Second, participants should also not demonstrate a pervasive pattern of processing distractors in high perceptual load conditions as this would indicate that perceptual load may not be the main determinant of stimulus selection. As will be discussed in the literature review, there are conditions under which these effects can occur, but within a perceptual load theory framework they are thought to reflect a temporary lapse in the maintenance of task processing priorities.

The goal of this study is to investigate the role that stimulus salience plays in determining the degree to which perceptual load influences selective attention. Of particular interest is the extent to which participants would be distracted by salient distractors in low and high perceptual load trials. The results are discussed with specific reference to the theoretical tension between the load theory of selective attention and the bottom-up and top-down control of attention.

1.2 Research problem

Two broad classes of theories have attempted to clarify the cognitive mechanisms that allow us to select stimuli from the stream of perception: early selection theories and late selection theories. According to early selection theories, all stimuli are processed to the level of basic physical attributes. After this initial rudimentary processing, non-selected stimuli are either filtered out completely (Broadbent, 1958) or attenuated (Treisman, 1960, 1964). The reason why selection of stimuli happens at an early stage is to prevent sensory processes from being overloaded (Luck & Vecera, 2002). Late selection theories, in contrast to early selection theories, maintain that all incoming stimuli are processed to the point of recognition and meaning, and only after recognition occurs does selective filtering occur (Duncan, 1980).

An important development in the field of selective attention is perceptual load theory of selective attention, as introduced by Lavie and Tsal (1994). The load theory of selective attention maintains that selective attention is mediated by the amount of load placed on the perceptual system. Subsequently, selective attention might occur both early and late, depending on the type and amount of load placed on the perceptual system.

Building on the work of Treisman (1969), perceptual load theorists maintain that perceptual capacity allocation happens in an all-or-nothing fashion, where any and all stimuli that enter the senses will be registered and processed in parallel (Lavie, 1995). Only after perceptual capacity has been reached will the selection of task-relevant stimuli occur out of necessity as outlined by the early selection theorists. Thus the main factor driving early or late selection of visual stimuli is the level of load the perceptual system is placed under.

Experimentally, the perceptual load theory of selective attention has been supported through the demonstration of a compatibility effect under high and low perceptual load conditions. The compatibility effect occurs when the mean response time or error rates are higher for trials where the target and distractor are incompatible than for trials where the target and distractor are either neutral or compatible. The presence of the compatibility effect is taken as evidence that increased perceptual load decreases distractor processing, since there would be no perceptual capacity left over to allocate to the processing of the distractor, thereby eliminating the potential interference that it might produce.

Although the load theory of selective attention has garnered much support from experimental findings since its proposal (see Lavie & Tsal, 1994; Lavie, 1995) some serious questions regarding the interaction of perceptual load and distractor salience still remain unanswered. This study thus aims to further elaborate upon the relationship between target-distractor salience and perceptual load in particular. More precisely, to what extent does the relative salience of perceived stimuli influence the selection of stimuli under high and low perceptual load conditions when utilising a hybrid visual-search flanker task?

1.3 Rationale

Without the ability to select and maintain representations of task-relevant stimuli we would be in a perpetual state of distraction, not knowing which stimuli should be given priority in order to successfully carry out the task at hand. Even seemingly mundane tasks such as driving a car or picking up an object from a table require complex selective filtering of perceptual stimuli. Certain occupations such as air traffic controlling and emergency room care constantly require individuals to make important decisions that rely on them effectively filtering out task-irrelevant stimuli in their environment. Research on selective attention is important due to the potentially serious influence of this selective mechanism in daily functioning. Forster, Robertson, Jennings, Asherson, and Lavie (2014), for example, have suggested that people who suffer from Attention-Deficit Hyperactivity Disorder (ADHD) may benefit from tasks that induce higher amounts of perceptual load; a hypothesis that appears to be counter-intuitive, as the addition of stimuli to tasks are assumed to lead to greater distraction in people who suffer from ADHD.

At present the nature of this selective or filtering mechanism within attention is still unclear. The load theory of selective attention proposed by Lavie (1995) is a promising development in the field of attention research, although many of the experimental findings that lend support to the theory have been heavily criticised (Giesbrecht, Sy, Bundesen, & Kyllingsbæk, 2014). In particular, some studies have suggested that stimulus salience can completely override the influence of perceptual load in determining when selective attention occurs (Biggs & Gibson, 2010). By building on prior research done on the influence of salient visual stimuli on distractor processing within a load theory framework, this study aims to advance the theoretical developments that inform our understanding of attention.

1.4 Aims and Objectives

According to Biggs and Gibson (2010) visual salience and perceptual load probably interact in meaningful ways to influence visual selective attention. The main aim of this study is to expand the debate on load theory by examining the interaction between distractor salience and perceptual load by utilising a hybrid visual search-flanker task. The primary objective of this study is to observe attentional changes in distractor processing that, in turn, lead to increased distractor interference across salience (colour) and distractor compatibility conditions in high and low perceptual load search arrays.

1.5 Description of Methodology

The study opted for a quantitative, factorial design in order to observe changes in response times and error rates in response to systematic manipulations of perceptual load, distractor compatibility, and distractor salience. All participants had to complete a visual-search task where they searched for one of two target letters in a circular search array. The search array consisted of one target letter, and, either five neutral non-target letters (high perceptual load) or five dashes (low perceptual load). All trials also contained one flanking distractor letter that was either salient (coloured) or non-salient (same colour as the target and neutral letters).Whenever the target letter that was not present in the search array appeared as the distractor, the distractor was classified as incompatible. Neutral letters consisted of irrelevant non-target letters. Participants completed a total of 192 experimental trials and 36 practice trials.

A combination of descriptive statistics, repeated measures three-way and two-way analysis of variance (ANOVA), and paired samples t-tests were used for the analysis of the data. The first step in the analysis process was to establish that high load trials increased perceptual load. This was done by considering the existence of a main effect for perceptual load after the three-way ANOVA was conducted. The second step was to establish the presence of a compatibility effect in non-salient and salient trials. The compatibility effect is calculated by comparing the mean response times or error rates of incompatible distractor trials and neutral distractor trials separately for high and low perceptual load trials (Lavie, 1995).

Due to the potentially confounding effect of age on cognitive functioning, an age-controlled convenience sample was used for the experiment. All participants were recruited from the 2015 postgraduate psychology cohort at the University of Pretoria. Participants voluntarily participated in the study.

1.6 Theoretical Framework

This study is situated within the paradigm known as the information processing approach to the study of cognition. According to van der Heijden and Stebbins (1990), the information processing approach developed, in part, as a reaction to the behaviourist approach which largely ignored the study of human cognition. Albeit an oversimplification, behaviourists sought to banish talk of inner mental events or the use of introspection as a method for investigating these inner mental phenomena. Given the dominance of the behaviourist paradigm in the scientific study of human behaviour during the first half of the 20th century, mental events, such as attention, were considered by many to fall outside the purview of the scientific study of human behaviour (Lovie, 1983).

The information processing approach in cognitive psychology, in contrast to behaviourism, seeks to explore inner mental events via the systematic study of the processing of information. The information processing approach is synonymous with the “brain-as-a-computer-metaphor”, where the human mind, much like a computer, operates according to laws for the handling and manipulation of different types of information within different contexts (Neisser, 1967). Through careful observation and experimentation, researchers can differentiate distinct processing stages and mechanisms that comprise phenomena such as attention; thereby informing researchers about the function and structure of mental processes (Casey & Moran, 1989). In this sense, attention is not treated as a mysterious mental event, but, instead, is treated as a process operating according to describable laws that can be used as scaffolding to construct broader and ever more inclusive models of attention.

1.7 Structure of the mini-dissertation

Chapter one provided a brief primer on the general background and framework of the study. The perceptual load theory of selective attention was introduced and situated within the scope of attention research. Finally the main aims and objectives of the study were given.

Chapter two will provide a more thorough treatment of the literature in order to orient the reader regarding the broader theoretical framework within which this study was conducted. Due to the large body of knowledge generated over the years that speak to the selective mechanisms of attention, preference will be given to studies that emphasise the role that perceptual load and stimulus characteristics play in mediating selective attention.

Chapter three will inform the reader as to the particular methodology and design chosen for the study; the sampling procedures; and apparatuses and experimental procedures utilised in this study. Chapter three will conclude by providing the hypotheses and the analysis framework chosen for the study.

Chapter four will report the analysis results and findings of the study. This chapter will contain all relevant statistical results and analyses.

Chapter five will then provide an in-depth discussion of the results and situate the findings within the broader theoretical debate, as well as a brief discussion of the limitations of the study.

Chapter seven will conclude the study and provide recommendations for future studies.

2. Literature Review

The development of the load theory of selective attention has been primarily influenced by the findings and limitations of theories of attention that preceded it. In order to gain an appreciation of the relevance -and limitations- of the load theory of selective attention it is important to situate the theory within the broader context of selective attention research. To this end, selective attention, as a sub-component of the broader conceptualisations of attention will be discussed before the focus turns to the development of the load theory of selective attention as proposed by Lavie and Tsal (1994) and Lavie (1995). After introducing the initial conceptualisation and empirical support on which the load theory of selective attention is based, subsequent modifications and paradigmatic developments within the field will be discussed. Of key interest are the empirical findings that support, or undermine, the theoretical pillars that support the load theory of selective attention. Key studies and approaches in studying selective attention and distractor interference will be discussed with specific reference to the influence of stimulus salience on distractor interference within a load theory framework.

2.1 Brief overview of approaches to the study of attention

Attention does not appear to have a universal definition that can be easily deduced from either its function or nature. One of the most famous quotes on attention from William James as cited in Luck and Vecera (2002) likens attention to the mind being possessed by several objects or trains of thought. According to Pashler (1998), attention as a phenomenon of interest to cognitive psychologists stems primarily from the observation that the brain -or mind- appears to contain inherent limitations to the type and amount of information that it can process or “be possessed by” at any one time. Banich (2004) points out that the study of attention can roughly be divided into four separate, but related, aspects of attention: capacity sharing or allocation, alertness and arousal, vigilance, and selective attention.

2.1.1 Attention as a limited capacity system

Researchers interested in attention as a capacity restricted process or system often conceptualise attention as a mechanism where the sharing of a limited number of resources is required to process information or stimuli (Pashler, 1998). According to capacity sharing theories of attention, the brain possesses a finite amount of resources that it can allocate to the processing of perceived stimuli or information (Kahneman, 1973). In order to optimise the use of these limited resources, attention has to direct the allocation of resources to those processes that are either first in line, or in later adaptations of the theory, to those tasks that are deemed more important according to specific criteria (Pashler, 1998).

The mechanisms for determining which processes should be given precedence in the allocation of resources can be problematic since it can easily lead to a sense of circularity, where stimuli that are processed first are assumed to have been allocated the most resources. The processing order of stimuli, however, does not provide a sufficient reason for deeming these stimuli to be more important than the other stimuli. Kahneman (1973) recognised this shortcoming but argued that the allocation of resources can be dynamic and depend on numerous factors such as arousal, enduring dispositions or momentary intentions; making it difficult to unambiguously attribute the allocating of attentional resources to any one mechanism.

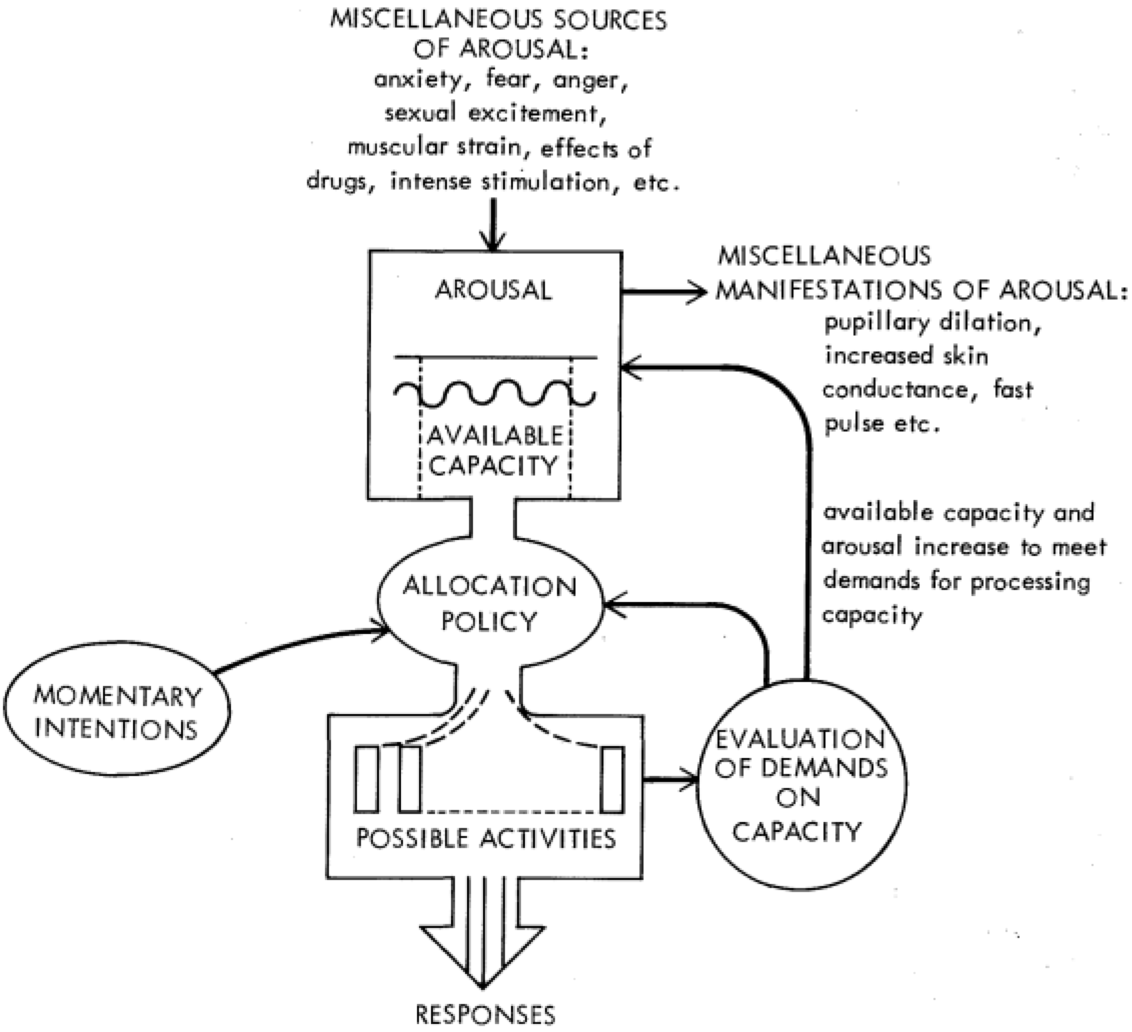

Figure 1: Kahneman's (1973) model of attenion and effort. Reprinted from “Attention and effort”. D. Kahneman. 1973, p 36. Englewood Cliffs, NJ: Prentice-Hall Inc.

Figure 1 outlines Kahneman’s (1973) model of attention. In this model the limited resources for processing appear to be undifferentiated, but the allocation of these limited resources can be modified according to the context. In other words, there are no separate resource pools for processing motor control processes and, say, mental arithmetic; all processing share the same finite pool of processing resources. Within this framework, attention is an important function to ensure that critical processes are allocated adequate resources for their completion.

2.1.2 Alertness and arousal

According to Banich (2004), alertness and arousal can be considered the most basic level of attention as any form of information processing would be impossible without alertness. To use a somewhat crude analogy, in much the same way that a computer cannot function without power, so attention is reliant on a bare minimum level of alertness on the part of an organism's attentional and perceptual systems in order to become functional at all. Without the bare level of alertness required for perception there can be no perception, and, consequently, no attention.

2.1.3 Vigilance

When conceptualised as a continuous process vigilance is an important aspect of attention whereby information or perceived stimuli are classified and processed (Banich, 2004). For attention to function in any useful way, sustained attention is as important as the initial perception of stimuli. Without the ability to sustain the allocation of attentional resources to the processing of incoming stimuli, attention is relegated to brief snapshots of the perceived stimuli. These one-time or intermittent periods of attention would severely limit and constrain the feedback produced by our actions (Luck & Vecera, 2002). In turn, without constant feedback, the accuracy or temporal relevance of our actions are likely to be outdated and may end up being inappropriate.

2.2 Selective Attention

Although alertness and vigilance are important sub-components of attention, the focus of this literature review will be on the selective mechanisms of attention and, to a lesser extent, the resource limited nature of attention.

2.2.1 A fundamental sub-component of attention

Throughout our daily lives we are confronted with an almost endless stream of stimuli that are available for us to perceive and process. Despite the large number of stimuli that enter our senses, we are consciously aware of only a fraction of these stimuli at any given moment (Pashler, 1998). The process whereby we orient ourselves toward certain stimuli can be thought of as the selective function of attention. Selective attention can formally be defined as the ability to attend to specific stimuli in the presence of irrelevant or distracting stimuli (Kahneman, 1973).

A core assumption of selective attention is the existence of a selective, or filtering, mechanism that allows us to discriminate between relevant and irrelevant stimuli. A significant amount of attention research conducted during the last 50 years has been focused on elucidating this attentional filter that makes discrimination and selection of specific stimuli amid the perceptual stream possible (Nelson, Crisostomo, Khericha, Russo, & Thorne, 2012).

Selective attention is a particularly important cognitive process, since any form of goal-directed behaviour would be impossible without it. Goal-directed behaviour requires us to attend to only the specific stimuli that are relevant to the task at hand; while simultaneously filtering out or ignoring irrelevant stimuli (Lachter, Forster, & Ruthruff, 2004).

Traditionally, two broad approaches have been followed in the study of selective attention: early selection theories and late selection theories. Although numerous alternative theories have been proposed to account for and explain selective attention, they tend to form derivatives of the two broader approaches mentioned above (Pashler, 1998).

2.2.1.1 *Early selection theories*

One of the earliest attempts to investigate the relationship between attention and perceptual processing was dubbed a *selective shadowing task* (Driver, 2001). This required participants to listen to two different spoken messages simultaneously but ignoring the one and attending to the other by repeating or shadowing the attended message. When participants shadowed the attended message successfully they did not register the unattended message at all, or, in some cases, they registered it only minimally. In light of these results, it was taken as evident that the unattended message may have been blocked out completely because the participant never perceived or registered it at all. In other words, selection of attended stimuli happened early in the processing stream based upon their relevance to the performance of the shadowing task. The non-selected stimuli from the unattended message appeared to have been filtered out completely and never processed.

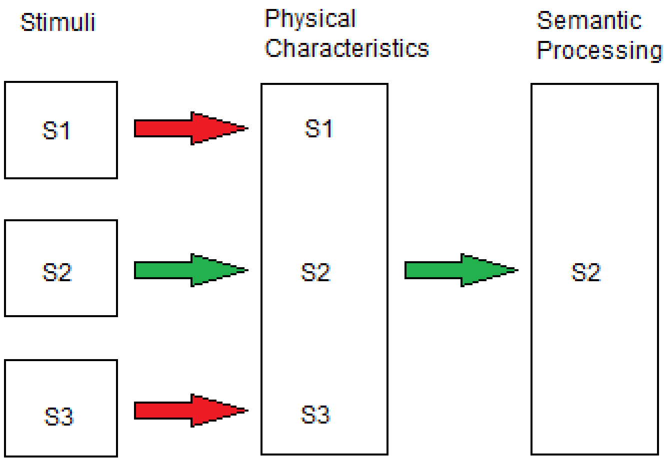

Figure 2: The filtering of perceived stimuli according to early selection theories. While stimulus one (S1) and three (S3) are processed for basic physical characteristics, only stimulus two (S2) is selected for further semantic processing (Pashler, 1998).

Figure 2 illustrates the processing of three stimuli given the simultaneous perception of the three distinct stimuli, S1, S2 and S3, where only S2 is attended to (as indicated by the green arrow). All three stimuli will be processed for basic physical characteristics, but only S2 will be processed for semantic meaning, meaning that it is the only stimulus that will be identified. S1 and S3 will be filtered out before semantic processing can occur. In early selection theories, all stimuli are processed to the level of basic physical attributes. After this initial rudimentary processing, non-selected stimuli are filtered out.

This raises the question regarding the potential for the processing of more than one attended stimulus at the same time. According to early selection theories this is not possible. Instead, when multiple stimuli are attended to at the same time, the processing of the stimuli for semantic meaning will only ever occur in a serial fashion as illustrated in Figure 3.

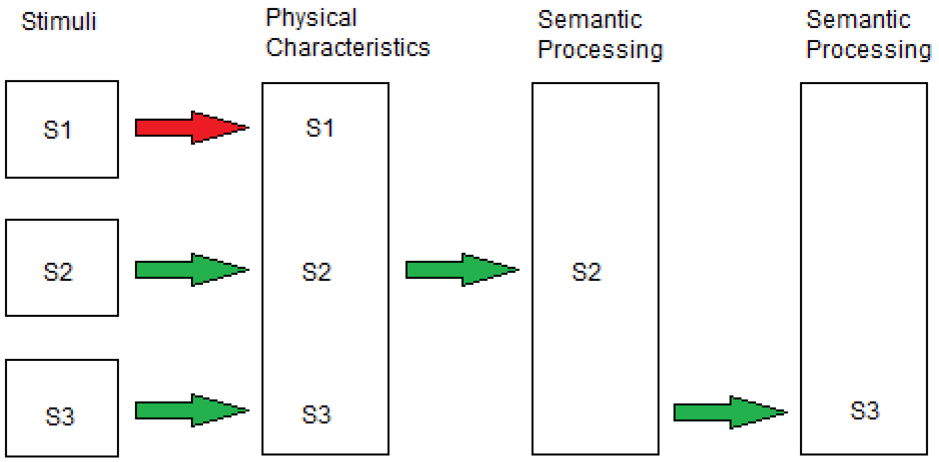

Figure 3: The filtering of perceived stimuli according to early selection theories when more than one stimuli is attended to. While stimulus two (S2) and three (S3) are both attended to simultaneously and processed for semantic meaning, stimulus two (S2) is processed first and only then is stimulus three (S3) processed for semantic meaning (Pashler, 1998).

When more than one stimulus is attended to at the same time, the processing of the basic physical characteristics occur in parallel but the semantic processing still occurs in sequential order. While the second stimulus attended to will (S3) not be filtered out, further processing is delayed until S2 is processed and identified.

2.2.1.2 *Late selection theories*

Late selection theories, in contrast to early selection theories, maintain that all incoming stimuli are processed to the point of recognition and meaning, and only after recognition occurs does selective filtering occur (Deutsch & Deutsch, 1963; Duncan, 1980). One of the key findings to support the late selection of stimuli came from an effect known as the *cocktail party effect*, where participants noticed their own names being spoken in the unattended ear of a dichotic listening task (Moray, 1959). The fact that some participants recognised their own names in the unattended message is taken as evidence that filtering only happens after semantic recognition. If the unattended message was only processed for basic physical attributes the participants would not have recognised their own names as the stimuli could not have been processed for meaning before being filtered out. The processing of all stimuli to the point of recognition is illustrated in Figure 4.

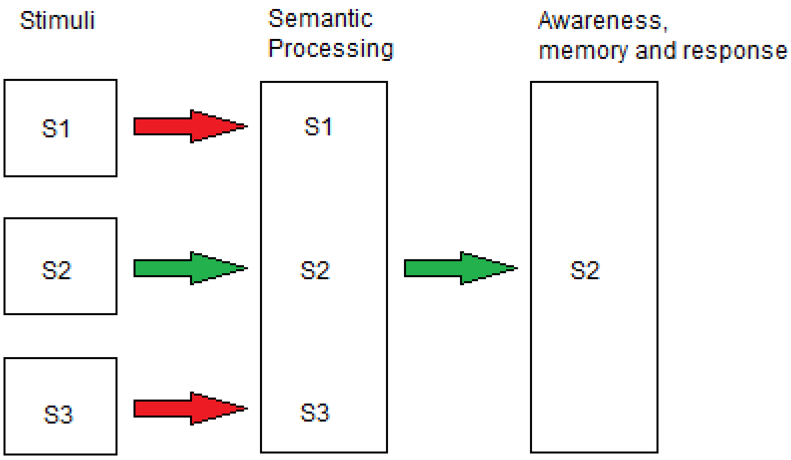

Figure 4: The filtering of perceived stimuli according to late selection theories when only one stimulus is attended to. Regardless of which stimulus is attended to, all stimuli are processed for semantic meaning, however, only the stimuli identified as important will proceed to be available for conscious awareness (Pashler, 1998).

At this stage it should become apparent that late selection theories emphasise the processing of semantic meaning, and subsequent identification of all stimuli, in the same way that early selection theories emphasise the parallel and unconstrained processing of all stimuli for basic physical characteristics. In short, while both theories acknowledge the limited capacity of attention, they differ on *where* in the processing stream the selection and rejection of stimuli occur. According to Pashler (1998), the selection of stimuli still occurs in late selection theories, but the selection is only applicable to stimuli earmarked by the discriminatory mechanisms as important. In other words, according to late selection theories incoming stimuli are fully processed, but discriminatory selection only occurs when certain stimuli are identified as important.

2.2.1.3 Attenuation of stimuli

One of the main drawbacks of the two approaches discussed above is the fact that they treat perception, physical processing, and semantic processing as immutable processes. In a landmark study Treisman (1960) demonstrated that the early *or* late selection of stimuli might be an oversimplification. Treisman presented participants with a dichotic listening task similar to the one used by Moray (1959). A different passage was played into the left and right ear simultaneously and participants were instructed to shadow only the story played into the one ear. However, at unexpected intervals the passages were switched so that the passage being played in the right ear was switched to the left ear, and *vice versa*.

Treisman (1960) found that participants sometimes repeated a few words from the unattended passage before switching to the correct passage, but did not notice that they had done so. This implies that participants, at some point after the switching of the messages, subconsciously realise that the words they are shadowing do not match the passage that they are supposed to shadow. The fact that they can switch to the attended passage without being aware of the fact that they also shadowed words from the unattended ear should not be possible according to early selection theory as the attended passage would immediately stop to make sense and the participant would realise this. Treisman accounted for this phenomenon by positing that the threshold for processing words that are associated with the passage they are shadowing had been temporarily lowered and the seamless switching had occurred because participants had also processed the words from the unattended ear after the switch and realised that this is the passage that they should be shadowing. This provided at least some evidence that, under special circumstances, two distinct stimuli can be processed at the same time in contrast to early selection theory's position that semantic processing cannot occur in parallel.

2.2.1.4 A paradigmatic shifts in the study of attention

There appeared to be a stalemate between the late and early selection theories for most of the 20th century. During the 1970s, however, increasing empirical support appeared to swing the consensus ever so slightly in the direction of the late selection theories. However, according to Kahneman and Treisman (1984) one of the reasons why this happened is that this period coincided with a subtle change in the experimental paradigm used to study attention. Kahneman and Treisman argue that two broad approaches to the study of attention can be identified that served to inform experimental designs and tasks during the 1950s through to the 1980s: divided attention approaches and focused attention or selective-set approaches.

Divided attention approaches to the study of attention were often geared toward establishing the limits and the extent to which different tasks can be performed and the influence of these tasks on attentional mechanisms. A good example of this type of approach is the selective shadowing task employed by early proponents of the early selection theory which emphasised the filtering of information; thereby being referred to as the *filtering paradigm*. These studies often involved presenting participants with complex and competing messages that induced a high level of perceptual and informational complexity (Kahneman & Treisman, 1984).

During the 1970s, the experimental paradigms for investigating attention shifted toward more controlled and narrowly defined experiments. Selective-set approaches usually required participants to indicate via speeded response when they recognise or detect a predefined stimulus or stimuli that the researcher presents to them. These experiments were often much easier in terms of task difficulty and induced much lower perceptual load when compared to the tasks derived from the filtering paradigm.

Kahneman and Treisman (1984) argue that the more complex and difficult tasks associated with the filtering paradigm may in fact not be directly comparable to the findings from the much simpler tasks associated with the selective-set approaches. The question regarding early or late selection only appeared to be heading towards a resolution due to this subtle paradigmatic shift that favoured the late selection of stimuli (Driver, 2001).

2.3 The perceptual load theory of selective attention

During the early years of the late versus early selection debate, researchers appeared to have emphasised the processing of perceived stimuli in terms of semantic or physical characteristics. However, both theories assumed that perceptual capacity itself was largely unlimited and processing bottlenecks mostly occurred later on in the processing stream. According to Treisman (1969, p. 296):

> … the nervous system is forced to use whatever discriminative systems it has available, unless these are already fully occupied with other tests or inputs, so that we tend to use our perceptual capacity to the full on whatever sense data reach the receptors. If we are correct in assuming the existence of independent analyzers, it

> would then follow that all dimensions of a stimulus input would be analysed unless the analyzers were already engaged on some other input.

Here Treisman, considering the literature published on selective attention, suggests that perception of stimuli will occur in parallel and automatically until the perceptual capacity of that particular system is exhausted. Mindful of the subtle change in paradigms pointed out by Kahneman and Treisman (1984), and how these paradigms might influence the experimental findings, Lavie and Tsal (1994), building on the work of Treisman (1969), suggested that the selection of stimuli for processing might in fact be linked to the extent that the operating capacities of these perceptual input channels are exhausted.

Perceptual capacity allocation happens automatically and in an all-or-nothing fashion, but what happens when these perceptual systems reach capacity and cannot capture any more stimuli? Lavie and Tsal (1994) noted that the majority of the studies that were rooted in the filtering paradigm produced high perceptual load tasks that were conducive to early selection, while the experimental tasks rooted in the selective-set paradigm produced tasks that induced relatively low perceptual load and mostly lead to late selection. Lavie (1995) realised that perceptual load might be the very mechanism that necessitates and initiates the selection of stimuli. In other words, any and all stimuli that enter the senses will be registered and processed, but when perceptual capacity has been reached for a particular input channel it becomes critical for the system to select some stimuli while rejecting others in order to avoid overload.

This hypothesis lead to the proposal of an alternative account of selective attention, referred to as the *perceptual load theory of selective attention*, where selective attention can occur both early or late depending on the type and amount of load the perceptual system is placed under (Lavie & Tsal, 1994; Lavie, 1995). The early work on the perceptual load theory of selective attention focused predominantly on visual perception. Perception proceeds automatically and in parallel on all items within the visual field. Only after perceptual capacity has been reached will the selection of attended stimuli occur out of necessity as outlined by the early selection theorists; the main factor driving early or late selection of stimuli being the level of load the perceptual system is placed under. The selection of stimuli would be a largely passive process that is not subject to voluntary control due to the automaticity of perception itself. Irrelevant distractor processing, and subsequent interference, is prevented because the distractors are not perceived due to the insufficient capacity required for their perception and processing.

Albeit theoretically elegant, Lavie's (1995) initial proposal failed to address a fundamental question regarding the selection of task-relevant stimuli. If the selection and rejection of stimuli is based largely on the process of passive perception, how are task-relevant stimuli selected and processing priorities maintained? Later modifications of the load theory of selective attention addressed this question by positing the existence of secondary active mechanisms, such as working memory, that operate on a higher level that provide the much needed cognitive control to maintain processing priorities (Lavie, Hirst, de Fockert, and Viding, 2004). The addition of these secondary more active mechanisms tasked with cognitive control is an important development in the perceptual load theory of selection and will be dealt with more thoroughly in sections to come.

2.3.1 Definition of perceptual load

Arriving at a precise definition of what constitutes high and low perceptual load, and where exactly the thresholds lie for overloading the perceptual system, is a major point of contention in the literature. Lavie's (1995) original definition relied on the relative differences in set-sizes (the number of items included in a display) between conditions. However, Lavie admits that this is potentially problematic since a grouping of letters can be considered one item if it forms a word, but can be considered numerous individual items if decomposed into individual letters. According to Benoni and Tsal (2013), a precise definition of perceptual load is difficult to formulate due to the difficulty of reliably operationalising perceptual load across all possible stimulus conditions. This lack of a formal and precise definition of perceptual load has formed the basis for authors such as Benoni and Tsal to criticise the load theory of selective attention, due to the inability of one of the cornerstones of the theory to be reliably operationalised or replicated.

Despite the limitations associated with defining perceptual load, the perceptual load theory of attention relies on the assumption that perception itself, being an automatic process with a limited pool of perceptual resources, will proceed until the system reaches capacity. When the perceptual system is faced with conditions that exceed perceptual capacity, early selection will occur because all available perceptual resources have been automatically allocated to the attendance of the task-relevant stimuli (Lavie, 1995). According to Giesbrecht et al. (2014), the value of load theory can be found in its attempt to identify the conditions of selection, rather than focusing on the dichotomous thinking traditionally associated with early or late selection hypotheses.

2.3.2 The experimental paradigm of the load theory of selective attention

Before discussing the main empirical findings that support or contradict the load theory of selective attention as a viable alternative to the early versus late selection dichotomy, it is once again important to consider the paradigmatic point of departure of the theory. As pointed out by Kahneman and Treisman (1984), the specific research and experimental paradigms utilised by researchers can have a profound effect on the outcome of the empirical findings, which, in turn, are used to inform and develop theory.

The majority of studies that investigate the influence of perceptual load on selective attention utilise derivatives of the selective-set paradigm and the filtering paradigm and combine them to produce a hybrid visual-search task that merge elements from search arrays and flanker tasks (Luck & Vecera, 2002). In both paradigms response times and error rates can be measured to establish the effect of perceptual load manipulations on processing. Additionally, exposure time of stimuli can be kept short to avoid participants from actively searching for the target item, thereby indicating which stimuli are given perceptual and processing priority in a given task.

2.3.2.1 *The visual search paradigm*

In the visual-search paradigm participants attempt to search for a target stimulus surrounded by irrelevant stimuli (Luck & Vecera, 2002). Visual-search tasks are popular in selective attention experiments because they allow researchers to study the conditions under which irrelevant distractors can interfere with the selection of relevant target stimuli, as well as perceptual and processing capacity limitations of the visual system. The majority of visual-search task experiments require participants to locate target stimuli embedded among a varying number of distractors (Luck & Vecera, 2002).

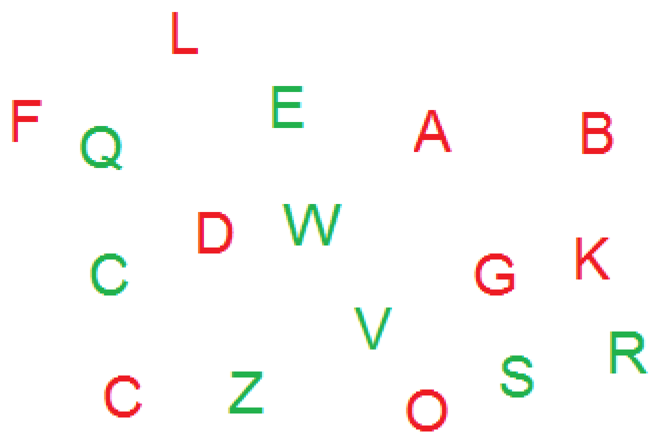

Figure 5: A typical example of a visual search task where participants are instructed to search for a red letter "O" amidst numerous distracting or irrelevant letters. Adapted from "Attention". S. J. Luck and S. P. Vecera. 2002. p. 239. In Steven's Handbook of Experimental Psychology: Sensation and perception.

Figure 5 for example highlights a typical visual search task where participants have to search for a target letter (O for example) imbedded within a group of distracting letters that share some identity feature (colour in this case) with the target. Often researchers also manipulate the number of items in the search arrays in conjunction with target-nontarget characteristics in order to examine the influence of these factors on response times and error rates. In this example for instance, Egeth, Virzi, and Garbart (1984) found that adding more red letters to the search array increased response times while adding more green letters did not, suggesting that participants limit the focus of their search along the colour identity feature before proceeding to process the letter identities.

2.3.2.2 The filtering paradigm

The filtering paradigm requires participants to attend to some stimuli but ignore other actively distracting stimuli. Filtering tasks, though very similar to search arrays, differ from search arrays because the distracting elements function at a more active level and are designed to trace the effects of distractor interference. A famous example of a filtering task is the Stroop colour naming task which requires participants to name the colour of a word that spells the name of a different colour, thereby producing interference between the word and colour elements (Stroop, 1935). Figure 6 illustrates this effect.

Figure 6: A typical illustration of the Stroop colour naming task. Naming the colour that the words are printed in is much harder for the words above the line than for the words below the line due to interference between the naming of the word and the automatic perception of the colour that the letters are printed in.

The flanker task devised by Eriksen and Eriksen (1974) is another example of the filtering paradigm that requires participants to accurately identify target letters (the middle letter) that are flanked by task-irrelevant, but potentially distracting letters. The task-irrelevant letters can either be compatible, neutral, or incompatible with respect to the targets on previous trials or the set of targets that need to be identified. For example, if the target letters were A and G, the first combination in Figure 7 would be classified as incompatible since the flanking letter G is one of the target letters. Due to its status as a target letter, including it as a distracting flanker could potentially create response competition. Eriksen and Eriksen found that incompatible flankers did in fact lead to response competition and increased mean response times when compared to compatible or neutral trials. This finding has been labeled the flanker compatibility effect (Miller, 1991).

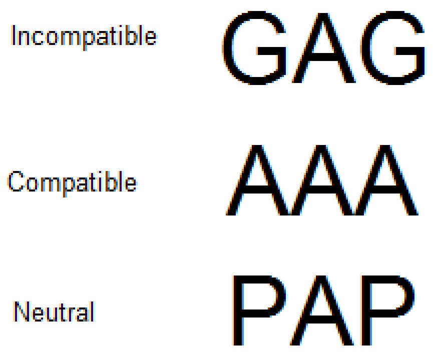

Figure 7: A typical illustration of the Eriksen flanker task. Identifying the middle target letter is harder when the flanking letter is one of the target letters in other trials due to a temporary state of response completion.

The filtering paradigm is useful because it allows researchers to study the mechanisms that lead to the processing of task-irrelevant stimuli or the successful suppression of interference effects (Luck & Vecera, 2002). Gaining insight into the conditions of distraction by irrelevant stimuli is especially important in understanding the basic mechanisms of selective attention because successful suppression of irrelevant information is a crucial function in effective selection of task-relevant stimuli.

2.3.2.3 Hybrid visual-search flanker tasks

When combining the search and filter paradigm, it is possible to produce a task where participants are required to search for target stimuli while attempting to ignore task-irrelevant, but distracting stimuli. The majority of perceptual load experiments have used a central array of letters with a peripheral distractor, though some studies have used a central distractor located at fixation (Beck & Lavie, 2005) (see C in Figure 8). The way in which the target array is organised also differs from study to study, although the majority use either a linear target array (Lavie, 1995; Tsal & Benoni, 2010a)(see A in Figure 8) or a circular target array (Benoni & Tsal, 2012; Eltiti, Wallace, & Fox, 2005; Lavie, 2005) (see B and C in Figure 8). Regardless of stimuli organisation, the emphasis is normally placed on the clear physical separation between targets and distractors.

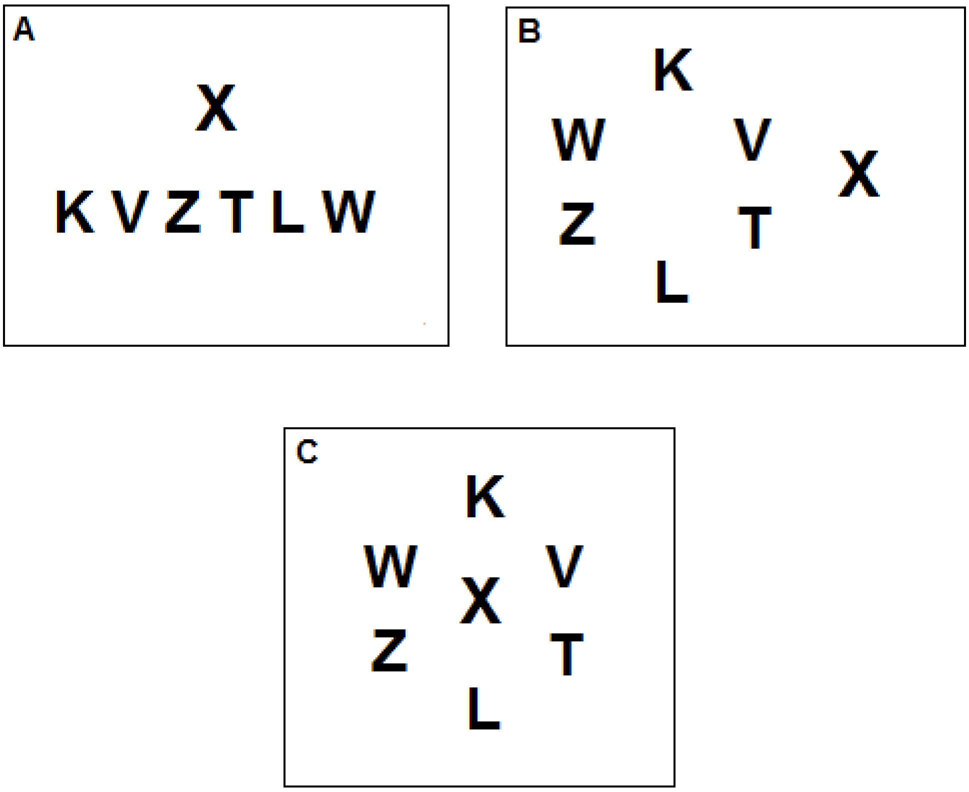

Figure 8: Examples of hybrid visual search flanker tasks where Z is the target letter and X is the distractor. NOTE: (A) Example of a linear search array with a flanking distractor. (B) Circular search array with a flanking distractor. (C) Circular search array with a central distractor.

One of the earliest attempts to investigate the perceptual load theory of selective attention required participants to make a two-choice speeded response by looking for one of two target letters (x or z) in a search array containing either five neutral items and one flanking distractor (high perceptual load) or just the target item and a flanking distractor (low perceptual load) (Lavie, 1995). The search arrays resembled the linear search array (A) in Figure 8.

The flanking distractor was either compatible with the target letter (target was z and distractor was z), incompatible (target was z and distractor was x), or neutral (target was z and distractor was a non-target letter). If the flanking distractor is processed semantically in low load conditions, the incompatible distractor will create response competition and should lead to increased mean response times for incompatible distractors trials, but not for neutral or compatible distractors trials.

Analysis revealed that, as predicted by the perceptual load theory of selective attention, low perceptual load conditions yielded increased distractor interference for incompatible distractors trials when compared to high perceptual load conditions. This lead Lavie (1995) to conclude that increasing the perceptual load by adding more neutral items to the search array sufficiently exhausted perceptual resources so that early selection could take place, thus preventing semantic processing of the distractor. On the other hand, when perceptual capacity was not reached, a spill-over effect occurred whereby the remaining perceptual resources were automatically allocated to the perception of the distractor, after which it was processed semantically and lead to distractor interference. The semantic processing of the distractor caused response competition in the low perceptual load conditions resulting in increased mean response times, manifesting as a flanker compatibility effect. Follow-up studies on the relationship between perceptual load and distractor processing have produced similar results while using a wide variety of experimental conditions. An especially influential study by Lavie & Cox (1997) replicated the results of Lavie (1995) by using circular search arrays and flanking distractors instead of the linear search arrays originally used by Lavie (1995). These two studies laid the foundation for subsequent investigations into the influence of perceptual load on selective attention.

2.3.2.4 The effect of aging on selective attention

One of the findings that lend considerable support to the perceptual load theory of selective attention is the effect of age on selective attention. A study by Maylor and Lavie (1998) compared the effect of perceptual load on distractor processing in young and old participants. As expected, older participants tended to respond slower when compared to young participants. The researchers also found that distractor interference was significantly higher for older participants when compared to younger participants in the lowest perceptual load search arrays. Maylor and Lavie attributed the greater distractor interference in the lowest load condition for older participants to the general lack of cognitive control and inhibition associated with aging, as noted by Hasher, Stoltzfus, Zacks and Rypma, (1991).

When increasing the set-size of the search arrays, however, Maylor and Lavie (1998) found that a smaller increase in perceptual load levels was required for older participants in order to reduce distractor interference compared to younger participants. The researchers attribute this finding to the general decreases in perceptual capacity associated with aging. In other words, lower levels of load are already sufficient to exhaust perceptual capacity for the older participants, leading to early selection and decreases in distractor interference. According to Maylor and Lavie this finding provides support for the perceptual load theory of selective attention since decreased perceptual capacity in older adults can directly be associated with decreased distractor interference as predicted by the perceptual load theory.

The findings of Maylor and Lavie (1998) raise an interesting paradox of sorts. The first scenario corresponds to the findings of Maylor and Lavie whereby decreases in perceptual capacity associated with aging lead to early selection, as the perceptual threshold that necessitates selection will be reached earlier for older participants. On the other hand, it can be argued that as cognitive control declines with age, distractor interference should increase regardless, because older participants might not be as successful at maintaining focus on task-relevant stimuli, due, in part, to decreased working memory function. Maylor and Lavie's (1998) result suggests that the passive perceptual capacity limitation is more fundamental than the active mechanisms of cognitive control such as working memory in determining early or late selection.

This example illustrates why accounting for the functioning of the higher order active control mechanisms becomes important within a load theory framework. The interplay between the passive perceptual capacity limitations and the more active cognitive control mechanisms may change if more strain is placed on the active control mechanisms. One way of facilitating this is to produce search arrays where distractors are more conducive to attention grab. If perceptual load capacity really is the main determinant of early or late selection, these attention grabbing distractors should not significantly increase distractor interference in high load search arrays for cognitively healthy participants as there would be no perceptual capacity left to process them, regardless of their salience. Lavie et al. (2004) recognised the importance of these cognitive control mechanisms, stating that:

> Despite perceiving irrelevant distractors, normal young adults are typically still capable of selecting the correct target response. The ability to ensure such accurate response selection in situations of late selection in which both relevant and irrelevant stimuli are perceived must depend on some active control process that ensures that behavior is appropriately controlled by goal-relevant stimuli rather than goal-irrelevant stimuli (p.341).

In an attempt to clarify the role of working memory in the selection of stimuli in both high and low perceptual load conditions, Lavie et al. (2004) manipulated working memory load by requiring participants to memorise a set of digits while they completed a hybrid search-flanker task similar to the experiment by Lavie (1995). The researchers found that increased working memory load lead to an increase in distractor interference in high load conditions. The researcher concluded that this indicates that two dissociable mechanisms are involved in the selection of stimuli. The first mechanism, perceptual load, determines whether or not distractors will be perceived and thus processed. The second mechanism, working memory, acts as a higher order control mechanism that is tasked with allocating attentional resources according to current stimulus processing priorities. When working memory is sufficiently loaded, this inhibits the attentional control mechanisms from maintaining processing priorities, thereby leading to increased distractor interference even in conditions of high load. A key finding from the study of Lavie et al. (2004) is the fact that in the low working memory load condition, perceptual load was still the primary determinant of stimuli selection.

2.4 Criticisms of perceptual load as a construct

The specific interplay between these higher order cognitive control mechanisms and the passive perceptual loading of input channels is a point on which many researchers differ. While Lavie et al. (2004) have demonstrated that when working memory is able to maintain task processing priorities perceptual load will be the primary determinant of selection, the role that the stimuli characteristics play is less clear. As will be discussed in the sections to follow, many researchers believe that perceptual load, albeit important, is not the primary mechanism responsible for early or late selection and that stimuli characteristics can either completely account for the results that researchers ascribe to perceptual load, or, in some cases, override it, thus casting doubt on the primacy of the role of perceptual load in the selection of stimuli.

2.5 Top-down and bottom-up processing

The interplay between the passive perceptual capacity limitations and the more active cognitive control mechanisms can also be expressed in terms of top-down and bottom-up processing. According to Egeth and Yantis (1997) one of the main debates in the history of visual attention research revolves around the role that top-down and bottom-up processing plays in visual perception and attention. Bottom-up attention, also called stimulus-driven attention, occurs when the characteristics of stimuli determine which stimuli are attended to.

Top-down attention, also referred to as goal-directed attention, maintains that the stimuli attended to depends on the perceiver's expectations as much as it depends on the stimulus characteristics themselves (Egeth & Yantis, 1997).

Clearly these two positions are mutually exclusive to a large extent. If stimulus characteristics are the sole, or even primary, determinant of which stimuli are given precedence in perception and processing, then the perceiver’s intentions play little to no role in determining which stimuli are attended to. On the other hand, if top-down processing has at least some part to play in which stimuli are selected and attended to, then it would be theoretically possible for participants to filter out salient stimuli that are task-irrelevant but would automatically grab attention according to bottom-up accounts of visual attention.

Of particular importance in this debate is the attentional set of the participant. Attentional set refers to the process whereby participants’ target searching behaviour is biased towards searching for the target due to the prioritisation of elements associated with the target, which is kept in working memory (Wolfe & Horowitz, 2004). Working memory thus plays a crucial role in maintaining attentional set. During visual search tasks, attentional set can facilitate the search for target stimuli since the participant’s visual search strategy is biased towards the target’s features, making it less likely that irrelevant stimuli will capture their attention; unless there are key feature overlaps between the target and the distractors. The findings from Lavie et al. (2004) is not surprising since impeding working memory from facilitating attentional set should produce increased distractor interference due to a decline in search efficiency on the part of the participant.

The goal of this brief introduction to the bottom-up versus top-down debate is to elucidate the broader findings within the field and how they relate to the perceptual load theory of selective attention. The debate regarding bottom-up versus top-down processing is especially relevant, and as will be discussed in due time, numerous researchers have utilised experimental manipulations (i.e. feature singletons) normally used by researchers interested in the debate regarding bottom-up versus top-down processing to problematise, and even contradict the original findings by Lavie (1995). The perceptual load theory of selective attention, as well as the findings from Maylor and Lavie (1998), suggests that top-down processing function secondary to the bottom-up processing, a position that some researchers do not support.

2.5.1 Evidence for bottom-up driven attention

Attempts to demonstrate the conditions under which participant's attention can be captured by task-irrelevant stimuli, despite their intentions, rely heavily on what are termed *feature singletons* (Egeth & Yantis, 1997). Feature singletons are stimuli that can be considered subjectively salient due to the fact that they contain feature characteristics that make them stand out relative to other stimuli. It is important to take into account that these feature singletons are only salient insofar as they produce a *subjective* experience of being more readily perceived.

Figure 9 (A) and (B) illustrate displays that contain different types of feature singletons. Despite the fact that all the lines are the exact same colour and length, the vertical line automatically grabs the viewer's attention in display (A). This attention grab effect is even stronger when one of the bars is a different colour (B). Notice, however, that the red bar becomes less salient in display (D) when all the bars are different colours. Display (C) is a good example of the argument made by researchers who consider bottom-up processing as more fundamental than top-down processing. Despite the fact that the display consists almost exclusively of alphabet letters, the number *4* is not easily identified despite its obvious difference in stimulus category. Despite the fact that it can be conferred semantic singleton status, their physical characteristic does not differentiate it from the alphabet letters sufficiently to facilitate attention grab. The red letter, on the other hand, easily facilitates attention grab despite its semantic similarity to the rest of the display.

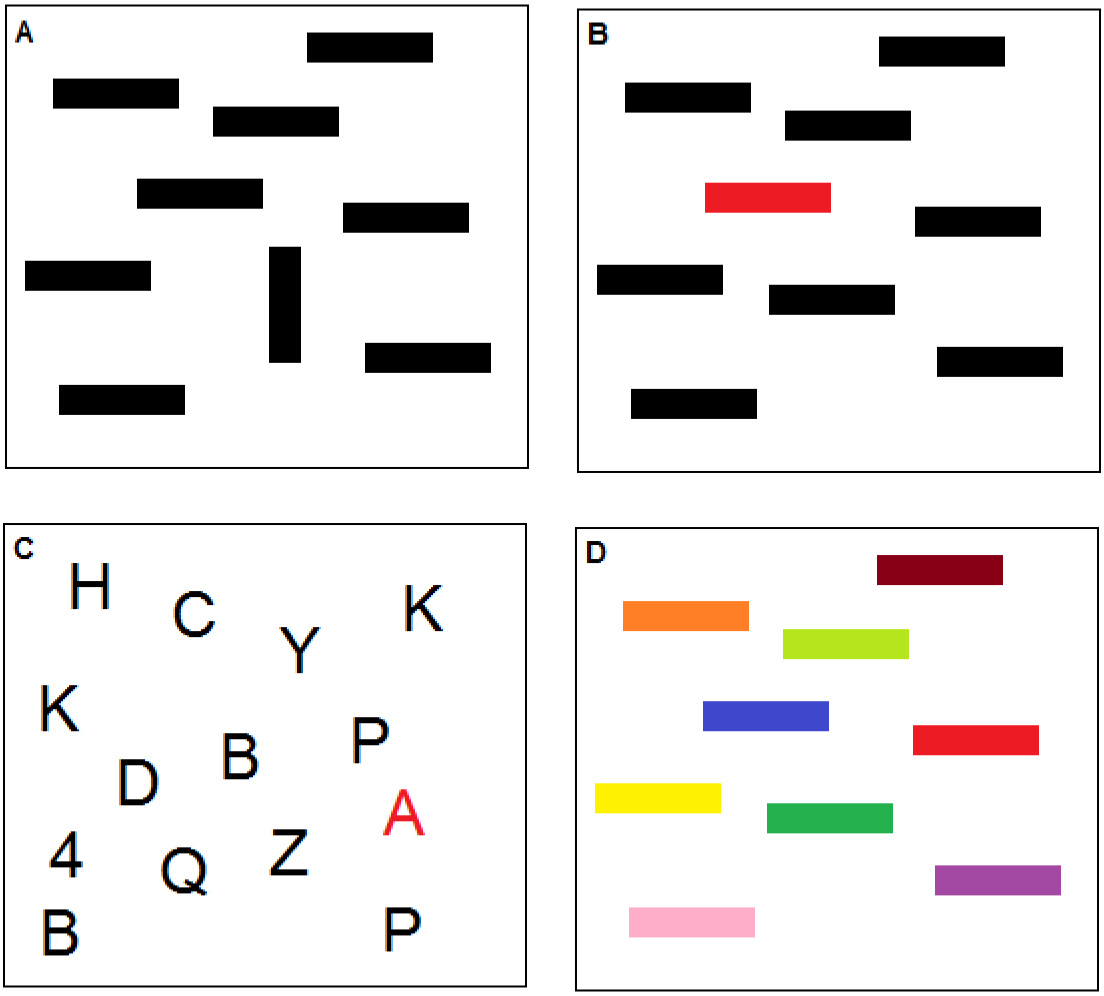

Figure 9: Different types of feature singleton displays. (A) Orientation singleton. (B) Colour Singleton (C) Semantic singleton (D) Colour singleton despite semantic similarity.

Although there are numerous experimental studies that have demonstrated the ability of task-irrelevant salient distractors[1] to automatically grab attention, a study by Theeuwes (1991) illustrates this effect particularly well. Theeuwes instructed participants to identify if the line embedded within a target circle was a horizontal line or a vertical line. Several distractor circles containing lines that were slanted were also present in the search display. If

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[1] For the sake of simplicity the terms *salient distractors* and *feature singletons* will be used interchangeably.

the target circle contained a vertical line, participants had to respond by pressing the left key on a response panel and respond by pressing the right key when the target circle contained a horizontal line. Participants had little trouble with this task when all elements within the search display were the same colour or intensity (i.e. bright or dim). However, when one of the non-target circles was a feature singleton in terms colour for example, participants responded significantly slower compared to the control condition. According to Theeuwes not even extensive practice could prevent the salient distractors from causing perceptual interference.

Experiments by Theeuwes (1992), Pashler (1988) and Theeuwes and Burger (1998) produced similar results to those of Theeuwes (1991) even when these studies defined salience along different dimensions. Despite the fact that participants were fully aware of the fact that the target would be defined in terms of shape, and that the colour singletons were entirely task-irrelevant, the colour singletons still captured their attention involuntarily; thus strengthening the proposal that top-down attentional set is not sufficient to override attention capture by feature singletons.

2.5.2 Evidence for top-down driven attention

The evidence that supports bottom-up driven attentional control appear to be quite persuasive. The top-down theorists, however, argue that only stimuli that share key feature characteristic with the target will be able to capture attention due to participants limiting their search parameters to the particular features of the target, referred to as the *contingent capture hypothesis* (Folk, Remington, & Johnston, 1992). A study by Wolfe, Cave, and Franzel (1989) found that participants’ response times, when searching for target stimuli defined by a particular feature, were faster when the features defining the target stimuli were blocked. In other words, participants responded slower when the feature that defined the target in a search task varied from trial to trial, despite the fact that the displays were identical between the random and blocked conditions. This suggests that during the blocked trial conditions participants could anticipate what targets would look like (i.e. top-down attentional set), thus making their search for the target more efficient. The researchers argued that this anticipatory effect is a strong indicator that top-down processing was guiding the way in which the participants were searching for the target stimuli.

A study by Hillstrom and Yantis (1994) also lends credence to the notion that top-down attentional set can influence the way in which participant perceive and process stimuli. Participants were instructed to search for the letter *T* embedded among distracting stimuli that appeared as the letter *L*. Participants had to indicate whether or not the target stimuli were present in the search display. The researchers constructed a control condition where the target stimulus exhibited one of several types of motion, thereby making it more salient than the other items in the search array. The fact that the response times of participants did not vary as a function of set-size provided evidence that the participants were using the motion within the target stimulus to efficiently guide their search for the target. The researchers then created a second condition where the motion occurred in an irrelevant distractor, i.e. one of the L's. Surprisingly, the presence of these moving distractors did not increase participant mean response times. Hillstrom and Yantis (1994) therefore concluded that, despite the salience of the distractors due to their motion, participants could effectively suppress their presence while searching for the target.

In order to account for the instances where feature singletons captures attention, Bacon and Egeth (1994) noted that when participants searched for a specific type of feature singleton they often narrow their attentional focus to include *any* type of stimulus that might be a feature singleton, a phenomena they called *singleton detection mode*. This may lead participants to include the unique singleton features displayed by the singleton distractors as being relevant, even when they are not. Two experiments by Bacon and Egeth corroborated this hypothesis. The first experiment replicated the results of Theeuwes (1992). The second experiment followed the same basic procedure as that of Theeuwes (1992), but included more than one target in the search displays. The researchers argued that this discouraged participants from adopting a singleton detection mode. Consequently, the distracting effect of the singleton distractor was significantly reduced, thus providing evidence that singleton attention capture might be a by-product of the search mode adopted by participants rather than the active attention grab of salient stimuli in a bottom-up processing driven way.

2.5.3 Implications of the bottom-up versus top-down debate for perceptual load theory

The top-down versus bottom-up debate leads to two scenarios that the load theory of selective attention will have to account for; both of which have been empirically demonstrated (Eltiti et al., 2005; Cosman & Vecera, 2012; Cosman & Vecera, 2009). On the one hand, if it is possible for top-down attentional set to negate the effect of perceptual load to the extent that participants do not display signs of increased distractor processing in low load displays, this would provide evidence for the fact that perceptual load functions secondary to top-down attention control mechanisms in at least some conditions. While Lavie (1995) also proposes a mainly bottom-up account of selective attention, it is not the stimulus characteristics *per se* that lead to selective attention but the perceptual load that the perceptual system is placed under. Attentional set, a mainly top-down process, plays an important role in maintaining processing priorities, but apart from catastrophic breakdowns such as the inhibition of working memory demonstrated by Lavie et al. (2004), it should not be able to override the influence of perceptual load regularly or reliably. Lavie's (2004) perceptual load theory of selective attention can thus best be classified as a hybrid between bottom-up and top-down accounts of selective attention, where the bottom-up process is driven largely by perceptual load and not stimulus characteristics and the maintianing of task-processing priorities is facilitated by active top-down control mechanisms, such as working memory.

The second empirical finding that the load theory of selective attention will have to account for is the possibility that salient colour singletons distract participants in high perceptual load conditions. If this occurs then it may indicate that feature salience overrides perceptual load when it comes to the selection of stimuli. Load theorists will most likely point toward the temporary failure of the attentional control mechanisms in maintaining focus on task-relevant stimuli as the likely cause (see Maylor and Lavie, 1998). However, it is unlikely that a group of cognitively healthy participants would experience repeated and pervasive failures to maintain task-relevant processing priorities, especially when searching for familiar targets where their top-down attentional set already biases their search efficiency in favour of the target stimuli. With these two challenges in mind, alternative accounts of the empirical evidence that support the load theory of selective attention will be discussed.

2.6 Alternative accounts of the effect of perceptual load on selective attention

Although the load theory of selective attention has garnered much support since its proposal, alternative accounts of the empirical findings have been proposed. For example, various studies that manipulated perceptual load jointly with other factors found that target-distractor salience (Eltiti, Wallace, & Fox, 2005; Biggs & Gibson, 2010), pre-cuing of the target letter (Johnson, McGrath, & McNeil, 2002), target-distractor dilution (Benoni & Tsal, 2010), target-distractor proximity (Paquet & Craig, 1997), and attentional set (Theeuwes, Kramer, & Belopolsky, 2004) all modify or even reverse the effects of perceptual load on selective attention. The two most important accounts attribute the findings of experimental manipulations of set-size (i.e. what Lavie (1995) attributes to perceptual load) to the dilution of the stimuli or the relative salience of the stimuli.

2.6.1 Dilution account

Tsal and Benoni (2010b) argue that much of the support for the perceptual load theory of selective attention stems from the use of set-size (number of neutral items) as the main manipulation of perceptual load. The authors point out that the use of set-size to manipulate perceptual load may in fact decrease distractor interference by decreasing the quality of the distractor representation and adding irrelevant *noise* from the neutral items. This is in contrast to perceptual load theory where distractor interference in high load conditions is eliminated due to the depletion of perceptual resources. In other words, according to the dilution account, any decreases in distractor interference can be attributed to a reduction in the relative weight of the distractor's interference amidst neutral items that also create interference.

In a study designed to examine this hypothesis, Tsal and Benoni (2010a) separated the effects of load and dilution by creating high perceptual load search arrays that required relatively low processing since the target letter was a different colour than the neutral items (see Figure 10). The results of the study were incompatible with the load theory of selective attention because no distractor interference was observed for this low perceptual load but high dilution condition. Furthermore, when the authors controlled for dilution, high load, and not low load, produced greater interference.

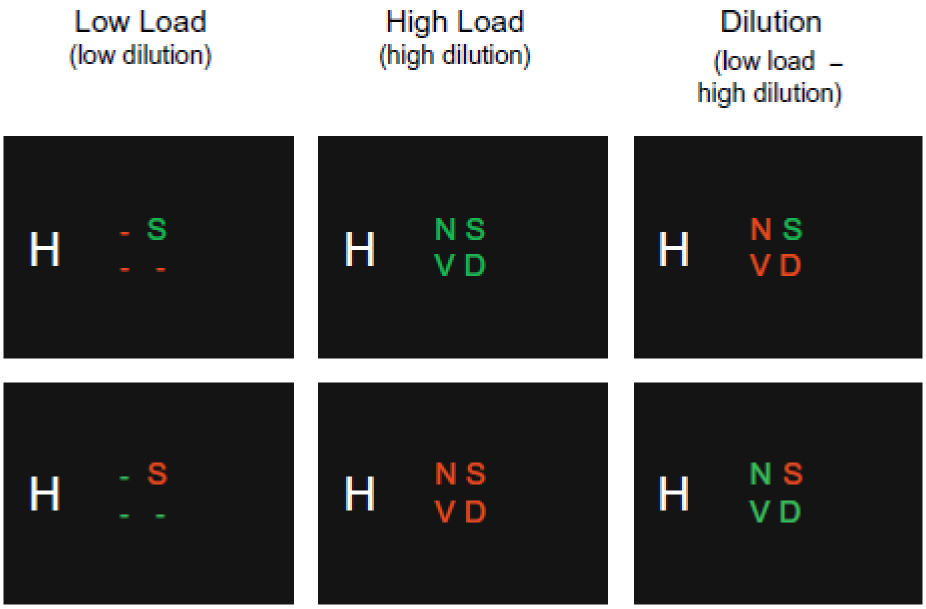

Figure 10: Examples of the different perceptual load and dilution search arrays. Reprinted from "Where have we gone wrong? Perceptual load does not affect selective attention". H. Benoni & Y. Tsal. 2010. *Vision Research*, 50, p.1293.

Tsal and Benoni (2010a) found that the compatibility effect could be manipulated independently of perceptual load when distractor dilution is accounted for. A study by Wilson, Muroi, and MacLeod (2011) observed the same pattern of results as Tsal and Benoni (2010a) by visually pre-cuing the location of the target stimuli, thereby decreasing perceptual load. Wilson et al. (2011) account for the confusion regarding the influence of perceptual load by stating that:

> Upon presentation of the search display, the search letters are processed in parallel to determine the likely target location (first stage). Having identified the probable target location, that location is selected for further processing (second stage). Because attention is focused on one location, the load for this second stage is essentially one item. Furthermore, the nontarget search letters and the distractor are all considered irrelevant items for this second stage and are all subject to the effects of dilution (p. 321).

According to this two-stage account of selection, high load displays reduce distractor interference because focus during the second stage of processing narrows sufficiently for the neutral items and the distractor to be considered irrelevant. Benoni and Tsal (2011) notes that a variety of condition can cause decreased distractor processing even in low load search arrays, thus shedding doubt on the role of perceptual load being the key mechanism for selection.

However, Lavie and Torralbo (2010) argue that Tsal and Benoni (2010a) mistakenly view their colour singleton target condition as a low load search array simply because the target is easily identifiable. Lavie and Torralbo then go on to argue that this is not necessarily the case, as neutral items will still be processed due to perceptual spill-over effect, regardless of their low level feature dissimilarity (i.e. colour) in comparison to the target. Lavie and Torralbo also point out that Tsal and Benoni's (2010a) high load displays were different to the low load displays as only the low load displays contained a colour singleton. This absence of a colour singleton may have influenced the results.

In addition to the confounding of dilution and perceptual load as mentioned above, Benoni and Tsal (2013) claim that the lack of a clear definition of perceptual load often leads to circular reasoning in the operationalisation of the construct. Tsal and Benoni (2013) argue that perceptual load lacks an *a priori* definition as the use of the dependent variable as a manipulation check is an indication that perceptual load cannot be defined independently of its effects. Successful manipulation of perceptual load is often inferred by noting increases or decreases in mean response times across perceptual load conditions, despite the fact that response time is a dependent variable in many of the studies. The use of a dependent variable as a manipulation check is problematic since it blurs the line between experimental manipulations of the independent variable and the resultant effect on the dependent variable.

The lack of any *a priori* criteria in defining perceptual load could potentially render perceptual load theory unfalsifiable. If increases in perceptual load fail to produce increased response times, researchers can simply claim that the experimental manipulation of load failed and that the subsequent results are not valid. In addition to this, if manipulation of perceptual load does not lead to increases or decreases in response time, then the interaction between perceptual load and other factors -such as distractor compatibility– may be uninterpretable. In effect, it would be unclear whether or not the null result was produced by a failure to successfully manipulate perceptual load or a lack of a significant interaction. Distractor processing can simply be attributed to insufficient perceptual load, thereby exposing the circularity of the argument. In order to fully disentangle dilution and perceptual load it would appear that one would have to experimentally manipulate these two constructs entirely independently; something that might not be possible to achieve experimentally via search arrays due to the potentially inherent conflation of these two constructs.

2.6.2 Salience account of selective attention

Similar to Benoni and Tsal (2013), Biggs and Gibson (2013) argue that the use of set-size to increase perceptual load may also reduce the distractor’s salience, thus decreasing any potential target-distractor interference. In this context salience can be defined as the degree to which a stimulus *stands out;* also referred to as the *pop-out effect* or the ability of the distractor to *grab* attention (Biggs & Gibson, 2010). The salience account maintains that the addition of neutral items to a search array leads to a reduction in the relative salience of the distractor, thus reducing its ability to capture attention and cause response competition and interference (Theeuwes, 2010).

A number of studies have investigated the relationship between perceptual load and salience, often using different experimental manipulations of both load and salience, depending on the particular paradigmatic point of departure of the study. For example, a study by Paquet and Craig (1997) that is similar to the one by Wilson et al. (2011) found that distractor interference can be significantly reduced in low perceptual load flanker tasks when the salience of the distractor relative to the target is reduced by pre-cuing the position of the target. This is a problematic finding for perceptual load theorists since the automatic perceptual spill-over account they use to argue against dilution accounts imply that distractors will automatically be processed in low load conditions regardless of target pre-cuing. If all items are perceived in parallel, then the automatic processing of the distractors should theoretically still lead to compatibility effects even if the target is identified. However, Paquet and Craig (1997) did not include any high perceptual load conditions in the study to compare their findings to, thus limiting the generalisability of the results.

Expanding on the study of Paquet and Craig (1997) a study by Johnson, McGrath and McNeil (2002) set out to investigate the interaction between load and target cuing utilising both low and high perceptual load search arrays similar to the ones used by Lavie and Cox (1997). Johnson et al. (2002) found that significant distractor interference occurred in low perceptual load search tasks but not in high perceptual load tasks when target letters were not pre-cued. This finding is important as it replicates the findings of prior experimental studies that support the load theory of selective attention. However, when pre-cuing the target positions, distractor interference was significantly reduced in low perceptual load search arrays. The researchers concluded that increasing the salience of the target by pre-cuing the position of the target can significantly reduce distractor interference, thereby strengthening the validity of the results of Paquet and Craig (1997). This finding supports the idea that the relative reduction in the salience of the distractor in high perceptual load conditions may be the mechanism behind reduced distractor interference and not perceptual load. An additional suggestion made by the authors is that these results indicate that top-down processes do play at least some role in selective attention under certain conditions, such as pre-cuing. This finding is problematic from a perceptual load theory perspective as the passive loading of the perceptual system, an inherently bottom-up process, is supposed to be responsible for selection of stimuli.

The relationship between target and distractor salience has been expanded on in a study by Eltiti et al. (2005) which found that distractors that were formed by taking away features of another task-irrelevant stimulus (offsets) caused less interference than distractors that were presented simultaneously with targets (onsets) in low load conditions. The authors account for the findings by suggesting that distractors formed by taking away elements of another stimulus decrease the salience of the distractor, thereby decreasing the distractor's ability to cause interference.

The studies described above partially contradict the predictions made by load theory, since they suggest that distractor interference can be accounted for independently of load by manipulating the salience of the distractor via pre-cuing or offsets. The basic assumption of the strong version of load theory is that distractors will be processed *only* when perceptual capacity has not been reached for task-relevant stimuli, irrespective of stimuli characteristics.

One fundamental drawback of the studies described above is that they used pre-cuing and distractor offset to manipulate the relative salience of the distractors. Due to the fact that traditional investigation such as those by Lavie (1995) and Lavie and Cox (1997) used static distractors, the results from Eltiti et al. (2005) and Johnson et al. (2002) may not be directly comparable as dynamic distractors might be inherently more salient than static distractors. Whereas these findings might problematise the strong version of the load theory of selective attention where perceptual load is the main determinant of selection, it is unclear whether these findings generalise to static salient stimuli, such as colour singletons.

In order to address this question Gibson and Bryant (2008) examined the relative influence of perceptual load and colour singleton distractors within a visual search task. The authors found that, despite the fact that salient distractors can attract attention, thereby influencing the order in which target items were searched, only load determined if the distractor's identity was processed. This is an important finding as it suggests that perceptual load can dominate salience in static displays depending on the level of load a search task induces. It should be pointed out, however, that the search task used by Gibson and Bryant differed from the hybrid flanker task used by Lavie (1995) or Beck and Lavie (2005) in three important ways since it resembled the experimental search arrays of Theeuwes and Burger (1998): the distractors were imbedded within the search array, stimuli remained on screen until the participant responded or two seconds had elapsed, and distractor compatibility was calculated only for compatible and incompatible items and not for neutral items.

Biggs and Gibson (2010) cite the last difference as especially important since it may be a biased measure of the compatibility effect. Additionally, whereas the traditional hybrid flanker task differentiates between relevant and irrelevant stimuli in terms of spatial features (by placing distractors as flankers), Gibson and Bryant (2008) followed a similar design to that of Theeuwes and Burger (1998) by differentiating between relevant and irrelevant stimuli based on a singleton colour feature i.e. different coloured rings around the distractors. Gibson and Bryant (2008) did demonstrate experimentally that salient distractors only capture attention in conditions that can be classified as low perceptual load conditions, although their search arrays embedded the distractor within the search array, thus potentially reducing the distrator's positional saliency and subsequent interference ability.

A study by Forster and Lavie (2008) also reiterated the primacy of perceptual load over salience in determining stimuli selection by presenting participants with search arrays where entirely task-irrelevant characters –such as Spongebob Squarepants or Spiderman- were displayed alongside the search arrays. Forster and Lavie found that only low load conditions facilitated processing of these entirely irrelevant, but highly distracting images.

Finally, a series of experiments by Gaspelin, Ruthruff, Jung, Cosman, and Vecera (2012) illustrated that salient distractors may have the opposite effect of that predicted by proponents of the bottom-up driven account of selective attention. Gaspelin et al. (2012) found that colourful salient distractors produced a smaller compatibility effect compared to non-salient distractors. The researchers argue that the inclusion of a salient colourful distractor can in fact aid participants' search efficiency by allowing them to effectively filter out the salient distractor based on the incompatibility with the target stimulus along the colour dimension. This finding is in line with the predictions made by the contingent capture hypothesis. Due to a fundamental mismatch in the stimulus features that the participant is searching for -despite its identity relevance– the participants effectively filter the distractor by never processing it beyond its basic feature identity such as colour.

At this stage it is not entirely clear to what extent top-down and bottom-up processing interacts within a load theory framework, or if the load theory represents a specific type of hybrid top-down\bottom-up account that applies only to certain types of search arrays or stimuli. Some researchers argue that salient distractors capture focal attention and causes interference when their identity is also processed independently of load (see for example Eltiti et al, 2005), while others argue that capture by salient distractors can only occur when perceptual selectivity is low, as in the case of low perceptual load conditions (see for example Lavie, 2010).

While the use of set-size may confound visual salience and perceptual load no experimentally viable alternative for manipulating perceptual load and visual salience independently from one another has been proposed. At best researchers can attempt to manipulate the relative levels of salience and load. A recent paper by Biggs and Gibson (2014) underscored this predicament by stating that "…the problem with using inseparable experimental manipulations is that they yield inseparable effects." (p. 8). This might also explain why the findings from empirical investigations of the perceptual load hypothesis have been so inconsistent. The complex interactions of factors that mediate selective attention very likely lead to minor, but important, differences in the operationalisation of various constructs such as perceptual load and salience across studies (Giesbrecht et al., 2014).

2.7 Conclusion

In conclusion, the perceptual load theory of selective attention posits that late selection of stimuli only occurs if perceptual capacity limitations have not been reached. If perceptual capacity has been reached, however, the perceptual system is forced to filter out irrelevant stimuli in order to prevent the overload of the system, thereby leading to early selection.

Although numerous studies have replicated these basic findings, some studies have failed to produce a compatibility effect for low perceptual load trials by manipulating key factors of the search task or the stimuli characteristics. One of the key findings is that pre-cuing the target letter can effectively suppress any compatibility effect, suggesting that top-down attentional control can easily override the functioning of perceptual load in determining early or late selection. This primacy of salience over perceptual load has also been demonstrated for target offsets. This has lead researchers to suggest that the results attributed to perceptual load can also be accounted for by the reduction in the salience or dilution of the distractor in high perceptual load conditions.

It is also not clear to what extent perceptual load and distractor salience can interact to produce early or late selection. The main question guiding this study is if a colour salient distractor, created by making it a colour singleton, will aid search efficiency, hinder it, or have no impact on search efficiency. If the colour singleton distractor can capture attention in a purely stimulus-driven, or bottom-up, manner then this would be especially prominent in the low perceptual load trials due to excess availability of perceptual capacity. Due to the automatic perception and semantic processing of the distractor identity caused by perceptual spill-over, a compatibility effect should theoretically occur regardless of the salience of the distractor if perceptual load is the primary determinant of early or late selection. Lavie et al. (2004) did propose the existence of top-down control mechanisms tasked with maintaining task processing priorities, but these mechanisms should only prevent the salient distractor from capturing attention in the high load conditions, but should not be able to effectively suppress the perception of the salient distractor in low perceptual load trials as suggested by Gaspelin et al. (2012), for example. In essence, perceptual load theory hypothesises that salient distractors should not produce significant deviations in the general pattern of results that support the theory, where low perceptual load trials produce a compatibility effect, but high perceptual load trials do not.

3. Methodology

3.1 Introduction

The following chapter outlines the methodology that was used for this study. In choosing the appropriate methodology, the researcher delineates the mode of inquiry that will guide the study. In other words, the particular approach a researcher takes in formulating the research questions, gathering and analysing the data, and even the limitations of the results, are all linked to the researcher's choice of methodology. It thus stands to reason that the researcher's choice of methodology is always underpinned by epistemological and ontological considerations (Hughes, 1990).

Before choosing the methodology, the researcher should anticipate which methodological approach can provide sufficient evidence to address the research questions. To this end, it is important to consider past work done in the field, as well as the broader research paradigm within which the study is situated. In reading the relevant literature, it becomes apparent that a significant proportion of modern approaches to studying attention emphasise the use of empirical data in evaluating the evidence that supports theories of attention. According to Pashler (1998) empirical approaches are important due to the inherent difficulty in evaluating different, often contradictory, nuanced derivations of models of attention. Empirical data, gathered during experimental testing of the hypotheses –formulated from a particular theoretical framework- can be used to modify or adapt theories and models of attention.

According to Shadish, Cook, and Campbell (2002) experimental approaches to science can be thought of as attempts to systematically expose causal relationships between phenomena or variables, and, in turn, generalise these relationships to higher order rules or theories. Echoing this sentiment Tversky and Kahneman (1981) state that one of the keys to testing a model's validity is to examine the outcomes of variable interactions of interest to the researcher. Internal coherence or theoretical elegance is important, but equally important is the empirical foundation that supports the model's predictions. This type of approach is exemplified by the information processing approach to the study of cognition, since data is used to shape and refine a theory, and the theory, in turn, is used to explain the data (van der Heijden & Stebbins, 1990).

Given the theoretical and paradigmatic point of departure for this study, a quantitative methodology was chosen. A quantitative methodology allows the researcher to utilise empirical data to test hypotheses about the relationships between the variables of interest. In order to draw causally valid inferences from the empirical data, however, three basic conditions have to be met (Shadish, Cook, & Campbell, 2002). First, the cause must precede the effect. Second, the cause and effect have to covary. Third, alternative explanations for the relationship have to be ruled out. For this particular study it was particularly important to minimise the impact of mediating variables that could serve as alternative explanations for the results. By leveraging experimental design strategies, attempts were made to negate the potential impact of these mediating variables. The rationale behind the choice of an experimental design will be expanded on in the section that describes the experimental design used for the study.

3.2 Research question, aims and objectives

According to Biggs and Gibson (2010), visual salience and perceptual load probably interact in meaningful ways to influence visual selective attention. The main aim of this study is to expand the debate on load theory by examining the interaction between distractor salience and perceptual load by utilising a hybrid visual search-flanker task. Of particular importance is whether or not attentional set can aid participants in ignoring salient distractors more effectively due to the irrelevance of the colour feature for salient distractors, thereby aiding their search efficiency.

3.2.1 Objectives and hypotheses

The primary objective of this study is to observe shifts in selective attention under different conditions of perceptual load, distractor compatibility and distractor salience. Shifts in selective attention are operationalised as increases or decreases in mean response times and error rates, though it was decided not to use error rates due to data constraints, as will be discussed in the chapters that report on the results of the analyses.

Given the factorial structure of the design, it is possible to formulate seven hypotheses reflecting all main effects, as well as two-way and three-way interactions effects. The alternate hypotheses are given below:

3.2.1.1 Hypothesis 1

(H_0: $\mu_{\text{Low Load}} = \mu_{\text{High Load}}$: H_1: $\mu_{\text{Low Load}} \neq \mu_{\text{High Load}}$): the mean response times for high perceptual load trials will be different from the mean response times for low perceptual load trials.

3.2.1.2 Hypothesis 2

(H_0: $\mu_{\text{Salient}} = \mu_{\text{Non-salient}}$: H_1: $\mu_{\text{Salient}} \neq \mu_{\text{Non-salient}}$): the mean response times for salient distractor trials will be different from the mean response times for non-salient distractor trials.

3.2.1.3 Hypothesis 3

(H_0: $\mu_{\text{Incompatible}} = \mu_{\text{Neutral}}$: H_1: $\mu_{\text{Incompatible}} \neq \mu_{\text{Neutral}}$): the mean response times for incompatible distractor trials will be different from the mean response times for neutral distractor trials.

3.2.1.4 Hypothesis 4

(H_0: $A - B = 0$: H_1: $A - B \neq 0$: where $A = (\mu_{\text{Low Load\textbackslash{} Incompatible}} - \mu_{\text{Low Load\textbackslash{} Neutral}})$: $B = (\mu_{\text{High Load\textbackslash{} Incompatible}} - \mu_{\text{High Load\textbackslash{} Neutral}})$: there is a two-way interaction between perceptual load and distractor compatibility.

3.2.1.5 Hypothesis 5

(H_0: $A - B = 0$: H_1: $A - B \neq 0$: where $A = (\mu_{\text{Low Load\textbackslash{} Salient}} - \mu_{\text{Low Load\textbackslash{} Non-salient}})$: $B = (\mu_{\text{High Load\textbackslash{} Salient}} - \mu_{\text{High Load\textbackslash{} Non-salient}})$: there is a two-way interaction between perceptual load and distractor salience.

3.2.1.6 Hypothesis 6

(H_0: $A - B = 0$: H_1: $A - B \neq 0$: where $A = (\mu_{\text{Incompatible\textbackslash{} Salient}} - \mu_{\text{Incompatible\textbackslash{} Non-salient}})$: $B = (\mu_{\text{Neutral\textbackslash{} Salient}} - \mu_{\text{Neutral\textbackslash{} Non-salient}})$: there is a two-way interaction between distractor compatibility and distractor salience.

3.2.1.7 Hypothesis 7

(H_0: $A - B = 0$: H_1: $A - B \neq 0$: where $A = (\mu_{\text{Low Load\textbackslash{} Incompatible\textbackslash{} Salient}} - \mu_{\text{Low Load\textbackslash{} Incompatible\textbackslash{} Non-salient}}) - (\mu_{\text{Low Load\textbackslash{} Neutral\textbackslash{} Salient}} - \mu_{\text{Low Load\textbackslash{} Neutral\textbackslash{} Non-salient}})$ and $B = (\mu_{\text{High Load\textbackslash{} Incompatible\textbackslash{} Salient}} - \mu_{\text{High Load\textbackslash{} Incompatible\textbackslash{} Non-salient}}) - (\mu_{\text{High Load\textbackslash{} Neutral\textbackslash{} Salient}} - \mu_{\text{High Load\textbackslash{} Neutral\textbackslash{} Non-salient}})$: there is a three-way interaction between perceptual load, distractor salience, and distractor compatibility.

Recall that the compatibility effect occurs when incompatible distractor trials produce higher mean response times compared to neutral distractor trials, but only in trials that induces low perceptual load. By decomposing the interaction between perceptual load and distractor compatibility using two separate two-way ANOVA’s and planned comparisons for the different levels of distractor salience, the following hypotheses were also addressed:

3.2.1.8 Hypothesis 8

(H_0: $\mu_{Incompatible} \leq \mu_{Neutral}$: H_1: $\mu_{Incompatible} > \mu_{Neutral}$): mean response times for incompatible distractor trials will be higher than the mean response times for neutral distractor trials when the distractor is non-salient and the search array induces low perceptual load.

3.2.1.9 Hypothesis 9

(H_0: $\mu_{Incompatible} \leq \mu_{Neutral}$: H_1: $\mu_{Incompatible} > \mu_{Neutral}$): mean response times for incompatible distractor trials will be higher than the mean response times for neutral distractor trials when the distractor is non-salient and the search array induces high perceptual load.

3.2.1.10 Hypothesis 10

(H_0: $\mu_{Incompatible} \leq \mu_{Neutral}$: H_1: $\mu_{Incompatible} > \mu_{Neutral}$): mean response times for incompatible distractor trials will be higher than the mean response times for neutral distractor trials when the distractor is salient and the search array induces low perceptual load.

3.2.1.11 Hypothesis 11

(H_0: $\mu_{Incompatible} \leq \mu_{Neutral}$: H_1: $\mu_{Incompatible} > \mu_{Neutral}$): mean response times for incompatible distractor trials will be higher than the mean response times for neutral distractor trials when the distractor is salient and the search array induces high perceptual load.

These planned comparisons were all tested against the null that mean response times for incompatible distractor trials were equal to or lower than mean response times for neutral distractor trials.

In order to conclude that a compatibility effect exists for non-salient distractor trials, sufficient evidence to warrant the rejection of null hypothesis 8, but not hypothesis 9, will have to be demonstrated. Conversely, in order to conclude that a compatibility effect exists for salient distractor trials, sufficient evidence to warrant the rejection of hypothesis 10, but not hypothesis 11, will have to be demonstrated. Hypotheses 9 and 10 are primarily aimed at establishing the existence of a compatibility effect in non-salient distractor trials that can serve as a baseline against which the results from salient distractor trials can be qualitatively compared. Hypothesis 10 is aimed at investigating the possibility that salient incompatible distractor trials lead to a reduction in response competition as predicted by Gaspelin et al. (2012). Hypothesis 11 is aimed at establishing if it is possible for high perceptual load trials to produce distractor interference in the presence of salience distractors as predicted by bottom-up driven accounts of selective attention (Theeuwes & Burger, 1998).

3.3 Experimental Design

In the context of this study the experimental design served two main goals: (1) to control for variance that may obscure the results and (2) to provide a framework within which to align the research questions with the data gathering strategies and techniques (Kerlinger, 1988). In order to negate the effect of potential confounds, the study used a 2 x 2 x 2 crossed repeated-measures design. A crossed design allows the researcher to expose all participants to all levels of the independent variables (Gravetter & Forzano, 2009). The main advantage of using a crossed design is the fact that meaningful interactions between the factors of interest can be systematically evaluated and traced (Shadish, Cook, & Campbell, 2002).

The principal within-subjects factors were: *perceptual load level* (high load vs low load), *distractor compatibility* (incompatible distractors vs neutral distractors) and *distractor salience* (salient distractors vs. non-salient distractors). Perceptual load levels were characterised by the number of neutral items included in the search array. Low perceptual load conditions contained no neutral letters, while high load conditions contained five neutral letters. Incompatible distractor trials contained a distractor that was the non-represented target and neutral trials contained an irrelevant distractor. Distractor salience was manipulated via the colour of the distractor relative to the target. High salience trials contained a distractor that was orange in colour, while low salience trials contained a distractor that was the same colour as the target and neutral letters. The main dependent variables in all conditions were response time measured in milliseconds and error rates expressed as percentages. Table 1 provides a summary of the different experimental conditions that this design yielded. Appendix A graphically illustrates the different experimental conditions.

Table 1

Summary of the factor level combinations to produce the experimental conditions

	High Load	Low Load	Incompatible Distractor	Neutral Distractor	High Salience	Low Salience
HIS (Condition 1)	+	-	+	-	+	-
HIN (Condition 2)	+	-	+	-	-	+
HNS (Condition 3)	+	-	-	+	+	-
HNN (Condition 4)	+	-	-	+	-	+
LIS (Condition 5)	-	+	+	-	+	-
LIN (Condition 6)	-	+	+	-	-	+
LNS (Condition 7)	-	+	-	+	+	-
LNN (Condition 8)	-	+	-	+	-	+

Note. A plus sign (+) indicates the presence of the factor in the trial condtion

3.4 Sampling

A review of the literature reveals that the samples of previous studies comprised of undergraduate university students (see Benoni & Tsal, 2010; Biggs & Gibson 2014; and Lavie & Cox, 1997, for examples). To create a comparative sample, a convenience sample of university students was chosen for the experiment. The use of university students allowed for comparisons of the results with studies that used similar samples.

The study utilised a non-probability sampling strategy. Non-probability sampling involves the selection of individuals from a population where the particular parameters of that population are unknown (Gravetter & Forzano, 2009). The individuals from the population do not have an equal chance of being selected, thus increasing the chances of sample bias. In an effort to negate possible sampling bias from influencing the outcome of an experiment, researchers often control for sample characteristics by attempting to ensure homogeneity of the sample along participant characteristics of importance (Harris, 2008). Although numerous factors such as gender, language ability and computer usage patterns may have had a significant effect on participants' response times and error rates, the limited focus of the research questions meant that these factors could not all be reasonably controlled for.

Given the utilisation of response times and error rates as the dependent variables, the sampling strategy controlled for age as a potential confounding factor. The reason for explicitly controlling for age in this experiment is attributable to the well established link between aging and decreases in general cognitive functioning and response times (Ratcliff, Thapar, & McKoon, 2001). A study by Hultsch, MacDonald, and Dixon (2002) also found that aging was associated with greater dispersion of response times across tasks and inconsistency of performance across trials. In order to align the sampling strategy with those done by other researchers in the field and to ensure that age related cognitive decline did not serve as a confounding factor, age was controlled for in the study by limiting the age range of eligible participants to between 21 and 30 years of age. All participants had normal to corrected-normal vision and displayed no signs of colour-blindness after completing a shortened version of the Ishihara colour-blindness test (Ishihara, 1972).

3.4.1 Sampling procedure

Twenty full-time postgraduate students from the University of Pretoria between the ages of 21-30 were recruited as participants for the study. Students were invited to participate in the experiment via a short presentation during one of their scheduled classes. After the presentation a list was provided where students who were interested in participating in the experiment could write down their contact details, thus giving the researcher permission to contact them. An email was sent to the students who provided their contact details. The email contained information on the selection criteria for eligibility, as well as additional instructions for those students who were still willing to participate in the study. The eligibility criteria were: (1) the participants had to have been between the ages of 21 and 30 years of age, (2) have normal or corrected-to-normal vision and no indication of colour-blindness, (3) must have been enrolled as a full-time postgraduate student at the University of Pretoria, (5) participants had to have been proficient in English, and lastly (6) participants had to be able to give oral or written consent to be a part of the study.

The eligibility criteria served a dual role. On the one hand, these criteria ensured that a sample could be obtained that would be comparable to samples used in prior research on selective attention and perceptual load. On the other hand, these criteria served as sampling restrictions aimed at limiting the influence of potential confounds such as age and education level on the results. The age of participants served as exclusion criteria in order to create a sample that would be comparable with previous studies found in the literature and to control for age related cognitive deficits that may have influenced response times. Due to the use of bright orange distractors as colour salient stimuli, participants who suffer from colour-blindness may experience the stimuli to be less salient than those participants who are not colour-blind. It was therefore important that none of the participants displayed symptoms of colour-blindness. In order to ensure homogeneity in terms of education levels only postgraduate students from the University of Pretoria were eligible to participate in the experiment. Lastly, in order to read and understand the consent form and the instructions for the experiment, participants had to have been proficient in English.

Before the start of the experiment, participants were once again informed of their right to voluntarily withdraw from the study at any stage without penalisation. After giving written consent, participants were allowed to start the experiment. Table 2 reports the final sample obtained for the study in terms of gender and age.

Table 2

Summary of the Sample Demographics (n = 20)

	Females	Males	Total
Age	%	%	%
21 years old	40% (8)	-	40% (8)
22 years old	25% (5)	5% (1)	30% (6)
23 years old	25% (5)	-	25% (5)
24 years old	5% (1)	-	5% (1)

The majority of the sample consisted of female participants (n = 19) with only one male participant having taken part in the experiment. The sample was thus heavily biased in terms of gender distribution. Forty percent of the sample consisted of 21 year old participants with the oldest participant being 24 years of age. This means that the sample was relatively homogonous in terms of age.

3.4.2 Colour blindness

In order to assess whether or not any of the participants displayed symptoms of colour-blindness a truncated version of the Ishihara colour-blindness test was completed by all participants before the experiment. The Ishihara colour-blindness test, published in 1917 by Shinobu Ishihara was designed as a quick and reliable way to assess red-green colour-blindness (Ishihara, 1972). The full test comprises 38 plates and the shortened version consists of 24 plates. All plates consist of patterns of dots which form a number or shape that is invisible to people who suffer from colour-blindness. People who suffer from colour-blindness are not able to detect the numbers or patterns due to the lack of differentiation between the dots surrounding the number or pattern and the dots that make up the number or pattern. No analysis was conducted for the results of the truncated Ishihara colour-blindness test as all participants responded correctly to all plates, thereby giving no indication of colour-blindness.

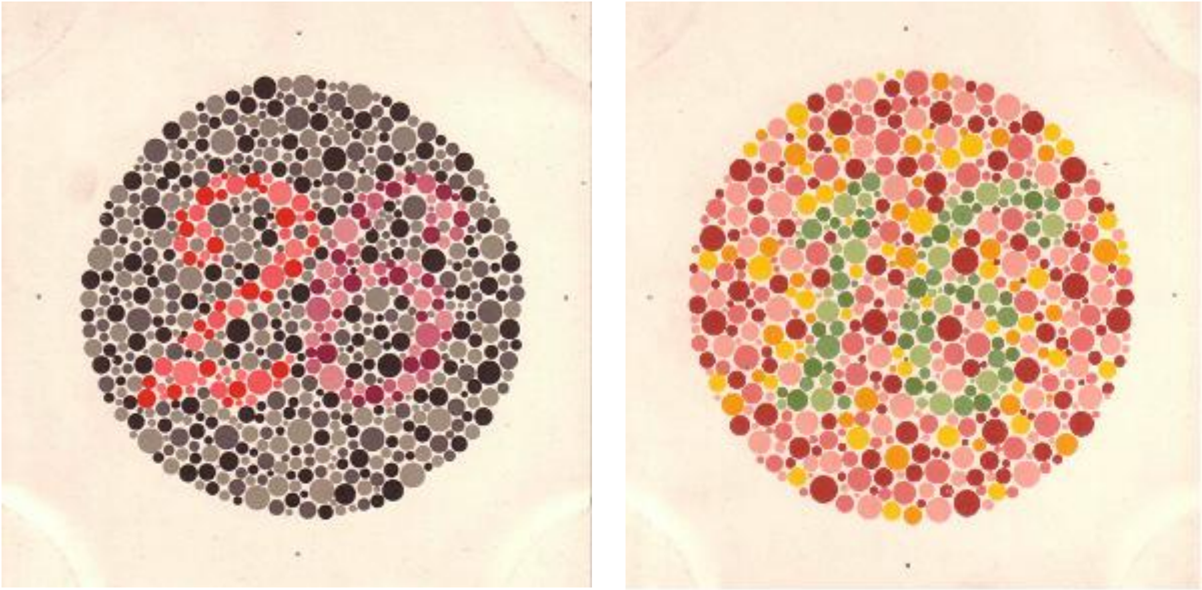

Figure 10: Two example plates from the Ishihara colour-blindness test. Reprinted from "Ishihara tests for colour-blindness". S. Ishihara. 1972. Tokyo: Kanehara and Co.

3.5 Stimuli and apparatus

3.5.1 Stimuli

The experiment was conducted in a room on the Hatfield campus of the University of Pretoria. The search items appeared in a circular search array and were placed at equal intervals at a viewing distance of approximately 60cm. Sixty centimetres was chosen as the standard viewing distance, as this is the optimal distance to avoid eye and postural fatigue. Monitors that are placed too close to a participant's eyes may cause eye strain. Rempel, Willms, Anshel, Jaschinski, and Sheedy (2007) recommend that the monitor be placed between 52cm and 73cm from the participant's eyes to optimise visual and postural comfort.

Equal spacing of the stimuli is required in order to create a symmetrical search array where all stimuli are an equal distance from the fixation point. This is important, since any asymmetry within the search array could lead to increases in the relative salience of the letters closest to the fixation point. One of the key considerations for selecting the size of the stimuli was the extent to which peripheral visual acuity would impact on the participants' ability to identify the distractors. Due to the structure of the eye's retina, foveal acuity is much sharper than peripheral acuity (Anstis, 1998). In order to compensate for the change in visual angle and the degradation of visual acuity as the stimuli move towards the periphery of vision, distractors were slightly larger in size compared to neutral and target stimuli.

All target and neutral letters subtended a visual angle of 0.75° inside a circle with a radius subtending 1.64° of the visual angle. Distractor letters subtended 1.17° degrees and was located along a ring that subtended 3.52° in radius from fixation. These particular viewing angles were chosen as they yielded stimuli sizes that were big enough for participants to easily register visually, but were small enough to minimise the effect of decreased visual acuity due to the peripheral acuity degradation (Eriuckson, 1964).

All letters included in the experiment were Arial font. In order to reduce stimulus feature overlap, target, distractor and neutral letters were chosen that shared few visual similarities. The target letter, either the capital letters *A* or *K*, appeared within the circular search array that also contained either five neutral letters (C, S, Z, V, and N) for the high perceptual load conditions, or five small dashes for the low perceptual load conditions.

Perceptual load levels were thus characterised by the number of neutral items included in the search array, also known as set-size (Lavie, 1995).

Distractor salience was manipulated by changing the colour of the distractor relative to the target letter. In order to facilitate a sufficient degree of *pop-out* effect from the distractor the salient trials contained a distractor that was orange (1.000, 0.004, -0.498 on the colour palette), while target and neutral letters were all light grey (0.506, 0.506, 0.506 on the colour palette). Non-salient trials, on the other hand, contained distractors, target letters and neutral letters that were all light grey (0.506, 0.506, 0.506 on the colour palette).

Incompatible distractor trials contained a distractor that was the non-represented target (i.e. *A* as distractor when the target was *K*) and neutral trials contained an irrelevant distractor (for example *M* when the target was *A)*. In other words, for neutral trials when *A* was the target, a letter other than *K*, such as *M* functioned as the distractor. All stimuli for the experiment were presented against a black background (-1.000, -1.000, -1.000 on the colour palette). A black background was chosen to facilitate the recognition of the stimuli by creating sufficient contrast between the stimuli and the background. Figure 11 illustrates the eight different experimental conditions produced by crossing the perceptual load, distractor compatibility and distractor salience.

High load/ Neutral salient distractor
Low load/ Neutral salient distractor

High load/ Neutral non-salient distractor
Low load/ Neutral non-salient distractor

High load/ Incompatible salient distractor
Low load/ Incompatible salient distractor

High load/ Incompatible non-salient distractor
Low load/ Incompatible salient distractor

Figure 11: Example search displays illustrating the eight different experimental conditions

Target letters, neutral letters and distractor positions were partially counterbalanced by ensuring that each distractor letter appeared once on each side of the search array and that each target letter appeared once in each of the six positions within the search array. When accounting for the salience, perceptual load, distractor compatibility and target letters (*A* and *K*) combinations, this approach yielded a total of 192 trials that each participant had to complete.

3.5.2 Response time as an inferential tool

In general three distinct types of response times can be isolated depending on the nature of a task. These tasks were identified by F.C Donders, a contemporary of Wilhelm Wundt in the 19th century, at the dawn of modern psychology (O'Shea & Bashore, 2012). According to Donders simple reaction tasks elicit the shortest response times. Simple reaction tasks usually require the participant to simply respond by initiating a motor response such as pressing a button when a stimulus is detected. These reaction tasks can include visual, auditory, or even tactile stimuli (O'Shea & Bashore, 2012).

The second type of task is a recognition task. Recognition tasks require participants to indicate whether a specific stimulus is present or not. For this reason recognition tasks are often referred to as Go/No-Go tasks since participants should indicate when a predefined stimulus is present and withhold response when it is not. These recognition tasks usually lead to slightly longer response times when compared to simple reaction tasks.

The third type of task identified by Donders is choice tasks. Choice tasks usually present the participant with specific responses that are paired with certain stimuli. During the task the participant must then choose which response is the appropriate one given the presented stimulus. For example, participants can be instructed to respond by pressing the *K* on a keyboard when the letter *K* appears within a search array and respond by pressing the *A* key on the keyboard when the letter *A* appears in the search array. Choice task often produce the longest response times when compared to recognition tasks and simple reaction tasks.

One of the reasons why response times is such a popular tool in cognitive science is the fact that the time for both the preparation of a motor response and the motor response itself remains largely unaffected by the type of task. Researchers thus attribute any increases or decreases in response time to increases or decreases in processing time (Miller & Low, 2001). Due to the relative ease and apparent validity of this approach, it is unsurprising that the use of response times has become an important tool for researchers who seek to reliably infer the cognitive processing properties of humans or animals in response to tasks in a non-invasive way (van Zandt, 2002).

In addition to the relative ease of use and validity of response times, these response time measures have an additional property that make them especially attractive to researchers in the cognitive sciences. Response times can be treated as ratio scale measurement since time contains an absolute zero point and equal intervals. Because of the invariant nature of the scale, researchers can easily compare and contrast different tasks or participants with precision that would be all but impossible when using ordinal level measurement (Jensen, 2005). Response time data thus provide researchers with a highly replicable, relatively valid, and precise way of inferring mental processes in response to carefully controlled tasks. Researchers can construct complex and precise mathematical models of cognitive processing by systematically manipulating the nature of the task and observing the effect that these manipulations have on processing time (van Zandt, 2002).

3.5.3 Apparatus

The experiment ran on two laptops that had Microsoft Windows® installed as an operating system and connected via HDMI (High Definition Multimedia Interface) to one of two 24” light emitting diode (LED) monitors with a refresh rate setting of 59 Hz and a resolution setting of 1920 x 1080 pixels. Viewing distance was approximately 60cm. Stimuli were generated via the Python plugin PsychoPy2 Version 1.80 (Peirce, 2008; Peirce, 2007). PsychoPy allows for the accurate tracking of response time data via keyboard strokes in response to the computer generated search arrays. All responses were captured using two consumer grade rubber dome keyboards connect via USB (Universal Serial Bus) to the laptops.

One of the key requirements of programmes aimed at capturing experimental responses is temporal accuracy (Peirce, 2007). The timing precision of the responses captured in PsychoPy is at least partly dependent on the system clock of the system that is running PsychoPy. Peirce (2007) does point out, however, that PsychoPy running on most modern computers systems should provide sub-millisecond timing precision. In order to assess potential problems in the presentation timing of the search arrays, PsychoPy also reports if the program detects the dropping of frames that would indicate potential discrepancies in the timing of the displays (Peirce, 2007). No such errors were reported by the program during the experiment, indicating that the potential errors in the timing precision originating from PsychoPy were of negligible concern.

3.6 Procedure

Participants were given verbal instructions before the commencement of the experiment on the nature of the task. The experiment also included a short tutorial that participants had to complete before the start of the experiment. In order to familiarise participants with the nature of the task, the tutorial included 36 practice trials. Practice trials were included in order to help participants gain familiarity with the speeded nature of the choice task, as well as to ensure that participants understood the task. Thirty six practice trials were chosen in order to ensure participants did not experience any fatigue before the start of the actual experiment. The data from the practice trials were not included in any of the analyses and were captured in a separate database. In the tutorial, participants were instructed to respond as quickly and accurately as possible to the identification of the target letters (*A* and *K*) by pressing the corresponding key on the keyboard. Participants were then informed that a distracting letter will be displayed outside of the circular search array and that they should ignore this distracting letter.

During the experimental and practice trials a fixation cross was displayed in the middle of the display area for 1500ms before each trial. The fixation cross was followed by the circular search array. The search array was displayed for approximately 120ms, after which participants were able to use the *A* and *K* keys on the keyboard to register their response. One hundred and twenty milliseconds was chosen as the exposure time as this is generally believed to preclude participants from overt eye movements during which they can actively search for the target (Cosman & Vecera, 2009). Feedback was given to participants after each trial via a message lasting 500ms, informing the participant of the accuracy of the response and the response time in milliseconds. Feedback was included as a subtle reminder for participants to respond as fast and accurately as possible. Figure 12 illustrates the sequence of events during the trials.

One hundred and ninety two trials were produced by crossing the three experimental factors and partially counterbalancing the location of the distractors and target letters within the search array. Partial counterbalancing of the target position meant that each target appeared at least once in each of the six possible target locations for each of the eight experimental conditions, whereas the distractors appeared once in each of the two possible distractor locations.

Experimental trials were presented in two blocks in order to give participants the opportunity to take a short break during the experiment. Each block contained 96 trials. The crossing of the three experimental factors and the partial counterbalancing of the locations meant that each factor combination yielded 24 trials, the presentation of which were randomised between and within the two presentation blocks. Participants were allowed to take small breaks between trial blocks. In accordance with established practice in working with response time data, some proportion of the trials was deleted and all incorrect responses were deleted before the response time analysis was conducted (Whelan, 2010). More information on the data trimming procedures will be presented in the results section.

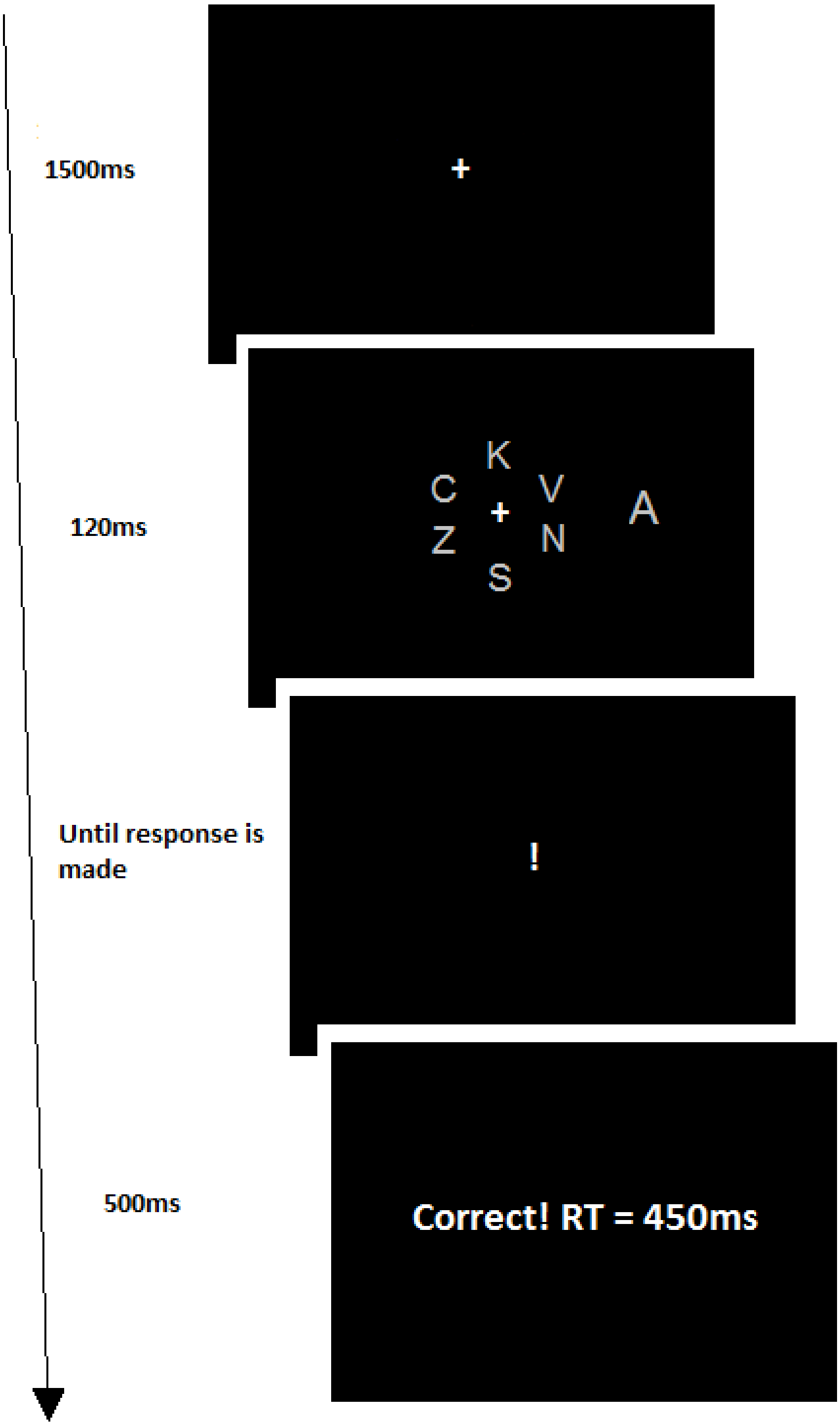

Figure 12: Sequence of events for all trials across all conditions.

3.7 Analysis

The following section will highlight the challenges associated with working with response times as an inferential tool in the study, as well as provide a brief overview of the statistical analyses used in this study.

3.7.1 Response time distributions

While the use of response times as an operationalisation of cognitive processing has enjoyed a rich history within cognitive psychology, there are some caveats in using response time measures to infer mental processing for choice tasks in particular. One of the peculiar characteristics of most response time distributions involving choice tasks is the presence of a distinctly long right tail in the distribution, i.e. a positively skewed distribution (Baayen & Milin, 2010). Figure 13 graphically illustrates the positive skew via a density plot of response times generated for one of the participants in this study.

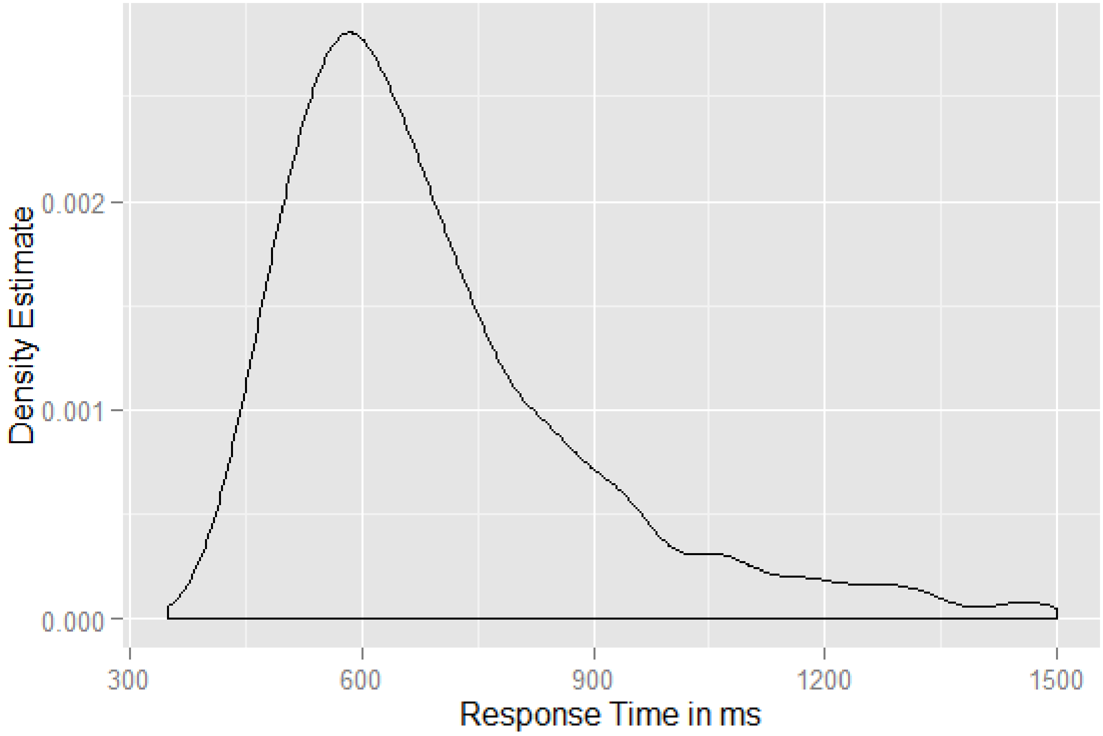

Figure 13: Density plot illustrating the positive distributional skew associated with response time data.

Due to the asymmetric shape of the distribution, the mean and the variance are probably not the best parameters to characterise these distributions (van Zandt, 2002). Although the particular reason for the occurrence of this long tail is still a point of contention, what is immediately apparent is the presence of a potential floor effect when measuring response time for choice tasks. There appears to be a lower limit to the speed at which humans can process perceived stimuli and initiate a response which a researcher can measure. Duncan Luce (as cited in Whelan, 2010), for example, argues that genuine response times cannot be faster than 100 to 200ms as this is the limit for perceiving and responding to stimuli. While there is concrete evidence to suggest that there is a lower limit to how fast humans can respond, there appears to be no obvious upper limit for response times.

The time it takes a participant to process the information contained in the stimuli and decide on the correct response will vary as a function of the complexity of the task; even if the time to perceive the stimuli and the initiating of a motor response remain largely consistent. The response time can also be influenced by factors other than the process of interest to the researcher. For example, momentary lapses in concentration, or even something as mundane as blinking at the exact same time that the stimuli are presented, can results in response times that are noticeably longer than a particular participant’s theoretical true mean response time.

Researchers can deal with these unusually fast response times by setting a cut-off point, where response times faster than this cut-off point are treated as anticipatory responses and discarded. Depending on the study, these lower limit cut-off points can vary significantly. In general, however, response times ranging from 150ms (Cosman & Vecera, 2009) to 200ms (Biggs & Gibson, 2010) are treated as anticipatory responses by researchers using simple flanker distraction tasks.

While dealing with anticipatory responses is relatively easy, dealing with unusually slow response times is significantly more difficult. As Ratcliff (1993) pointed out, the first step in dealing with these unusually slow response times is to unambiguously identify them. While obvious outliers are quite easy to identify and deal with, there tends to be a degree of overlap between the distribution of response times that reflect the actual process of interest and those response times that were influenced by some outside factor such as a momentary lapse in attention or distraction not controlled for by the researcher. This is problematic since it becomes almost impossible to differentiate between legitimate response times and confounded or illegitimate response times.

To illustrate this point, considered the ex-Gaussian based model of response times proposed by Ratcliff (1979). According to Ratcliff, response time distributions can be modelled as being a combination of a normal Gaussian distribution (A in Figure 14) and an exponential distribution (B in Figure 14). When combined (C in Figure 14) they form a positively skewed distribution that can best be described in terms of the mean (μ) and standard deviation (σ) parameters derived from the Gaussian distribution and the parameter tau (τ) derived from the exponential distribution.

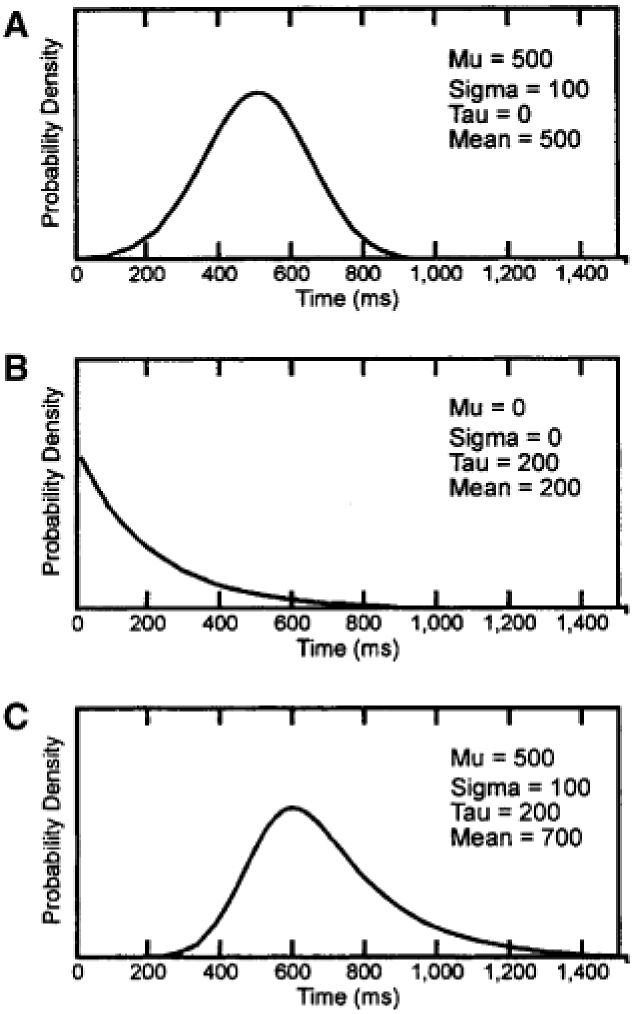

Figure 14: Convolution of the Gaussian and Exponential distribution to form the ex-Gaussian distribution. Reprinted from “Beyond mean response latency: Response time distributional analyses of semantic priming” D. A., Balota et al. 2008. Journal of Memory and Language, 59, p. 497.

Although the relative merits of theoretical models of response times, such as the ex-Gaussian distribution, is beyond the scope of this study, the basic idea can nevertheless be leveraged to understand the predicament faced by researchers who use response time data and error rates as an inferential tool of mental processing. In much the same way that the ex-Gaussian distribution is a convolution of two distinct and independent distributions, attributable to two distinct processes, response time distributions can also be thought of as containing the distribution that is associated with the processes of interest to the researcher and the response time distribution that is the results of confounding factors that influenced the response time in some way. For example, when a participant is distracted even for a moment during a trial, the response time for that particular trial has been contaminated and can no longer serve as a valid indicator of the cognitive process of interest to the researcher. Though the underlying measurement principles have not changed, what the measurement *represents* has. These contaminated trials are a threat to validity as they represent the interaction between the process of interest and an additional factor that the researcher is not controlling for.

Despite the fact that some of these contaminated trials will likely fall beyond the limits of the legitimate response time distribution and can easily be identified and eliminated due to their outlier status, many of these invalid trials will be mixed in with the legitimate response time trials, giving them the appearance of legitimate trials. If there are a sufficient number of these invalid trials they can seriously compromise the validity of the inferences regarding the relationship between the stimulus and cognitive process that the researcher draws from the response time data, especially if they are not taken into account or eliminated.

In order to minimise the compromising effects of these invalid trials, researchers often assume that the long tail reflects some form of error and attempt to eliminate these trials by trimming response times that fall too far beyond the parameters they theorise will encapsulate the distribution formed by the process of interest to them. This places the researcher in a predicament. Set the cut-off point too aggressively and there is a chance that the researcher might reduce statistical power by trimming legitimate trials. It is also possible that these longer response times reflect an integral part of the processing of particular tasks or stimuli and the researcher unjustifiably assumes that the distribution of response times should approximate a Gaussian distribution and that the long tail reflects some form of error. On the other hand, hypothesis tests that utilise a measure of central tendency and some parameter of dispersion could potentially lead to a drastic reduction in power when there are outliers in the data or the distribution is severely skewed (Whelan, 2010).

Researchers normally attempt to compensate for this dilemma by outright deleting trials above an upper limit set by the researcher –called *a priori* trimming–, trimming using standard deviations, transforming the data, or using parameters that are less sensitive to these extreme reaction times, such as the median (Ratcliff, 1993). Incorrect responses are, as a rule, excluded from analysis of response times, as they are thought to contain an additional component not controlled for by the researcher that influences the response time. However, guessing may also come into play as numerous invalid trials will not have been detected due to participants having guessed correctly, especially when only two responses are possible. In much the same way that it would be difficult for researchers to differentiate between valid and invalid trials based on the response time distributions alone, in all but the most extreme of cases, it would also be very difficult to differentiate between valid and invalid trials based on correct responses alone.

The particular trimming strategy or lack thereof, is particularly important since this will determine the extent to which the positively skewed distribution can be corrected to exclude potentially confounded trials. The two most popular strategies for dealing with the positive distributional skew are to trim response times that fall two to three standard deviations above and/or below the mean (see for example Benoni and Tsal, 2010), or to set absolute lower or upper cut-off times, usually below 200ms and/or above 1500 to 3000 ms (see for example Lavie et al., 2004). A limited number of studies have also employed a combination of these two approaches (see for example Gibson and Bryant, 2008).

Another key difference between studies is the level at which response times are trimmed. Some researchers trim response times for individual participants (see for example Roper and Vecera, 2013); while other researchers trim response times within conditions (see for example Kim and Cave, 1999). The particular trimming strategy chosen for this study will be covered in-depth in the next chapter.

3.7.2 Data analysis procedures

The following section briefly outlines the data analysis procedure and the statistical tests used for the analysis of the data. All analyses were conducted in the statistical computing program R (2014). Alpha levels were set at $\alpha = 0.05$. If an alpha level of $\alpha = 0.05$ is chosen, the null hypothesis will only be rejected if there is at least a 95% probability that the rejection of the null is the right decision and not caused by sampling error. This also implies, however, that there is a roughly 5% chance that a type I error will be committed by rejecting the null hypothesis when in fact it is true. By conducting repeated measures ANOVA’s the probability of committing a type I error can be kept at $\alpha = 0.05$ by pooling the error associated with each comparison and essentially comparing the conditions at the same time, thus compensating for the increased probability of committing a type I error associated with multiple comparisons (Field, 2013).

There is one major concern when using the potential interaction from analysis of variance procedures to investigate the potential interaction between distractor compatibility and perceptual load in order to establish the presence of a compatibility effect. The compatibility effect in perceptual load studies is calculated by comparing the difference between incompatible and neutral distractor conditions between high and low perceptual load trials. If incompatible trials produce higher mean response times compared to neutral trials in high but not low perceptual load conditions, then this is taken as evidence that the incompatibility of the distractor causes response interference, thereby leading to longer response times. However, if the incompatible distractor trials in the high perceptual load conditions also produce distractor interference this could potentially obscure an effect that would not be classified as a compatibility effect, but would be important to take note of nonetheless.

Recall that distractor interference in high perceptual load trials is one of the scenarios that should not occur according to perceptual load theory; as there should be no processing of the distractor identity in high perceptual load conditions due to a lack of perceptual capacity required for the processing of the distractor. Proponents of purely bottom-up driven attention, however, would argue that the salient distractor can capture attention even in high perceptual load conditions due to its salience (Theeuwes & Burger, 1998). A second scenario that should also not occur according to perceptual load theory is that participants can increase their search efficiency by utilising the salience feature to reject the distractor early, thereby avoiding potential response competition even in incompatible trials under low perceptual load conditions (Gaspelin et al., 2012). It is important to consider these two possibilities, as evidence for either would undermine the primacy of perceptual load in determining when and how stimulus selection occurs. To test these two hypotheses the use of planned comparisons or post hoc tests are necessitated to provide a more detailed breakdown of the effect than the one provided by considering just the two-way interaction between compatibility and perceptual load. Planned comparisons were used for these analyses to provide more statistical power and to avoid inflating the experiment-wise error rate by decomposing interactions that are of little relevance to this study. In order to compensate for the increased risk of committing a type I error, the planned comparisons were also subjected to a Bonferonni-Holm alpha correction (Holm, 1979).

The first step in the analysis process was to devise a strategy for dealing with response time distributions that exhibited unacceptable levels of skew by following the recommendations set out by Ratcliffe (1993) and Bayen and Milin (2010). After the appropriate trimming of the data, a mean response time was calculated for each participant for each of the eight experimental conditions, derived from the crossing of the three factors. These mean response times were then subjected to a three-way repeated measures ANOVA with perceptual load, distractor compatibility and distractor salience as the factors and mean response time as the dependent variable, after which follow-up two-way repeated measures ANOVA's and planned comparisons were conducted via paired samples t-tests in order to investigate the possible existence of compatibility effects for salient and non-salient distractor conditions.

Table 3 indicates the comparisons of interest in this study for which orthogonal planned comparisons were conducted.

Table 3

Description of planned comparisons for the study

Comparison	Description
Comparison 1	Low perceptual Load Incompatible Non-salient vs Low perceptual Load Neutral Non-salient distractors
Comparison 2	High perceptual Load Incompatible Non-salient vs High perceptual Load Neutral Non-salient distractors
Comparison 3	Low perceptual Load Incompatible Salient vs Low perceptual Load Neutral Salient distractors
Comparison 4	High perceptual Load Incompatible Salient vs High perceptual Load Neutral Salient distractors

3.8 Ethical Considerations

3.8.1 Informed consent

Participants were provided with an English consent form that everyone signed voluntarily having been informed during the initial phase of the sampling procedure that they would not be incentivised and that participation is completely voluntary. Participants were informed, both verbally and in the consent form, of their right to withdraw from the study at any point without any negative consequences. After signing the consent form participants were briefed on the nature of the experiment.

Preventative measures were taken to ensure that participants did not experience fatigue during the experiment by allowing them to take breaks between or within trials and allowing them to voluntarily withdraw without penalty (Health Professions Council of South Africa, 2008). Before the commencement of the experiment participants were verbally assured that, should they feel the need to temporarily suspend the experiment without wishing to withdraw completely, that they can do so since the experimental program will simply pause without user input. The participant could then continue with the experiment at any time during their allocated time slot.

3.8.2 Confidentiality

The participants were informed, in writing and verbally, that all information pertaining to the study would be treated as strictly confidential. Participants were also informed of the fact that the data would be reported at an aggregate level and, in cases where participant data is reported at individual level, participants would not be personally identified. Each participant received a unique identifying number that was not connected to their personal identity, other than their age and gender, in any way. Additionally, participants were informed that all data collected will be stored in digital format at the University of Pretoria for the duration of 15 years.

3.8.3 Debriefing of participants

All participants were debriefed after the experiment. During the debriefing the participants were thanked for their participation and reminded that, despite the completion of the experiment, they still had the right to withdraw from the study. Participants were also informed that, should they request to withdraw from the study any at time after the completion of the experiment, their data would be immediately destroyed by the researcher.

Participants were encouraged to contact the researcher if they had any questions regarding the experiment or the use of the data emanating from the experiment.

4. Results

4.1 Introduction

As discussed in the previous chapter, there are numerous ways in which response time data can be analysed when considering the wide variety of experimental designs employed by researchers. This chapter will be roughly divided into two sections. The first section will elaborate on the strategy chosen for dealing with the challenges of working with response time data. The second section of this chapter will contain the results of the statistical analyses conducted in order to address the main research questions of the study.

4.2 Exploration of the response time distributions for the study

As was expected, the response time distributions tended towards a positive skew as can be seen in Figure 23 contained in Appendix A. Considering the severity of the positive skew, the parameter estimates derived from these distributions may have been severely compromised. Due to the factorial approach to the analysis of the data, the focus was on investigating the distributional properties of response times within conditions, as these conditions would be contrasted and compared in the analyses.

Ideally researchers can avoid having to trim the tails of the distribution in the first place by simply using a more robust estimator of response times; such as the median or by transforming the dependent variable. The first consideration therefore was whether or not to use median response times, as opposed to mean response times. However, given the small sample size and the current established practice to remove incorrect responses from response time analysis, the choice of median response became problematic. Simulations run by Miller (1988) demonstrated that the sample median tends to overestimate the population median when samples are small and distributions are skewed. There is also a tendency for medians to be overestimated in conditions were there are fewer trials compared to conditions were there are more trials; a situation that arose because of the deletion of incorrect responses.

The second consideration was to transform the response variable (i.e. response time in milliseconds) by using either an inverse transformation or a log-transformation (Ratcliff, 1993). One of the drawbacks of transforming the response variable is that the interpretation of the results may become less intuitive. While the inverse transformation transforms *response time* into *response speed* (i.e. the number of responses a participant can make in one second) log-transformations are not easy to interpret and back-transformations are not easy to perform (Baayen & Milin, 2010). An inverse transformation of the response times did not lead to a sufficient reduction in the upper tail of the distribution for the data in this study. Due to the disadvantages associated with the interpretability of transformed variables no analyses were conducted using the transformed responses, as this approach was largely ineffective (see Figure 15).

The final general option is the use of modest *a priori* trimming of the data or the use of standard deviations to trim data. Baayen and Milin (2010) recommend that minimal *a priori* trimming be employed, since trimming should only aim to eliminate those response times that can reasonably be attributed to processes not under investigation. *A priori* trimming should therefore be used conservatively in order to avoid unnecessary loss of statistical power. It was decided to use a two-stage trimming strategy for this particular study. The first step was aimed at establishing a hard cut-off point to eliminate potential outliers or responses that occurred due to participant's being distracted. The second reason for this hard cut-off point was to ensure that unusually high response times did not influence the standard deviation estimate used during the second stage

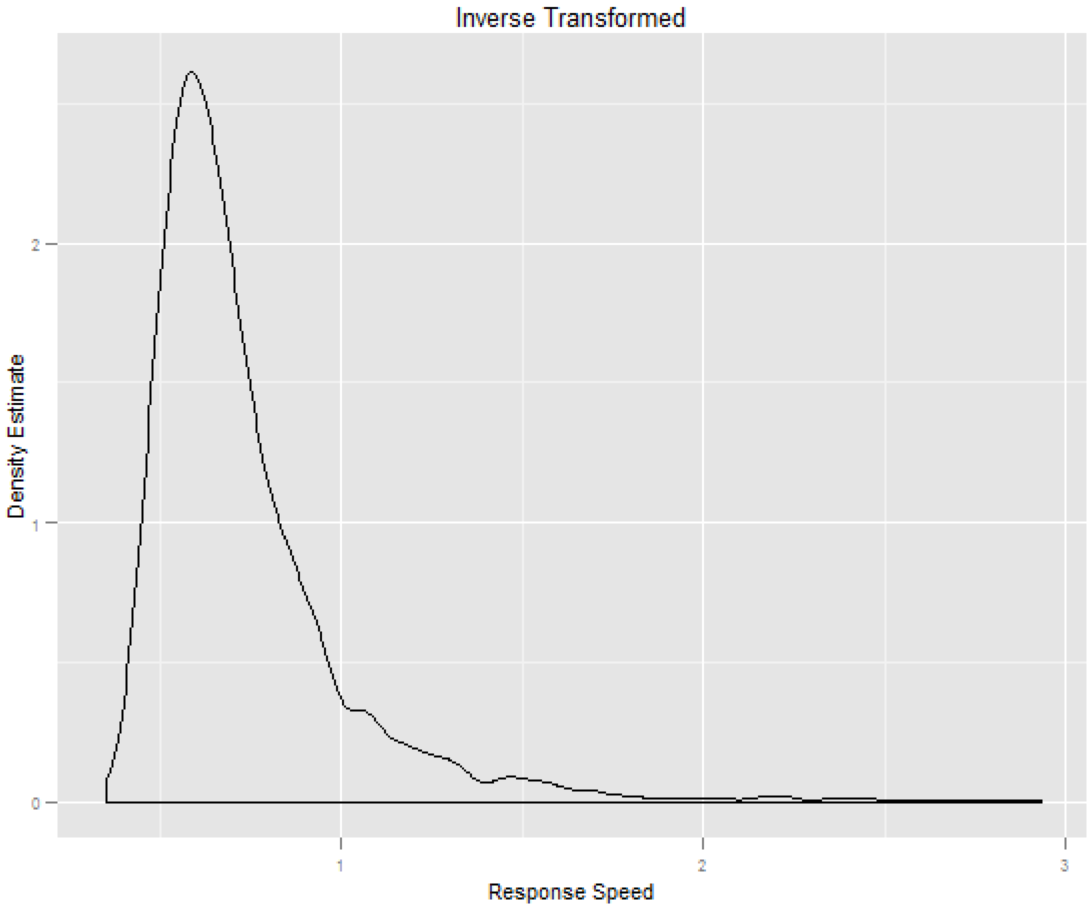

Figure 15: Density plot of the response distribution after the inverse transformation

of the trimming procedure. To this end, response times longer than 2000 ms –the cut-off point- were deleted.

During the second stage of the trimming procedure z-scores were calculated for all responses within a particular experimental condition. Response times that fell more than two standard deviations *above* the mean within a particular condition were deleted. This lead to the deletion of 5.3% of the total response times. It was decided not to delete response times from the lower end of the distribution as this would likely lead to a reduction in statistical power due to the trimming of potentially valid responses. Instead, the data trimming strategy involved trimming all anticipatory responses, i.e. response times faster than 200ms. However, there were no response times faster than 200ms, thus no response times were deleted from the lower half of the distribution. All incorrect responses were removed in the analysis of response times, comprising 8.9% of the total number of trials. The two-stage data trimming strategy, combined with the deletion of incorrect responses, meant that 14.1% (n = 543) of the total (n = 3840) trials were deleted.

One of the main concerns with the use of this two-stage strategy was that some participants may have had a significant number of their responses trimmed; especially those participants who displayed greater variability in their responses or responded much slower than the other participants. In much the same way that there are only guidelines regarding the trimming strategy used by researchers, when to exclude a participant from the analysis is also normally at the discretion of the researcher. Tsal and Benoni (2010a) for example excluded participants if their error rates exceeded 30%, while Gaspelin et al. (2012) excluded participants if their error rates fell more than two and a half standard deviations above the group mean. If either the error rate or the number of trimmed responses exceeded the 30% threshold for a particular participant, that particular participants would be excluded from the analysis in this study.

To investigate the possibility that participants exceed this 30% threshold Table 4 reports the percentage of trials that each participant responded incorrectly to and the percentage of responses trimmed across all conditions for that particular participant using the two-stage trimming strategy described above. The table shows that none of the participants committed enough errors, or had enough trials trimmed to exceed the 30% cut-off point. Consequently, no participants were excluded from the analysis.

Table 4

Percentage Errors and Trimmed Trials

Participant	Errors %	Trimmed %	Total %
1	3.65	7.81	11.46
2	4.69	1.04	5.73
3	18.75	4.17	22.92
4	15.63	9.38	25.00
5	6.77	10.42	17.19
6	6.77	3.65	10.42
7	2.08	9.38	11.46
8	7.81	27.60	35.42
9	15.10	1.04	16.15
10	4.69	8.85	13.54
11	2.08	0.00	2.08
12	13.54	1.04	14.58
13	13.54	0.00	13.54
14	8.85	3.65	12.50
15	10.94	0.52	11.46
16	10.94	1.04	11.98
17	8.33	5.73	14.06
18	4.69	4.17	8.85
19	11.46	2.08	13.54
20	6.25	4.17	10.42

After the trimming strategy, a mean response time was calculated for each participant, for each condition. Figure 16 displays the median, 25th percentile and 75th percentile for each experimental condition via boxplots after the data trimming procedure. The boxplots indicate that the distributions are sufficiently symmetrical apart from the High Load Neutral Salient (HNS) condition, and that there are few extreme values. The compressed nature of the box for the High Load Incompatible Non-salient (HIN) condition indicates that variability of the response times for this condition were slightly more constrained than for the other conditions.

The boxplots also indicate that the median response times were very similar for the Low Load Incompatible Salient (LIS), Low Load Neutral Non-salient (LNN) and Low Load Neutral Salient (LNS) conditions despite differences in the variability of response times in these conditions.

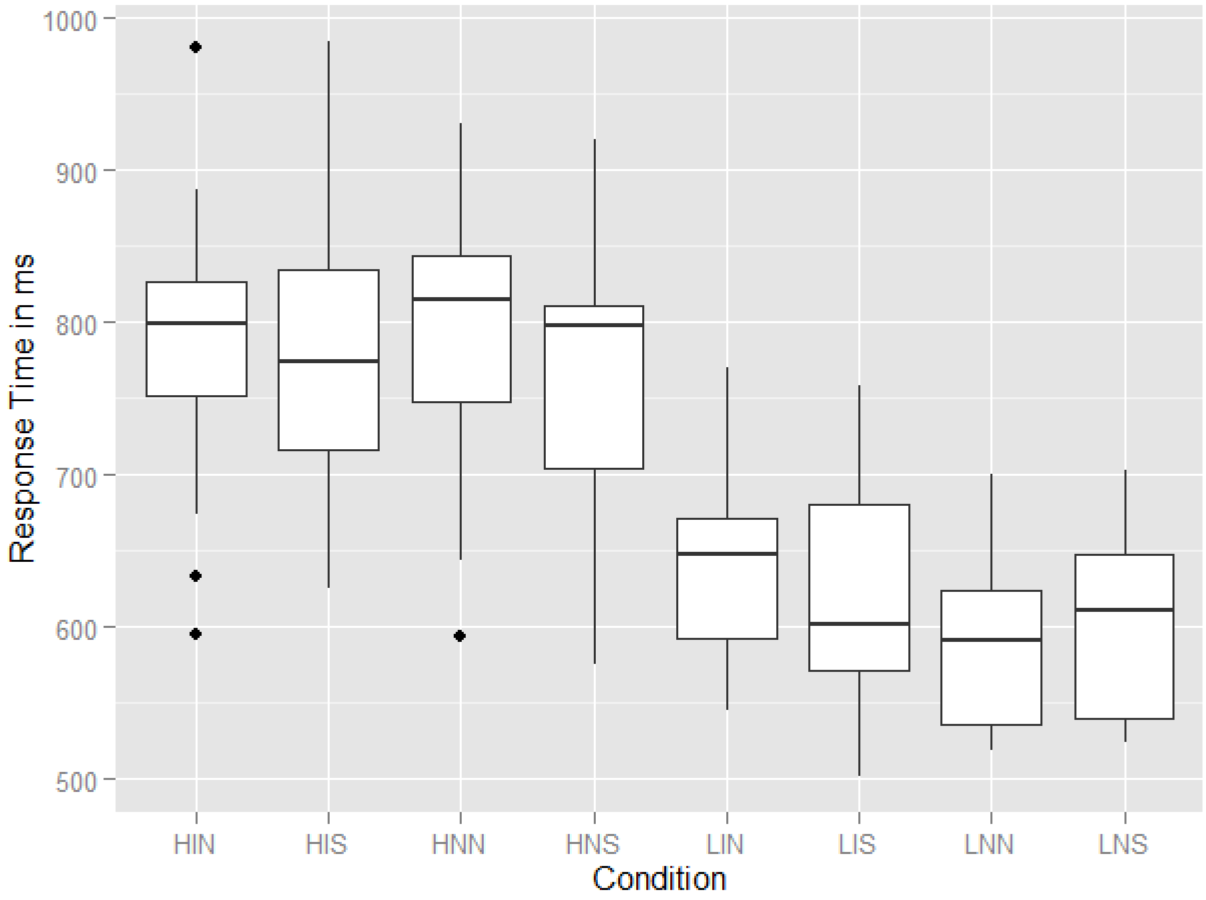

Figure 16: Boxplots for all eight experimental conditions.

4.3 Statistical assumptions

Although the boxplots indicate that there does not appear to be any serious distributional concerns, the skewness and kurtosis of the response time distributions were also calculated for each experimental condition. The analysis revealed that none of the distributions displayed skewness of more than an absolute value of one, therefore indicating that none of the distributions were excessively skewed either positively or negatively (Rasch, Kubinger, & Yanagida, 2011). The kurtosis statistics indicate that all of the distributions displayed marginal platykurtic properties, meaning that the distributions were slightly light tailed (Field, 2013).

While the use of boxplots and moments -such as skewness and kurtosis- of the distribution of the raw response times can be a valuable tool in investigating the distributional properties of the raw sample data, the appropriateness of utilising parametric statistical procedures to analyse the response time data will rely heavily on the residuals being normally distributed. Residuals can be considered the error not accounted for by the statistical model. If these errors are normally distributed this is an indication that the statistical model is a sufficient fit for the data as the errors structure is random. According to Tabachnick and Fidell (2006), while F-tests are relatively robust to departures of normality, they do become less and less robust the more severe the departure from normality, especially when outliers are present. The assumption of normality can be sufficiently evaluated by investigating the normality, linearity and homoscedasticity of the residuals (Tabachnick & Fidell, 2006). Due to the use of comparisons of mean response times across conditions, the reasonableness of the assumption that the model residuals were normally distributed within conditions was also considered.

A quantile-quantile plot (Q-Q plot) is a standard plotting tool used for visually assessing the degree to which a distribution deviates from normality (Rasch et al., 2011). If the distribution closely matches the $y = x$ line, then it is reasonable to assume that the distribution is a good approximation of a normal Gaussian distribution. There is one caveat in using Q-Q plots on small sample sizes: trends that would have been more prominent using larger samples often become somewhat obscured when plotted using small sample sizes. In order to provide a frame of reference, four randomly simulated normal distributions that contain 20 observations each were included in Figure 17 and Figure 18 as a visual comparison. As a final check, a Shapiro-Wilk test was conducted on the residuals. The test results indicated that the errors are unlikely to have come from a non-normal distribution. However, the use of null hypothesis tests to investigate normality are subject to the same limitations as other statistical procedures when conducted on small samples sizes, since the rejection of the null (i.e. the distribution is non-normal) might not occur due to a lack of statistical power. The Shaprio-Wilk test result for the LNS condition for example suggest that the residual are normally distributed (W = .914, p = .075) despite the fact that a visual inspection of the Q-Q plot suggest a slightly bimodal distribution.

Table 5

Shapiro-Wilk Normality Test Results Split by Condition

	W	*p*-value
High Load Incompatible Non-Salient (HIN)	.956	.465
High Load Neutral Non-Salient (HNN)	.965	.651
High Load Incompatible Salient (HIS)	.966	.678
High Load Neutral Salient (HNS)	.930	.154
Low Load Incompatible Non-Salient (LIN)	.967	.691
Low Load Neutral Non-Salient (LNN)	.916	.082
Low Load Incompatible Salient (LIS)	.969	.723
Low Load Neutral Salient (LNS)	.914	.075

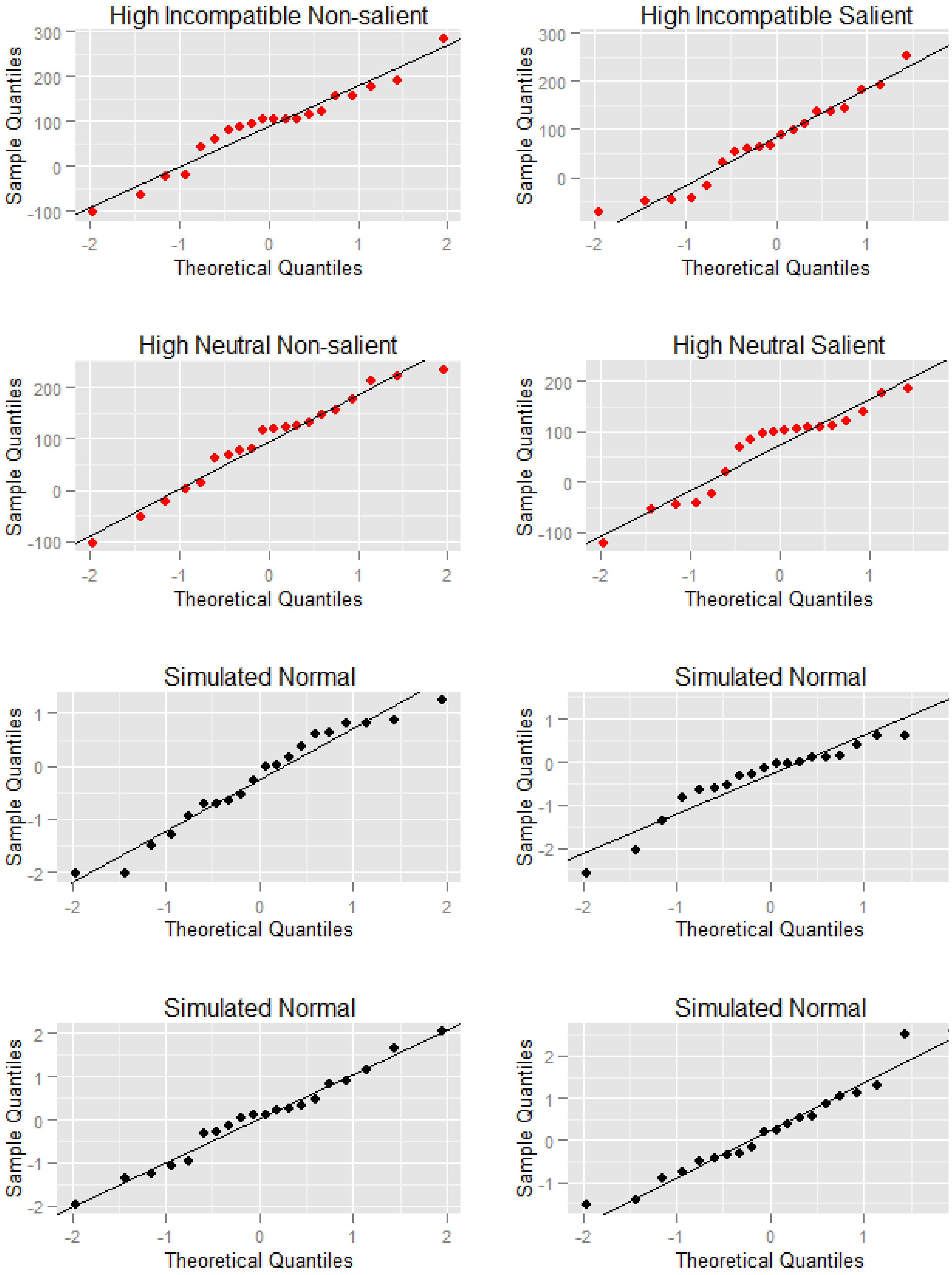

Figure 17: Residual Q-Q plots for the four high load experimental conditions with simulated normal distributions included for comparison.

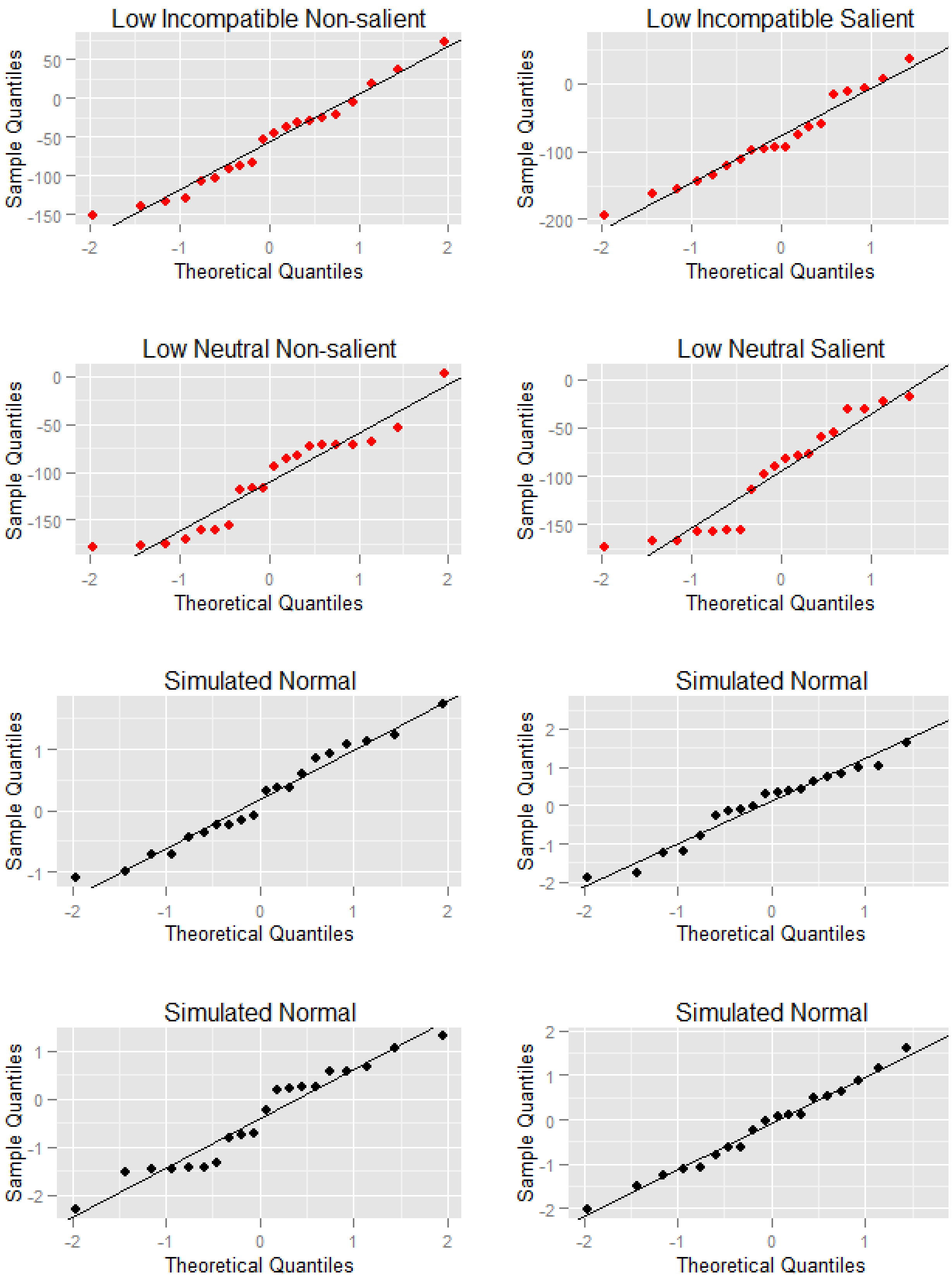

Figure 18: Residual Q-Q plots for the four low load experimental conditions with simulated normal distributions included for comparison.

Given the combination of the Shapiro-Wilk test results, the relative symmetry of the distributions, and the visual similarity between the residuals Q-Q plots and the simulated normal distributions it is reasonable to assume that the assumption of normality is sufficiently satisfied that the use of parametric statistics would be appropriate. The results have to be interpreted with a degree of caution however, given the slight differences in distributional properties displayed by the different experimental conditions.

4.4 Overview of results

Figure 19 indicates the mean response times across all perceptual load, distractor compatibility and distractor salience conditions for the sample. Mean response times for the low perceptual load condition appeared to have yielded lower response times when compared to the high perceptual load search conditions, regardless of distractor salience or distractor compatibility. The error bars represent the interval within which there is a 68% chance that the population mean for a particular condition will fall. When visually inspecting the bars, it appears that no compatibility effects will be found for any of the high perceptual load conditions, due to the overlapping error bars. When error bars representing the standard error of the mean overlap the difference between those two conditions will not be significant at $\alpha = 0.05$ (Belia, Fidler, Williams, & Cumming, 2005). If error bars do not overlap, however, this does not automatically imply that the difference will be statistically significant, merely that there is a *possibility* that the difference will be statistically significant at $\alpha = 0.05$. Therefore, the lack of overlap between the error bars for incompatible and neutral conditions suggest that there is a possibility that these two conditions might be different to a degree that reaches statistical significant at $\alpha = 0.05$, while the other comparisons will probably not reach the threshold required for statistical significance.

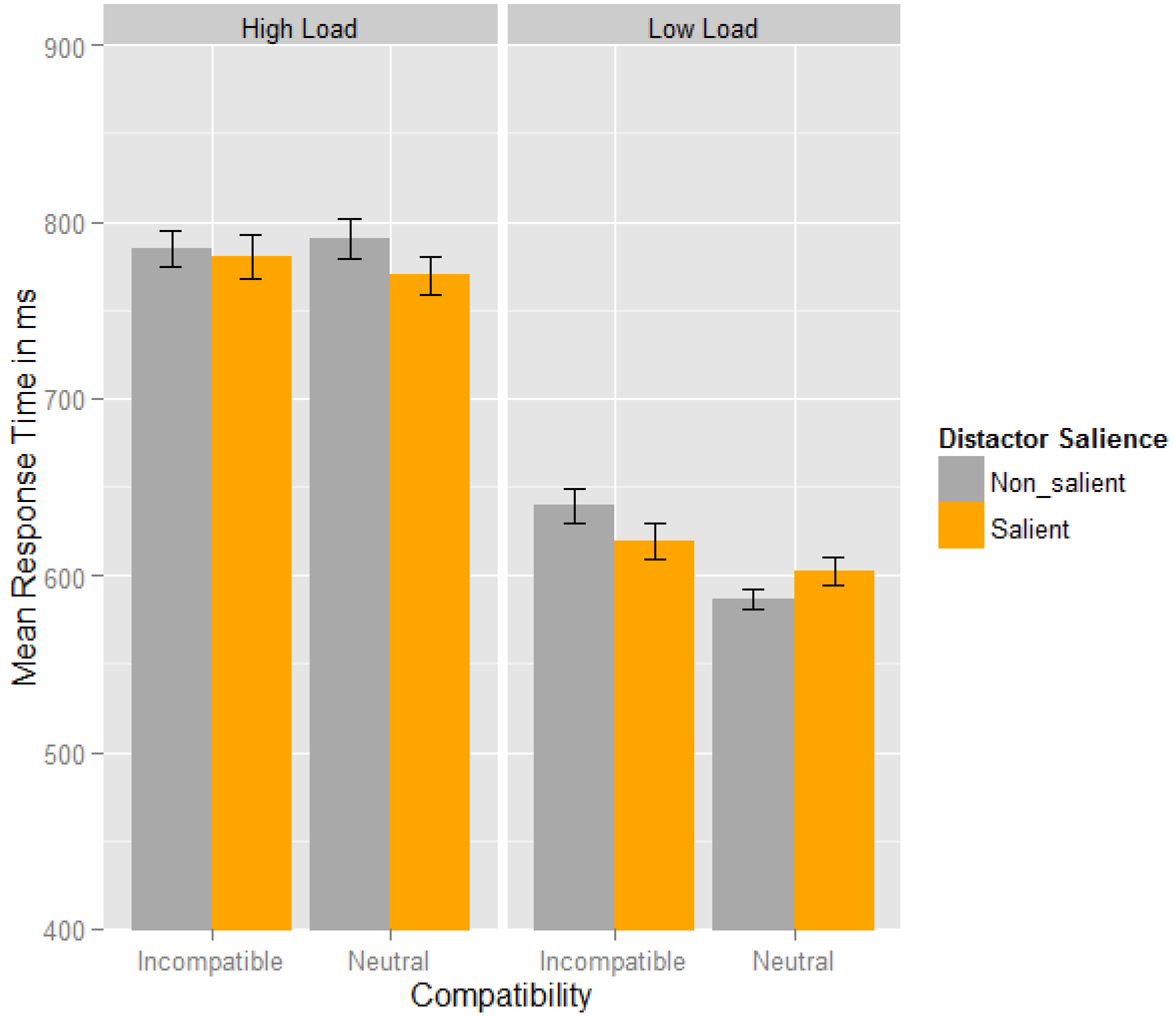

Figure 19: Mean response time in milliseconds for the eight experimental conditions. The error bars represent standard errors of the mean corrected for repeated measures data using Morey's (2008) method.

Table 6 reports the mean response times and error rate expressed as a percentage for the different experimental conditions. The numbers in brackets represent the standard error of the mean. High perceptual load trials produced higher response times and higher error rates than low perceptual load trials in general. Low load Incompatible Non-salient (LIN) trials produced almost double the number of errors compared to Low Load Incompatible Salient (LIS) trials. The incompatible distractors in low load conditions also produced more errors compared to the neutral conditions indicating that the incompatible distractors may have led participants to respond incorrectly more often than when the distractors were simply irrelevant letters.

Table 6

Mean Correct RTs and Percent Error Rates as a Function of Perceptual Load, Distractor Compatibility and Distractor Salience

Condition	RT	% Error
High Load		
Incompatible Salient	780 (22.4)	13.3
Incompatible Non-Salient	785 (20.2)	15.6
Neutral Salient	770 (20.1)	11.7
Neutral Non-Salient	791 (20.3)	12.3
Low Load		
Incompatible Salient	619 (15.6)	4.2
Incompatible Non-Salient	639 (13.8)	8.1
Neutral Salient	602 (13.1)	2.7
Neutral Non-Salient	587 (11.4)	2.7

4.5 Main analysis of response times

Figure 20 plots the mean response time interactions between perceptual load and distractor compatibility, split by the distractor salience conditions. The plot confirms the possibility of at least one significant two way interaction between distractor compatibility and perceptual load for both salient, as well as non-salient distractors.

4.5.1 Three-way repeated measures ANOVA for response times

In order to investigate the potential interactions between perceptual load, distractor compatibility and distractor salience conditions, a three-way repeated measures ANOVA was conducted on the mean response times. Outputs from all statistical analyses are included in tabular form in Appendix B.

The results of the three-way repeated measures ANOVA revealed a significant three-way interaction between perceptual load, distractor compatibility and distractor salience, F(1, 19) = 6.08, p =.023, η_p^2 = .242. This result indicates that perceptual load and distractor compatibility likely interact in different ways depending on the salience of the distractor. The degree to which simple main effects can be interpreted in the presence of a significant three-way interaction appear to be a point of contention among researchers.

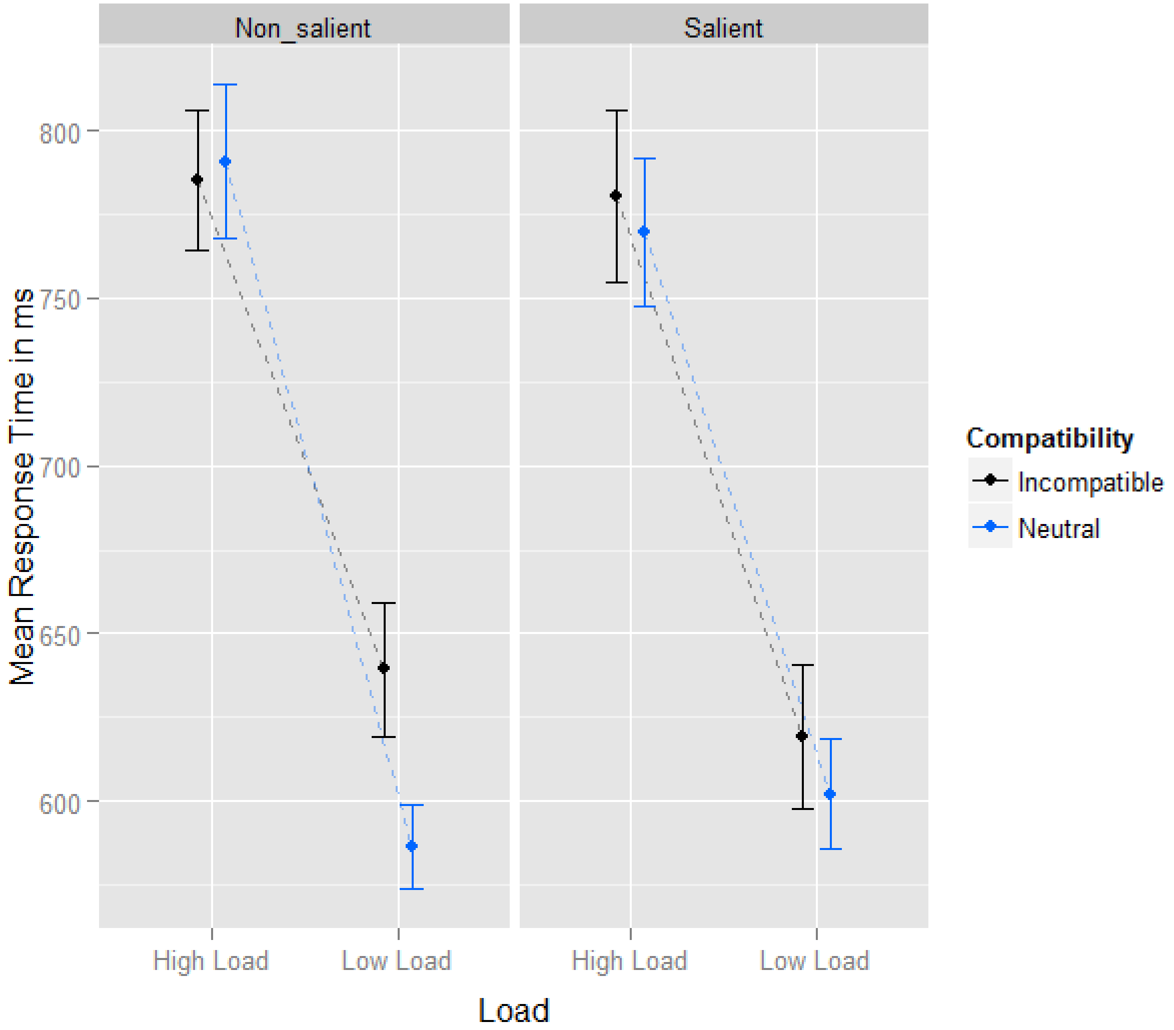

Figure 20: Mean response time as a function of perceptual load, distractor-target compatibility and distractor salience. Error bars indicate the 95% confidence interval.

Buckless and Ravenscroft (1990) for example, argue that interpreting any main effects when the interactions are disordinal could lead to a misinterpretation of the main effects. In statistical models that consider three-way interactions between factors, disordinal interactions occur when the interaction pattern between two factors differ across the levels of the third factor. In this particular study, for example, mean response time for the high load incompatible salient (HIS) distractor condition (M = 780, SD = 100) was higher than mean response times for the high load neutral salient (HNS) condition (M = 770, SD = 90.1). However, this pattern is reversed in the presence of non-salient distractors where high load trials containing incompatible (HIN) distractors (M = 785, SD = 90.3) have a lower mean response time than the high load neutral (HNN) trials (M = 791, SD = 91.1). This is an indication that the interaction between distractor compatibility and salience might be disordinal across different levels of perceptual load. Consequently, in order to investigate the simple two-way interactions between perceptual load and distractor compatibility for salient and non-salient distractors, the data set was split and separate two-way repeated measures ANOVA’s were conducted for salient and non-salient distractor conditions.

4.5.1.1 Results for salient distractor trials

A two-way repeated measures ANOVA indicated that there was no significant two-way interaction between perceptual load and distractor compatibility for salient distractor trials, $F(1, 19) = 0.181$, $p = .675$, $\eta_p^2 = .009$. As expected, however, there was a statistically significant main effect for perceptual load, $F(1, 19) = 113$, $p < .0001$, $\eta_p^2 = .856$ with the estimated marginal mean for high perceptual load (M = 775, SE = 20.3) trials being higher than the estimated marginal mean for low perceptual load (M = 611, SE = 13.8) trials. This is important, as the increased set-size yielded comparable increases in mean response times for both salient and non-salient distractor trials. No statistically significant main effect was found for distractor compatibility, $F(1, 19) = 3.4$, $p = .081$, $\eta_p^2 = .152$, indicating that distractor compatibility was unlikely to affect mean response time in the presence of salient distractors. This, in turn, could be an indication that the presence of salient distractors sufficiently reduced the compatibility effect due to a decrease in distractor interference. However, this might also indicate that the compatibility effect is small for low perceptual load trials when the distractor is salient or that high perceptual load salient trials produced a marginal compatibility effect that obscured the interaction.

4.5.1.2 *Results for non-salient distractor trials*

The two-way repeated measures ANOVA conducted on non-salient distractor trials was particularly important since it served as a baseline against which the lack of interaction between compatibility and perceptual load for salient distractors can be contrasted. The results revealed that the main effect for perceptual load was statistically significant F(1, 19) = 196, $p < .0001$, $\eta_p^2 = .912$. The results indicate that a significant interaction between perceptual load and distractor compatibility existed when the distractors were non-salient, F(1, 19) = 16.8, $p < .001$, $\eta_p^2 = .470$. This significant interaction could indicate that a significant compatibility effect was produced due to increased interference for incompatible distractor trials when compared to neutral distractor trials.

4.5.1.3 *Planned comparisons*

In order to further investigate the significant interaction between distractor compatibility and perceptual load, four planned comparison paired-samples t-tests were conducted on mean response times for the salient and non-salient trials by comparing incompatible trials to neutral trials for both perceptual load conditions. Planned comparisons were chosen in line with the hypotheses stated, as this lessens the risk of unnecessarily inflating the experiment-wise error rate by including comparisons between conditions that are of little interest. The *p*-values of the planned comparisons were corrected using the Bonferroni-Holm method to compensate for the increased risk of experiment-wise error. The Bonferroni-Holm alpha adjustment method is a less conservative version of the Bonferroni method where *p*-values are organised in ascending order and each subsequent test's *p*-value is divided by (*n-1)* where *n* is the number of significance tests conducted (Holm, 1979).

In order to maximise statistical power and to investigate the specific effects a one-tailed test was conducted against the null that the mean response time for incompatible distractor trials is equal to, or lower than mean response time for neutral distractor trials ($H_0 : \mu_1 \leq \mu_2$). The analysis revealed that mean response time difference (M = -5.65) between *incompatible* (HIN) (M = 785, SE = 20.2) and *neutral* (HNN) (M = 791, SE = 20.4) distractor trials were not statistically significant for *high perceptual* load trials containing non-salient distractors, t(19) = -0.392, *p* = .650, *d* = .093.

The mean difference (M = 52.8) in response time between incompatible (LIN) (M = 639, SE = 13.8) and neutral (LNN) (M = 587, SE = 11.4) distractor trials for *low perceptual load* trials containing non-salient distractors was statistically significant *t*(19) = 7.247, *p* < .0001, displaying a very large effect size (*d* = 1.69). This indicates that a significant compatibility effect occurred, since incompatible distractor trials lead to a 52.8 ms increase in mean response time when compared to neutral trials for low load search arrays containing non-salient distractors. This result replicates the findings of prior studies that produced evidence for increased interference of incompatible distractors in low, but not high perceptual load trials. For salient distractor trials, neither high perceptual load, t(19) = 0.820, *p* = .422, *d* = .175, nor low perceptual load trials t(19) = 2.139, *p* = .068, *d* = .501, produced significant result after the Bonferroni-Holm correction was applied. It is noteworthy, however, that the low perceptual load trials containing salient distractors, despite the non-significant *p*-value after the application of the Bonferonni-Holm adjustment, displayed a moderate effect size (*d* = .501).

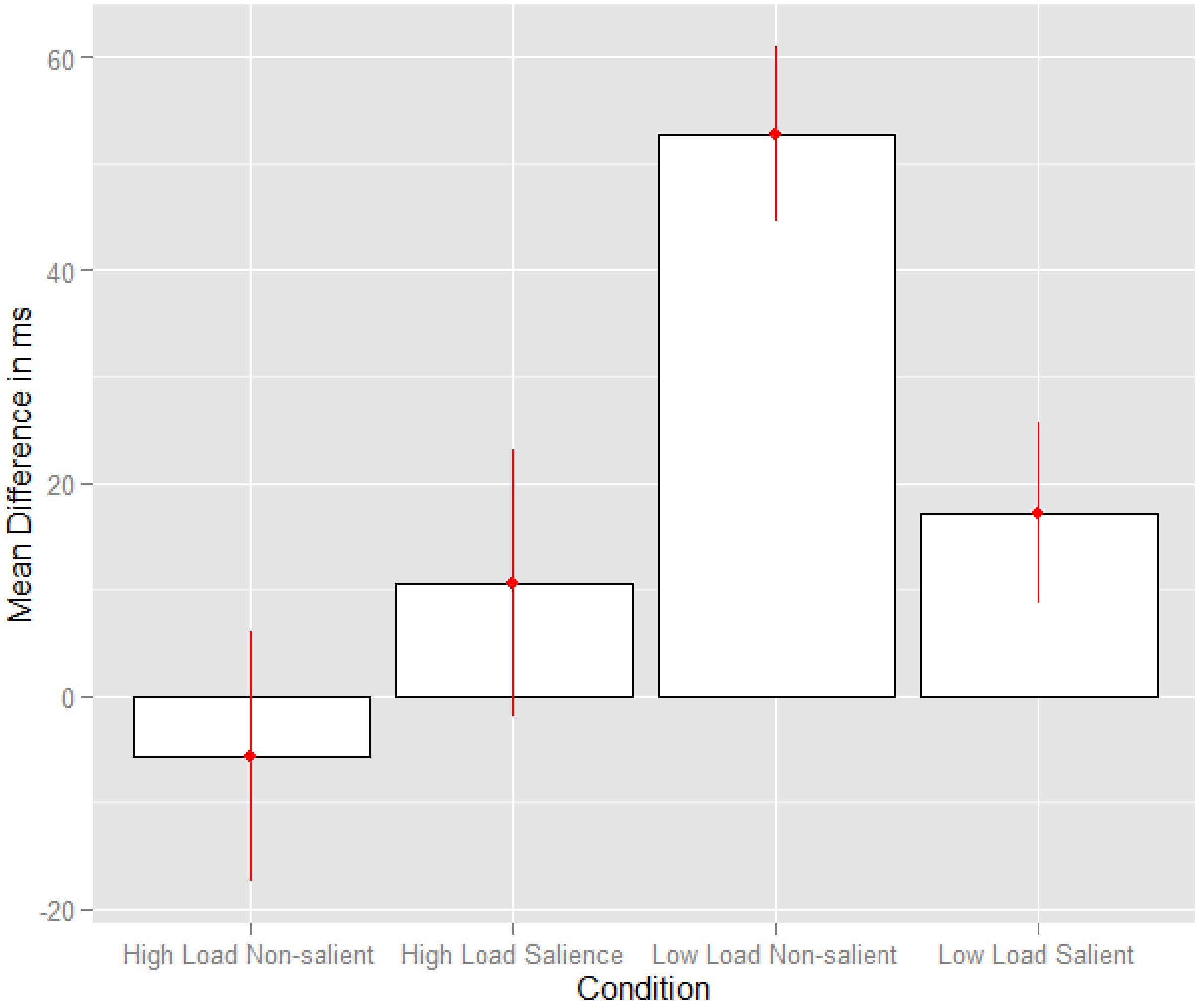

Figure 21: Mean difference in compatibility effects for the different combinations of perceptual load and distractor salience calculated by subtracting neutral response times from incompatible response times for each participant. The error bars represent the standard error of the mean.

Figure 21 summarises the result by plotting the *difference* in mean response time between incompatible and neutral distractors as a function of distractor salience and perceptual load. Although a highly significant compatibility effect was found for the *non-salient* distractor trials, the *salient* trials exhibited a statistically significant *main effect* for perceptual load, but no statistically significant compatibility effect after the Bonferonni-Holm correction was applied. It therefore appears that the compatibility effect found in the non-salient distractors trials did not occur when the distractors were salient. This finding provides at least some evidence that top-down attentional set may have aided participants by allowing them to use the discordant feature of the distractor (different colour) to more efficiently search for the target letter and successfully avoid distractor interference.

Table 7 reports the mean difference between incompatible and neutral distractor trials. These mean differences were calculated by subtracting the mean response time for neutral distractor trials from the mean response time of incompatible distractor trials for each participant. Examining the table it interesting to note that there is significant variation in the differences between participants. This is an observation that has been raised by Fitousi and Wegner (2011) who also found that, despite the fact that the perceptual load theory is supported by analysis of the data on an aggregate level, there appears to be significant variability across participants; with response patterns from some participants exhibiting robust compatibility effects, while others do not. What is also interesting to note is the fact that all but five participants responded slower to incompatible distractor trials when the distractor was also salient, with seven participants responding significantly slower on average, evidenced by mean differences of more than 30ms between incompatible and neutral trials when the distractor was salient. It would appear that, examining these data, distractor interference *could* have played a role even in low perceptual load trials with salient distractors for a significant portion of the sample. This observation problematises the results from the analyses as it would appear that the results are not as easy to interpret as the aggregate level analyses would suggest and the general pattern of responses is not the same for all participants.

Table 7

Mean difference in response time between Incompatible and Neutral distractor trials for each participant

	High Load		Low Load	
Participant	Salient	Non-salient	Salient	Non-salient
1	79,36	45,55	-34,15	88,06
2	2,40	-27,36	-38,99	33,98
3	66,99	-28,87	4,84	41,95
4	-77,32	110,15	55,30	109,49
5	27,36	-63,61	22,93	27,34
6	-46,47	32,90	-44,56	28,42
7	-13,9	25,61	66,78	102,85
8	102,89	49,16	54,43	69,75
9	39,03	-42,19	1,02	139.01
10	-121,29	-94,28	38,03	36,79
11	-21,95	79,46	45,85	51,64
12	49,67	59,03	-5,66	30,46
13	-5,32	-102,66	-38,92	42,28
14	71,08	-40,26	18,88	34,82
15	80,26	80,27	73,36	18,65
16	-38,55	-20,06	9,44	53,34
17	16,27	-56,57	48,58	28,70
18	-16.00	-79,46	21,65	38,07
19	-28,21	33,14	21,99	46,54
20	46,32	-72,89	23,07	33,50

4.6 Main analysis of response errors

The analysis of error rates can be challenging for repeated measures experiments where factors are crossed and trials are replicated within participants. One of the main reasons for this is the fact that the error rates are binary in nature and the replications and non-independence of the observations preclude the researcher from easily employing standard statistical procedures such as logistic regression to analyse the data. Despite the binary nature of the data, many researchers convert the proportion of incorrect responses to error percentages and run statistical procedures such as ANOVA's on these data. One of the major conditions for using ANOVA's is that the dependent variable has to be continuous (Field, 2013).

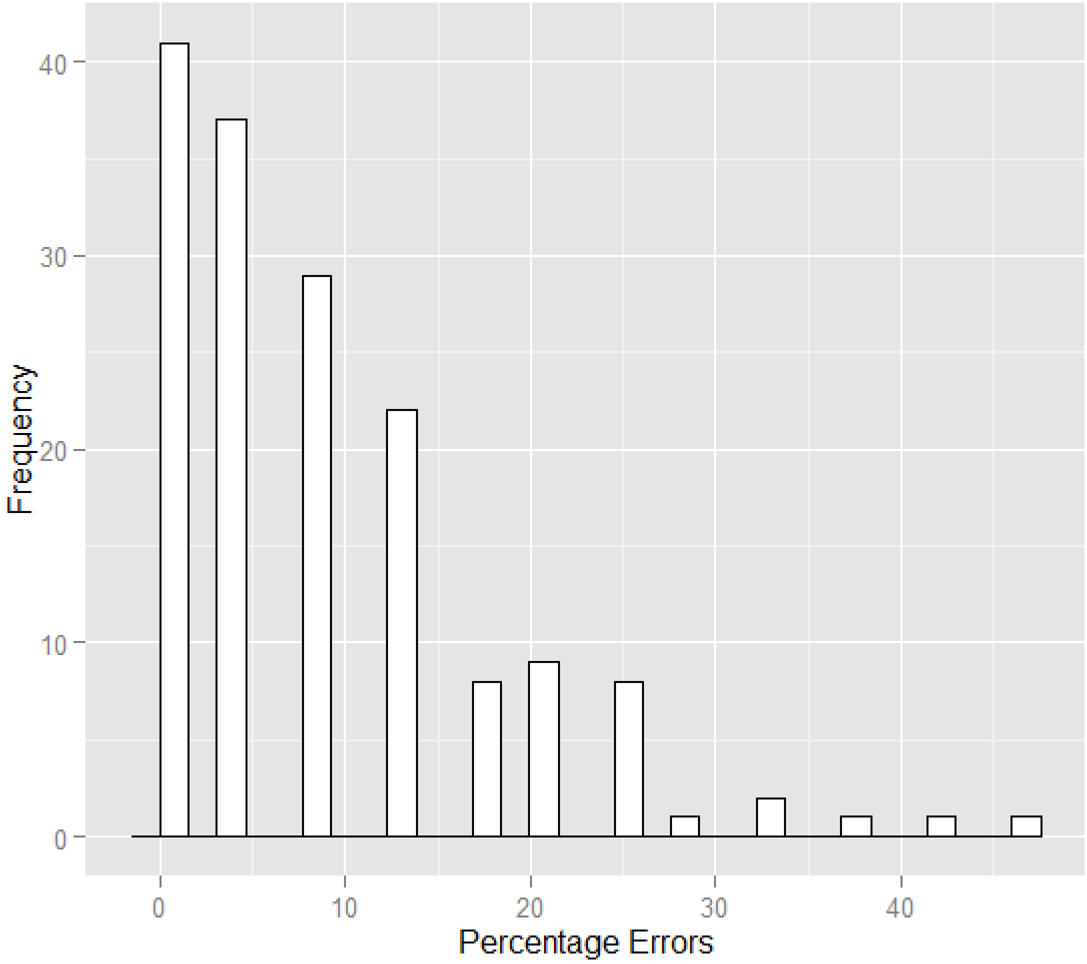

Figure 22: Histogram of error percentages

The main concern regarding the use of ANOVA's on error percentages is the fact that, despite the transformation of the data to percentages derived from proportions, the data still fundamentally represent binary data, as participants can either respond correctly or incorrectly to a trial. Converting these binary data to *percentage correct or incorrect* may not be successful in approximating the behaviour of the type of continuous normal dependent variable required for the use of parametric statistical procedures. From the histogram in Figure 22 it is evident that data with a high frequency of zero occurrences, despite being converted to percentages, cannot follow the type of continuous normal distribution required for analysis using parametric statistical procedures such as ANOVA.

In the case of this particular study, due to the use of 24 replications per participant per condition, the error percentages can only take on a particular value in intervals of 4.2%, a phenomenon known as a scaling artefact (Dixon, 2008). This occurs because the data is not truly continuous and can only take on discrete values despite being converted to what appears to be a continuous scale; the everyday use of the scale itself gives the impression that the data are continuous since the scale ranges from 0% to 100%. These scaling artefacts can cause serious distortions in the parameter estimates when analysed using, for example, ANOVA’s, and lead to a significant increase in the probability to commit both type I and type II errors (Dixon, 2008).

The interactions for the low load conditions, where numerous participants did not commit a single error, might be artefactually underestimated compared to the high load conditions. Clearly the use of ANOVA’s would not be appropriate in this situation. Dixon (2008) does, however, recommend the use of generalised linear mixed effect models (GLMM) from the binomial family that utilise quasi-maximum likelihood techniques to estimate model parameters. Although GLMM’s are better suited to analysing data such as these found in this study, Dixon also points out that accurate parameter estimates for error data are difficult to obtain if the error rate does not exceed 25% or exceeds 75%, due to a lack of variance. The generally low percentage of errors (8.9%) in this study means that no inferential statistical procedures were conducted for the error data. Instead, basic descriptive statistics were used to gain a general understanding of the error data, without exposing the conclusion to potential inferential errors attributable to the use of potentially inappropriate analysis procedures.

4.6.1.1 Descriptive statistics for the error data

Table 8 reports the descriptive statistics for the error data that were disaggregated according to the experimental condition. The marginal means indicate that high perceptual load trials (M = 13.2%, SE = 7.6%) produced more errors than did low perceptual load trials (M = 4.4%, SE = 4.5%). Incompatible trials (M = 10.32%, SE = 6.6%) also produced more errors than neutral trials (M = 7.35%, SE = 4.5%).

Table 8

Descriptive statistics of error percentages

		Non-salient			Salient		
		Mean	SE	CI 95%	Mean	SE	CI 95%
High	Incompatible	15.63	8.1	5.6-10.6	13.33	7.6	5.1-10.1
	Neutral	12.29	7.3	4.8-9.8	11.67	7.2	4.7-9.7
Low	Incompatible	8.13	6.1	3.6-8.6	4.17	4.5	2.0-7.0
	Neutral	2.71	3.6	1.1-6.1	2.71	3.6	1.1-6.1

Of particular interest is the comparison between incompatible and neutral trials across different levels of perceptual load and distractor salience. The biggest raw difference in error rate between incompatible (M = 8.13%, SE = 6.1%) and neutral (M = 2.71%, SE = 3.6%) distractor conditions was for the non-salient distractors in the low perceptual load condition. These are the two conditions that exhibited the only statistically significant compatibility effect in the analysis of the response times. Whether or not the difference in error rates between these two conditions is a result of increased distractor interference in the incompatible distractor condition is not clear, especially given the large overlap in the confidence intervals.

4.7 Conclusion

In conclusion, no participant had enough responses trimmed or committed enough errors to warrant excluding them from the analysis based on the 30% criterion for the two-stage trimming strategy chosen for this study. The trimming strategy was also relatively effective in producing response time distribution on the experimental condition level for which normality would be a reasonable assumption, thus meriting the use of parametric ANOVA’s and paired-samples t-test for the analysis of the data.

The presence of a main effect for perceptual load in the both salient and non-salient two-way ANOVA analyses provided evidence that high perceptual load trials produced higher mean response times when compared to low perceptual load trials. This finding is important as it indicates that the manipulation of perceptual load produced comparable effects when considering previous studies. In addition to the apparent successful manipulation of perceptual load, the replication of the compatibility effect for non-salient distractor trials provided direct evidence that the results obtained from this sample are, to a large extent, comparable to previous studies that also produced a statistically significant compatibility effect in the absence of salient distractor trials. The main analysis for the salient distractor trials, however, failed to produce a statistically significant compatibility effect after the Bonferonni-Holm correction was applied. The interpretation of these findings will be discussed in-depth in the next chapter.

5. Discussion and limitations

5.1 Introduction

The following chapter will provide a discussion of the results obtained for this study and will orientate the results within the larger framework of the perceptual load theory of selective attention. A critical discussion of potential limitation of the study will also be provided.

The main research question was whether a colour salient distractor, created by making it a colour singleton, will aid search efficiency, hinder it, or have no impact on search efficiency. The perceptual load theory of selective attention maintains that perceptual load, operationalised as set-size in experiments such as this, is the main determinant of early or late selection. According to the perceptual load theory of selective attention, when spare perceptual capacity is available it will automatically be allocated to the perception of additional stimuli, whether these stimuli are irrelevant or not. This happens because of the spill-over effect of perceptual capacity that occurs when perceptual capacity has not been reached (Lavie, 1995). Evidence for this perceptual spill-over account have been provided via the presence of a compatibility effect in low perceptual load search arrays, but not high perceptual load search arrays (Lavie, 1995). Secondary top down attentional mechanisms, such as working memory, serve an important role in ensuring that task irrelevant stimuli are not processed.

This leads to an interesting question, however. What happens when automatic perceptual capacity allocation and these secondary top-down attention mechanisms find themselves at odds? This is exactly what occurs in low perceptual load trials where the distractor is also salient, but irrelevant (Biggs & Gibson, 2010). According to the spill-over hypothesis, the distractor identity should automatically be processed, whereas the top-down attentional control mechanisms can theoretically utilise the irrelevant feature of the distractor to efficiently filter out the distractor, thereby preventing the incompatibility of the distractor identity from leading to response competition. On the other hand, it would also be possible for these salient distractors to capture attention in a stimulus-driven fashion and capture participants' attention even in high perceptual load conditions, leading to increased response times, regardless of the distractor identity. Either of these results could potentially problematise or diminish the primacy of the role that researchers assign to perceptual load in the selection of stimuli.

Both of these scenarios have been demonstrated. Eltiti et al. (2005) found that salient distractors can lead to increased distractor processing even in high perceptual load search arrays. An experiment by Johnson et al. (2002) showed that it is possible to negate the interference effect of distractors in low perceptual load trials. According to the spill-over account of perceptual capacity allocation, this should not be possible. These two findings, and other like them, demonstrated that salience can come to dominate perceptual load in determining selection of stimuli. However, these two studies used non-static search arrays, and it is possible that the threshold for detecting movement is much lower than detecting difference between stimuli that are static in nature. Though these two studies, and other like them, demonstrate some shortcomings in the strong version of the perceptual load hypothesis, it is critical in establishing how perceptual load and stimulus salience interact in static search arrays similar to the ones used by Lavie (1995) and Lavie and Cox (1997).

Gaspelin et al (2012) found that static salient distractors did not lead to an increase in mean response time for low perceptual load search arrays where the distractor was also a flanking letter. On the contrary, the researchers found that the inclusion of salient colour singletons as distractors diminished the interference effect as demonstrated by the lack of a statistically significant compatibility effect for low perceptual load search arrays. These results partially contradict the results of Eltiti et al. (2005) by demonstrating that static colour singleton distractors do not automatically lead to increased distractor interference. The results from Gaspelin et al. (2012) also problematise the spill-over account of perceptual capacity allocation that forms the cornerstone of perceptual load theory, since a lack of distractor processing was found for low perceptual load trials. These results lend further support to the primacy of top-down control of attention allocation as participants could have used the salient feature contained in the distractor to effectively guide their search for only the target.

In order to further clarify the way in which perceptual load and distractor salience may interact in affecting selective attention this study investigated the effect of salient distracting stimuli using a typical hybrid visual-search flanker task. Salient distractors that were bright orange in colour were included in half the trials, while the other half of the trials included non-salient distractors to serve as a baseline condition and to ensure that the traditional compatibility effect found by previous research (see Lavie, 1995, Lavie and Cox, 1997) could be at least partially replicated. All experimental conditions were presented in random order with trials split into two blocks to allow participants to take a small break in the middle of the experiment.

5.2 Results

Eleven hypotheses were tested in this study. These eleven hypotheses were formulated based on results of previous studies that manipulated perceptual load, distractor compatibility and perceptual load either jointly or investigated specific interactions of these factors. Error rates were also included as dependent variables in the original hypotheses, but error rates were not analysed beyond basic descriptive statistics due to the unacceptably high risk of committing type I and type II errors when analysing these data using the null-hypothesis significance testing paradigm. The reason for this decision was discussed in the methodology and results chapters, but will be briefly summarised after the results of the study have been contextualised.

5.2.1 Hypothesis 1

In order to ensure that the manipulation of set-size brought about an increase in perceptual load mean response times for high perceptual load trial were compared to mean response times for low perceptual load trials. As was discussed in the literature review the lack of an *a priori* operationalisation of perceptual load renders the construct vulnerable to potential abuse (Benoni & Tsal, 2013). The use of response times as a manipulation check when it is included as a dependent variable is a problematic and the potential pitfalls of taking this approach are acknowledged. One of the main critiques of using this approach is that the use of response times as a manipulation check, when it is also included as the dependent variable, is that it comes dangerously close to being self-affirming. This, in turn, can lead to results that favour a confirmation of the theory; since failures to establish the effect will likely lead researchers to conclude that the manipulation of perceptual load was unsuccessful, invalidating any null results (Benoni & Tsal, 2013). In this study the comparison between high and low perceptual load trials was done primarily to ensure that the results are comparable to those found by other researchers, as it has been reliably demonstrated that increasing set-size leads to increased response times as well. However, the results should be interpreted with caution as the possibility exists that the interactions may have been disordinal across different levels of the factors (Buckless & Ravenscroft, 1990).

A main effect for perceptual load was found for both salience and non-salient distractor conditions. This finding established that increases in set-size brought about an increase in means response time as well. Whether or not this increase reflects an increase in perceptual load is not entirely clear due to the lack of a sufficient *a priori* definition of perceptual load, something that has been heavily criticised by Benoni and Tsal (2010) and

Benoni and Tsal (2013). This results does establish however that the basic manipulation of set-size has produced results that are in line with the findings of similar studies who also found that increased set-size leads to increased mean response times.

5.2.2 Hypothesis 2

No statistically significant main effect was found for distractor salience, indicating that salient distractors, in and of themselves, were unlikely to lead to increases or decreases in mean response time. The compatibility effect applies to the processing of the distractor *identity* under different conditions of perceptual load and does not apply to distraction caused by the colour feature of the distractor itself. This is not to say that this result is meaningless, merely that this result is not very informative in the context of this study, apart from providing an indication that it is unlikely that salient stimuli automatically grabbed attention in a purely bottom-up driven fashion.

5.2.3 Hypothesis 3

No statistically significant main effect for distractor compatibility was found for salient distractor trials, whereas, non-salient distractor trials exhibited a main effect for distractor compatibility. This indicates that the difference between incompatible distractor trials and neutral distractor trials was statistically significant for non-salient distractor trials, but not for salient distractor conditions across both conditions of perceptual load. This finding, although interesting, is not very informative within the context of this study (see Hypothesis 2 above).

5.2.4 Hypothesis 4

There was no statistically significant interaction between distractor compatibility and perceptual load for salient distractor trials. There was, however, a statistically significant interaction between distractor compatibility and perceptual load for non-salient distractors. This finding can be interpreted as evidence that there is a traditional compatibility effect for non-salient distractor conditions that reflects the general pattern observed in other studies such as those of Lavie (1995) and Lavie and Cox (1997), for example. This compatibility effect appears to be absent for salient distractor conditions. However, given the possibility that high perceptual load trials may have yielded increased distractor interference or that the distractor interference for low perceptual load trials may have been diminished, this result is incomplete and cannot meaningfully interpreted in isolation.

5.2.5 Hypothesis 5

No statistically significant interaction effect was found for distractor salience and perceptual load. This finding is also not very informative within the context of this study as no specific theoretical claim was made or investigated regarding the potential of distractor salience and perceptual load to interact in any meaningful way.

5.2.6 Hypothesis 6

No statistically significant interaction effect was found for distractor salience and distractor compatibility. Interpreting the lack of a statistically significant interaction would not be useful given the scope of the main objectives of this study.

5.2.7 Hypothesis 7

A statistically significant three-way interaction was found for perceptual load, distractor compatibility and distractor salience. This finding indicates that perceptual load and distractor compatibility likely interact in different ways depending on the relative salience of the distractors in the search arrays.

5.2.8 Hypothesis 8

A significant difference between mean response times for incompatible and neutral distractor trials was present when the distractors were also non-salient and the search task induced a low level of perceptual load. This indicates that the incompatible distractor likely lead to significant interference effects, thereby delaying the response of participants in incompatible distractor trials.

5.2.9 Hypothesis 9

No significant difference was found between mean response times for incompatible and neutral distractor trials in search arrays where the distractor was non-salient and the search task induced a high level of perceptual load. Together with the finding for hypothesis 2, the results indicate that the traditional flanker compatibility effect has been replicated successfully. These two results, supports the pattern of results expected when perceptual spill-over occurs in low, but not high perceptual load conditions. The perceptual spill-over could have been prevented in the high perceptual load conditions, due to the unavailability of perceptual resources.

5.2.10 Hypothesis 10

No significant difference was found between mean response times for incompatible and neutral distractor trials in search arrays where the distractor was salient and the search task induced a low level of perceptual load. This finding partially contradicts the perceptual load theory of attention as this demonstrates that participants likely did not process the distractor identity and therefore avoided any potential distractor interference in conditions of low perceptual load. This result, in turn, suggests that it is possible for stimulus salience to dominate perceptual load in the selection of stimuli. This truthfulness of this finding, however, is questionable as will be discussed in the section to follow.

5.2.11 Hypothesis 11

No significant difference was found between mean response times for incompatible and neutral distractor trials in search arrays where the distractor was salient and the search task induced a high level of perceptual load. Taken together with hypothesis 10, it can be concluded that no compatibility effect occured when distractors were also salient.

5.3 Tentative conclusion for response time analyses

In order to address the main research question repeated measures ANOVA's and planned comparisons were used to consider the possibility that non-salient distractor trials produce statistically significant compatibility effects while salient distractor trials do not. This basic findings has been demonstrated in a study conducted by Gaspelin et al. (2012) using colour singletons as distractors, as well as studies by Eltiti et al. (2005), Paquet and Craig (1997) and Johnston et al. (2002) who either pre-cuing or offsets to manipulate the relative salience of the targets and distractors.

A significant three-way interaction indicated that distractor compatibility and perceptual load likely interact in different ways depending on whether or not the distrators were salient or non-salient. Although this does not constitute sufficient evidence to conclude that a nuanced compatibility effect exists, it does provide evidence that one two-way interaction between compatibility and perceptual load is different from the other depending on the salience of the distractor. In order to investigate these results the follow-up procedure resulted in two separate two-way repeated measures ANOVA's being conducted on the non-salient and salient distractor trials. The results revealed that while a significant interaction between perceptual load and distractor compatibility existed for non-salient distractor trials, no such two-way interaction existed for the salient distractor trials. However, the interaction may have been obscured by relative increases or decreases in response times of incompatible distractor trial response times in comparison to neutral distractor trials.

Due to the specificity of the hypotheses, planned comparisons were used to test if mean response times for incompatible distractor trials were longer than mean response times for neutral trials. Two paired samples t-tests -one for low perceptual load trials and one for high perceptual load trials– conducted on the non-salient distractor trials revealed that only low perceptual load trials yielded a significant difference between incompatible and neutral distractor trials. This result replicates the existence of a compatibility effect in non-salient distractor trials since response times were significantly longer for incompatible distractor trials compared to neutral distractor trials in low perceptual load trials, but not in high perceptual load trials, as predicted by Lavie (1995). This finding also meant that the results from the salient distractors can be interpreted with some degree of confidence as the basic pattern of results predicted by perceptual load theory has been sufficiently replicated for this particular sample. This findings provides evidence that under conditions of low perceptual load, the excess perceptual resources can lead to a spill-over effect whereby the distractor identity is also processed therefore leading to response competition in incompatible distractor trials. This response competition is evidenced by the significant difference between mean response times for incompatible trials and neutral trials for low perceptual load conditions (see Lavie, 1995; Lavie and Cox, 1997; Lavie, 2005).

The results from the paired samples t-tests for salient distractor trials revealed that neither high perceptual load, nor low perceptual load trials, produced a significant difference in mean response time between incompatible and neutral trials after the Bonferonni-Holm correction was applied. This meant that both neither null hypothesis could be rejected in favour of the alternate hypotheses, in turn, indicating that there was no statistically significant compatibility effect for salient distractor trials. As predicted by Gaspelin et al. (2012), the compatibility effect appears to be absent in the presence of colour singleton distractors. The results are demonstrated in Figure 21. This finding may be a reflection of the argument made by top-down theories of attention as proposed by Hillstrom and Yantis (1994) and Wolfe, Cave, and Franzel (1989) who argue that top-down attentional set may in fact override bottom-up attentional capture by feature singletons. This finding is problematic from a perceptual load theory perceptive as it confirms that the top-down attentional control mechanisms can dominate perceptual load in the selection of stimuli.

The veracity of this finding is questionable however, since the salient distractor conditions did produce an apparent compatibility effect before the Bonferonni-Holm correction was applied. The application of the alpha correction is stressed since the low perceptual load conditions containing salient distractor trials did produce a statistically significant *p*-value (*p* = .023) before the alpha correction was applied. This makes it problematic to interpret the results as O' Keefe (2003), for example, argues that the use of corrections to compensate for the increased risk of experiment-wise error is unnecessary and should be abandoned. The author argues that the applications of these alpha correction methods are inconsistently applied as reviewers almost never require their application in the model fitting process of multiple regression analysis or the initial interaction estimates for factorial ANOVA's, but almost always insist on their application in the case of post hoc analyses or even planned comparisons for ANOVA's.

In addition to the contentious use of alpha level corrections, the use of formalised decision making regarding the null and alternate hypothesis found in the Pearson-Neyman approach to hypothesis testing may also not be appropriate. The Pearson-Neyman approach emphasises limiting the risk of committing Type I and Type II errors in the long run under uncertainty (Biau, Jolles, & Porcher, 2010). This formalisation may be convenient in making decisions regarding experimental effects over time, but it may also be inappropriate in cases such as this, where there may be doubts regarding the statistical power or the use of data trimming strategies and the interactions appear to be nuanced in nature and the effects potentially volatile. Under these conditions it becomes hard to justify and support the decision made when there is a high degree of uncertainty regarding the adequacy of the data in making the decision in the first place. In cases such as this it may be counterproductive to think in terms of the dichotomous outcomes regarding the null and alternate hypothesis.

The *p*-value is the probability of obtaining an effect equal to or more extreme than the one observed considering the null hypothesis is true (Biau, Jolles, & Porcher, 2010). This simply means that the lower the *p*-value, the less likely it is that the null-hypothesis is true. Also to this end, a quip by Rosnow and Rosenthal (1989, p. 1277) reflecting R.A Fisher's sentiments regarding the use of *p*-values may be appropriate:

> "…we want to underscore that, surely, God loves the .06 nearly as much as the .05. Can there be any doubt that God views the strength of evidence for or against the null as a fairly continuous function of the magnitude of *p*?"

Formally, according to the statistical criterion specified ($\alpha = 0.05$), the null hypotheses for low perceptual load salient distactor trials could not be rejected, despite a moderate effect size of $d = .501$. Accordingly, the conclusion for this study is that salient distractors probably do not lead to compatibility effects in low perceptual load trials, indicating that perceptual load may in fact play a secondary role to distractor salience within the contexts of search arrays with salient flanking letters that serve as distractors, as was argued by, for example, Gaspelin et al. (2012). This does seem to be an arbitrary decision that, taken at face value, would surely do a disservice to the potentially subtle and fascinating interaction between perceptual load and distractor salience; and amount to a marginal degree of scholarly negligence that goes against the spirit of empirical inquiry. Although the effect size of the difference between incompatibility and neutral distractor trials are much smaller for salient trials ($d = .501$) compared to non-salient trials($d = 1.69$) the serious shortcomings, both in terms of analysis, as well as in terms of design, preclude any definitive or, even reasonable, decisions from being made regarding the hypotheses. This is not to say that the results are worthless, merely that the use of the analysis framework for this study may not be appropriate in evaluating the nuanced interaction between the factors.

The results are difficult to interpret as low perceptual load distractors may be more salient than distractors in high perceptual load conditions, as posited by researchers who argue that salience is responsible for the compatibility effect and not necessarily perceptual load (see for example Eltit et al., 2005; Gaspelin et al., 2012; Johnson et al., 2002; Paquet & Craig, 1997). This underscores the drawback of manipulating load as a function of set-size since it probably confounds salience and perceptual load. If the experimental manipulation of these properties is inseparable, the results will also be inseparable. Additionally, when there are only two elements in a search array, one of which is a colour singleton, it is not clear to what extent this will influence the relative salience of that particular element, making it difficult to compare salient and non-salient trials as there may be an additional component to the processing of these stimuli that was not accounted for in this study, further obscuring the results. What is clear, however, is that the magnitude of the compatibility effect appears to be much larger for non-salient distractors compared to salient distractor trials for this study.

5.4 Error rates

Error rates were not used in the analysis of the data despite its inclusion as an independent variable in the study. According to Dixon (2008), the analysis of discrete data using ANOVA’s may lead to an unacceptably high risk of committing type I and type II errors depending on the degree to which scaling artefacts are present in the data. When binary data are converted to percentages, these scaling artefacts are introduced since a fundamentally discrete scale is essentially mapped onto a continuous scale when in fact the scale still retains its discrete properties. In the case of the data for this study for example, the use of 24 replications per condition per participant meant that participants’ error percentages could only take on discrete values in intervals of roughly 4%. Reducing participants’ error performance to a mean error percentage is thus problematic. The presence of a scaling artefact combined with the very low error percentages meant that no inferential analyses were conducted on the error data. Additionally, the lack of any errors for a significant number of participants, in especially low perceptual load trials, meant that further biases may have been introduced into the analysis. Descriptive statistics did reveal that incompatible distractor trials yielded more errors in both low perceptual load, as well as high perceptual load trials when compared to neutral distractor trials. This may be an indication that the incompatible identity of distractor may have lead to participants making more errors due the response competition created by the incompatible distractor.

5.5 Limitations

The results obtained in this study should be interpreted within the context of the limitations of the study. The various limitations are discussed below.

5.5.1 Trimming of the data and analysis

As Ratcliffe (1993) points out, the trimming strategy used by the researcher can have a profound influence on the results of the analysis, since the parameter estimates may be severely biased in the presence of outliers or skewness. Due to the use of factorial repeated measures ANOVA’s for the analysis of response time, mean response times for each participant had to be calculated as ANOVA’s are not capable of handling replications. The trimming strategy used in this study was not particularly conservative as the distributions displayed significant positive skew. The use of a two-stage trimming process meant that some participants had as much as 20% of their responses trimmed while other participants had hardly any responses trimmed. It is thus not entirely clear to which extent an inadvertent crossing of the line between the legitimate trimming of outliers and the unintentional manipulation of the data occurred. The use of ANOVA’s that necessitate the trimming of the data to satisfy the assumptions of using the test may be an indication that this particular analysis strategy is inappropriate for the analysis of data as nuanced as response time data.

Fitousi and Wegner (2011), for example, found that whereas aggregate data generally supported the load theory of selective attention, participants in their study displayed significant variation in processing capacity and search performance when integrated hazard functions were used to analyse the data. These individual level results undermined the predictions made by perceptual load theory. These conflicting results, and the individual variability that load theory often ignores, may be an indication that perceptual load theory lacks the flexibility and specificity to deal with the often flexible and varying nature of selective attention and target searches.

5.5.2 Sample size

Prior research done on perceptual load on selective attention generally did not contain very large sample sizes. The original study by Lavie (1995) for example included just 14 undergraduate students, while studies by Benoni and Tsal (2010) and Biggs and Gibson (2013), contained 15 and 23 undergraduate students respectively. Although the sample for this study consisted of 20 participants, the small sample size meant that the statistical analyses may have been slightly underpowered. Generally, the smaller the effect the more statistical power is required to detect the effect and avoid committing a type II error (Field, 2013).

5.5.3 Sample bias

Due to the severe sample bias in favour of females, the results may not be generalisable. It is also not clear if the biased sample is entirely comparable to other studies, as these studies normally have more balanced samples in terms of the gender distribution. The restriction of the age range also meant that the sample ended up being largely homogenous in terms of age. Despite the fact that there is always a trade-off between experimental control and generalisability, this experiment was aimed at maximising internal validity by ensuring that age could not serve as an alternative explanation for the results, as age is known to influence response times and cognitive processing (Ratcliffe et al., 2001). This does have the consequence of severely limiting the generalisability of the results, as the sample comprised mostly females aged 21 to 24 years of age.

5.5.4 Input device associated measurement error

One of the main threats to internal validity that has not been addressed yet is the nature of the input device used to capture response times. Due to the relatively small difference in mean response time between some of the conditions in this experiment, the validity of the results rely on the precision and accuracy with which the response times are captured by the experimental program and the input devices i.e. keyboard. There are two potential sources of measurement error researchers often do not account for when using input devices to capture response times on a computer. The first is the polling rate of the USB input. Input ports such as USB are polled for input at 125Hz, meaning that input from USB peripherals such as keyboards are registered once every eight milliseconds. If an input is made directly after the polling cycle the signal will be stored in a buffer until the next polling cycle registers the signal. This means that a variable input latency of as much as eight milliseconds can occur on a specific trial depending on where in the polling cycle the participant responded by pressing the key on the keyboard. In addition to the polling rate of standard USB devices, the operating system may also add an unknown delay in handling the input received from the USB port.

The second source of uncontrolled input variance is the specific input device used. Input devices themselves also contain scanning cycles in order to increase the energy efficiency and life cycle of the device. A study by Shimizu (2002) demonstrated that while some PS/2 and USB devices registered input within 2ms, scanning procedures for some devices may be as high as 32ms. This represents a significant threat to validity as measurement error of this magnitude might have a profound influence on the results of the analysis. Unfortunately the specifications of consumer grade electronics are not always readily available and establishing the input lag of a device normally requires the use of specialised equipment such as an oscilloscope.

Even though the measurement error from polling rates is random and can therefore be assumed to be randomly distributed, the variability of the input error may still bias response time estimates if the number of trials are low and if some of the timing variability of the input device is non-random (Li, Liang, Kleiner & Lu, 2010). Without actively scrutinising the error attributable to the input device and operating system the input latency and variability of input timing remains a major threat to the validity of the study.

5.5.5 Practice effects

In the literature review it was briefly mentioned that participants might change their attentional set as the experiment progresses from a predominantly bottom-up to a predominantly top-down processing mode, thereby allowing them to more efficiently filter out distractors based on the incompatibility of the colour feature with the target (Wolfe, Cave, & Franzel, 1989). This, in turn, implies that the dominance of salience over perceptual load can be attributed to the practice and experience participants accumulated due to their continuing exposure to the experimental conditions as the experiment progressed. In other words, the primacy of perceptual load in determining selection is still maintained but the distractor interference is reduced in salient distractor trials due to a secondary and predominantly top-down selection mechanism that efficiently resolves the distractor interference whenever the task irrelevant colour feature is present. This may happen only when sequential trials are completed in such a short span that this top-down processing mode acts as an additional secondary attentional filter in order to increase search efficiency due to the relative predictability of the search arrays; something that might not necessarily occur otherwise. In essence, the distractor might still be perceived and processed semantically in salient conditions, thereby leading to response competition, but participants learn that the colour irrelevant feature can be used to resolve the response conflict faster because it represents an irrelevant stimulus. If this is the case, salience does not so much dominate load as it acts as a secondary mechanism to increase search efficiency when the nature of the irrelevant feature remains constant.

This possibility can be investigated by observing if the mean response times during the first half of the experiment is different to the second half for conditions in which distractors were salient. Unfortunately, due to the randomisation of the trial conditions this is not feasible as the number of trials would likely be too low to derive accurate response time estimates from data that are already rather noisy from a statistical point of view. In addition to the concerns regarding accurate parameter estimates the randomisation and trimming of trials also mean that some participants may have completed fewer salient trials during the first half of the experiment compared to the other participants, leading to even more unbalance data for estimating mean response times.

5.5.6 Compatibility effect

The use of the compatibility effect may also not be as good an indicator of the failure to suppress task irrelevant stimuli as researchers assume. Task irrelevant flankers are not necessarily task irrelevant *per se*, since the physical features of the flanking letter can still be task relevant. Buetti, Lleras and Moore (2014) for example argue that:

> The flanker effect exists not because attention has failed at selecting only the target from the display, but rather, the effect arises precisely because attention succeeded at selecting target-like (i.e., attentionally relevant) stimuli from the display (p. 1231).

Thus the processing of the identity of incompatible flanking distractors does not necessarily imply the automatic spill-over of attentional resources as the top-down mechanisms tasked with maintaining task processing priorities did exactly that, even when the positionally irrelevant distractor is processed. In studies such as this one, task irrelevance is defined solely in terms of the distractor position within the search array, but often fails to take into account its physical properties that are exceedingly task relevant in the case of incompatible distractor trials.

5.6 Conclusion

To conclude, the analysis of the data revealed that colour salient distractors effectively reduce distractor interference in low perceptual load trials. This effect may be due to a potential top-down attentional set that allows participants to use the colour feature of the salient distractors to effectively filter out the distractor identity, in turn, reducing the probability that the processing of the distractor identity will lead to response competition. This conclusion is only partially supported, however, as there appeared to be at least some evidence to suggest that Pearson-Neyman null hypothesis testing and the use of aggregated data may not be appropriate approaches for analysing complex and nuanced interactions.

There are numerous factors that may have influenced the results of the study. Due to the heavily biased nature of the sample in terms of gender, the results may not be generalisable to males for example. Of particular concern is the potential influence of the input devices used for this study. Although PsychoPy has been demonstrated to be a reliable platform for conducting experiments that rely on input precision, the consumer grade input devices used for this experiment may not meet the necessary reliability standards required, especially given the relatively small difference in mean response times between some of the experimental conditions. In the absence of any information regarding the latency and dispersion produced by the input devices, the potential effect that these devices may have had on the results is uncertain as well, thereby shedding at least some doubt on the results of the study. A second potentially confounding factor is the effect that practice may have had on participants' response times. The inclusion of 36 practice trials and the randomisation of experimental conditions should have counteracted potential practice effects to a large extent, though it is still possible that participants may have responded differently in the latter half of the experiment due to increased familiarity with the experiment, or even due to fatigue. Finally, there is also reason to believe that the use of the compatibility effect as an indicator of distractor interference may not be as valid and reliable as researchers perceive it to be (Buetti, Lleras, & Moore, 2014).

6. Conclusion and Recommendations

The problematic interpretation of the results once again underscores the idea put forward by Biggs and Gibson (2013) that even small changes in the experimental set-up can sometimes lead to contradictory results. In the case of this study for example, the constricted nature of the sample, the data trimming strategy used, the use of ANOVA's as the primary analysis, or even the use of mean response times as a dependent variable may all have contributed to the findings in a meaningful way. This emphasises the fact that the choice of factors, dependent variables, experimental, and design elements are extremely important in ensuring that the results are not only meaningful, but also that they are valid.

This study found that salient distractors lead to a decrease in the processing of distractors, since neither high perceptual load, nor low perceptual load trials, produced evidence that incompatible distractor trials lead to increased distractor interference compared to neutral distractor trials. This may be attributable to top-down attentional control processes using the irrelevant colour feature to increase participants' search efficiently when searching for the target letters. The salient distractors may still be salient, but the colour feature also becomes an additional dimension alongside the positional irrelevance. This makes it even easier for participants to suppress the processing of its identity and thereby avoiding any response competition that may have delayed a participant's response time. This finding is partly at odds with the perceptual load theory of attention since the lack of distractor processing in low perceptual load trials with salient distractors does not corroborate the spill-over hypothesis which dictates that perceptual capacity allocation happens automatically until perceptual capacity has been reached. At the very least some top-down attentional control mechanisms might in fact modify or override perceptual load in determining the selection of stimuli either during the perception of the stimuli or the rejection of their identity or properties.

The non-salient distractor conditions replicated the results found in other studies in that low perceptual load trials produced a statistically significant difference between incompatible and neutral distractor trials, indicating the processing of the semantic identity of the distractor may have led to response competition. The lack of a similar effect in the high perceptual load trials containing non-salient distractors indicate that the results are in line with the predictions made by the perceptual load theory of selective attention, whereby the perception and processing of the task-irrelevant distractor is mediated by the perceptual load that the visual system is placed under.

The finding of this study dovetails the results of other studies (Lavie, 1995; Lavie and Cox, 1997; Lavie, 2004) that also found the interaction between perceptual load and distractor salience to be a nuanced one that needs to be further explored in order to derive a sufficient theoretical framework for selective attention and the top-down and bottom-up attentional control mechanisms that influence selective attention.

6.1 Recommendations

6.1.1 Analysis

van Zandt (2002) argues that many of the more nuanced and interesting effects associated with response time data are lost when analysing only the means derived from response time distributions. In the case of this study for example, the data trimming procedure used, meant that 14.1% of the response times were trimmed. This signifies a significant proportion of the data. One might even argue that the line between cleaning data and manipulating data is one that researchers often unwittingly cross. Unfortunately this trimming stage is necessary if the researcher wishes to use ANOVA's as the distribution is reduced to a single parameter that has to capture the information contained within that distribution (i.e. the mean). There are at least some statistical techniques that researchers can utilise that do not require the compression of the distribution into a single parameter. Mixed effects models, for example, can be used to specify the participants as random factors and allow intercepts and slopes to vary across conditions. This approach does not require the compression of the distributions, but any outliers may still bias the parameter estimates, possibly necessitating the use of trimming strategies once again. The use of response times as an indicator of processing *capacity* may also be a good alternative to the use of simple mean response times. Fitousi and Wegner (2011) demonstrated that the integrated hazard function – a form of survival analysis– can be a good technique for mapping individual differences in processing capacity, which in turn will retain nuanced differences between individuals that may be lost when using only mean response times.

Error rate is difficult to directly manipulate within the parameters of an experiment without changing the task difficulty and therefore confounding task difficulty and perceptual load. This places the researcher in an awkward situation. In order to derive accurate parameter estimates it is important that the number of errors are not too high or too low, as crucial variability is lost if this occurs.

6.1.2 Salience as selection cue

Future studies should investigate the possibility that salient distractors lead to increased distractor processing for high and low load trials, but only during the initial phase of the experiment. As the experiment progresses, a secondary but primarily top-down attentional filter may be employed due to the predictability of the distractor features. To test this possibility, participants can be randomly assigned to one of two groups and presented with a high number of counterbalanced trials. One group is presented with alternating blocks of salient and non-salient distractor trials, whereas the other group is presented with trials where the presentation is randomised in much the same fashion as the experiment used in the current study. This will allow the researcher to compare the effect of repeated exposure to salient and non-salient distractors in both blocked and randomised presentations.

6.1.3 Longitudinal effects of practice

During the pilot testing and the design phase of the experimental presentation it was noteworthy that, after repeated exposure to the search task, no compatibility effect occurred even in the non-salient low perceptual load trials. In order to establish the effect that longitudinal exposure may have on search efficiency and any carry-over effects, the researcher can expose participants to a similar task at regular intervals over a period of weeks, allowing them to gain familiarity with the task and to develop efficient search strategies. The researcher can then expose them to a search array that uses different stimuli and organise the stimuli differently, but still require participant’s top make a two-choice speeded response task.

6.1.4 Eye tracking

A last alternative is the use of eye tracking technology to trace the cognitive load levels and eye movements of participants. According to perceptual load theory, working memory is tasked with maintaining task processing priorities. It would be interesting to note if cognitive load levels vary as a function of perceptual load and distractor salience. The use of short exposure times are used to avoid participants from making explicit eye movements, but there is no guarantee that participants do not shift their gaze away from the fixation point either before or during the presentation of the search array. If this is the case, some trials might reflect a failure of gaze control as much as it reflects selective attention.

6.2 Conclusion

In conclusion, this study provided evidence that salient distractors may produce a reduction in distractor interference by allowing participants to effectively use a top-down attentional set to filter out the distractors based on the salient feature of the distractor. This result supports the findings by Gaspelin et al. (2012) and Eltiti et al. (2005). Whereas this finding by no means implies that perceptual load has no influence on selective attention, it does problematise the theory’s reliance on perceptual load as the main determinant of early or late selection. As Biggs and Gibson (2014) suggests, perceptual load is probably an important factor in determining selection, but it likely interacts in complex ways with other factors such as stimulus salience in order to influence selective attention. Additionally, given the relative constraints of the experimental designs and the statistical analyses used to investigate selective attention from a behavioural point of view (via the use of response times and error rates), the nuanced nature of these interactions may be obscured to such an extent that these complex interactions cannot be sufficiently investigated. To this end, it is critical for researchers in the field to continually develop and improve the analytical techniques and experimental designs used to investigate the factors that affect perceptual and attentional selectivity.

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8. Appendix A

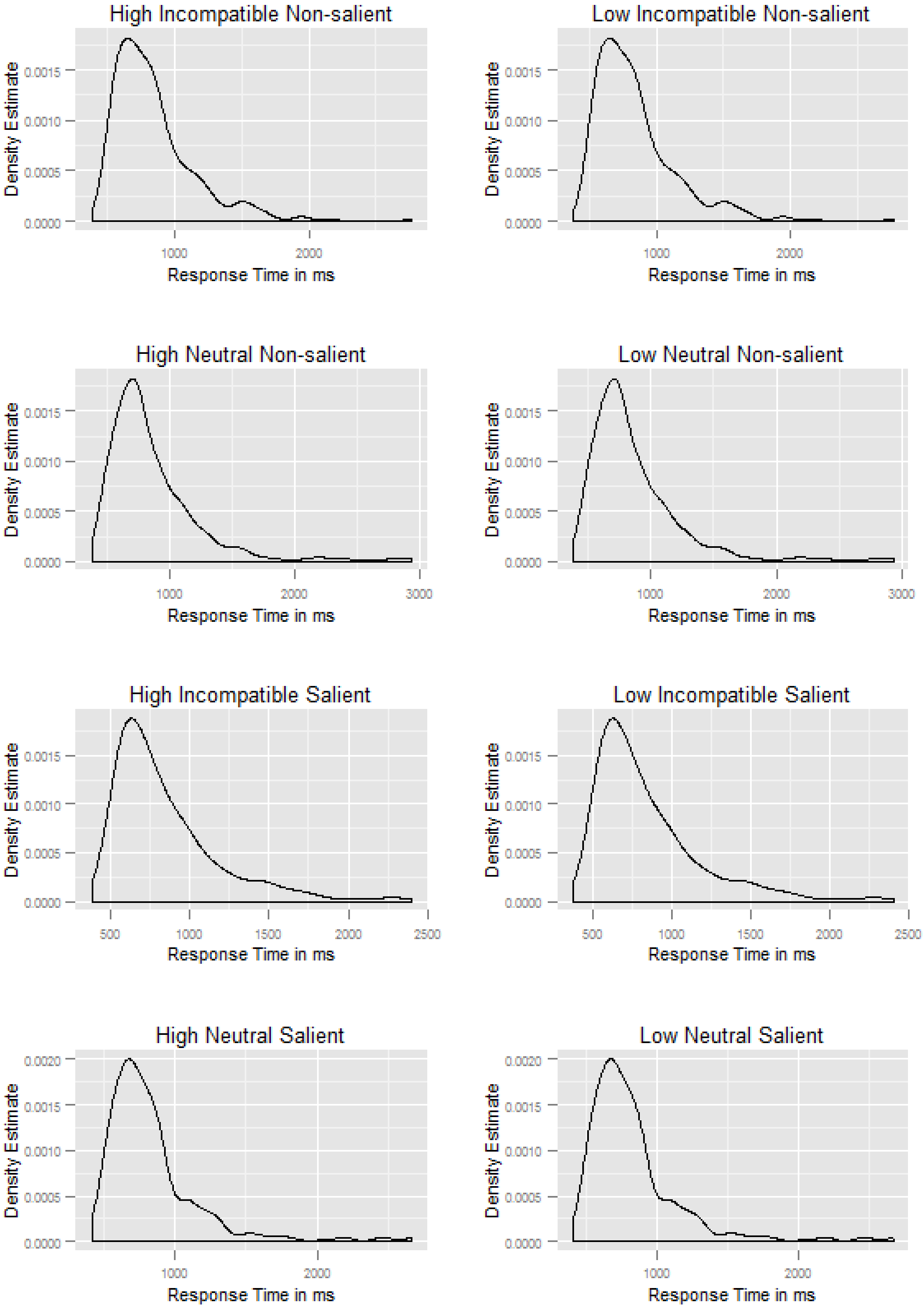

Figure 23: Density plots of response times for each experimental condition after the deletion of incorrect responses.

9. Appendix B

Table 9

Summary of three-way repeated measures ANOVA with Load, Compatibility and Salience as factors and response time as dependent variable

Effect	DFn	DFd	SSn	SSd	F	*p*	η_p^2
(Intercept)	1	19	77647606	677793	2176.63	<.0001	-
Load	1	19	1148912	128088	170.42	<.0001	.900
Compatibility	1	19	14047	31030	8.60	.009	.312
Salience	1	19	2206	15046	2.79	.112	.128
Load:Compatibility	1	19	10560	20792	9.65	.006	.337
Load:Salience	1	19	1129	21559	1.00	.331	.050
Compatibility:Salience	1	19	932	20710	0.86	.367	.043
Load:Compatibility:Salience	1	19	6725	21028	6.08	.023	.242

Table 10

Summary of two-way ANOVA for Salient distractor trials with Load and Compatibility as factors and response time as dependent variable

Effect	DFn	DFd	SSn	SSd	F	*p*	η_p^2
(Intercept)	1	19	38411036	367020	1988.47	<.0001	-
Load	1	19	538998	90547	113.10	<.0001	.856
Compatibility	1	19	3871	21634	3.40	.081	.152
Load:Compatibility	1	19	215	22570	0.18	.675	.009

Table 11

Summary of two-way ANOVA for Non-salient distractor trials with Load and Compatibility as factors and response time as dependent variable

Effect	DFn	DFd	SSn	SSd	F	*p*	η_p^2
(Intercept)	1	19	39238776	325818	2288.20	<.0001	-
Load	1	19	611043	59099	196.45	<.0001	.912
Compatibility	1	19	11108	30106	7.01	.016	.270
Load:Compatibility	1	19	17069	19250	16.85	.001	.470

Table 12

Paired samples t-test for compatibility effects in salient and non-salient distractors

Comparison	Mean difference	*t*	df	*p*-value (one-tailed)
High Incompatible vs High Neutral (Non-salient)	-5.65	-0.392	19	.650
Low Incompatible vs Low Neutral (Non-salient)	52.78	7.283	19	<.001
High Incompatible vs High Neutral (Salient)	10.63	0.820	19	.422
Low Incompatible vs Low Neutral (Salient)	17.19	2.139	19	.068