Testing the Robustness of the Perceptual Load Theory

by

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Abstract

Perceptual load theory (PLT) states that whether distractors capture attention depends on the easiness of the perceptual task. Evidence supporting PLT is almost exclusively from visual search, so it is unclear whether load effects can be found in non-visual-search tasks. To clarify this, an attentional blink (AB) paradigm was used. In Experiment 1, participants paid attention to two targets (T1 and T2), where T2 was presented after T1 at varying lags. T2’s position relative to T1 indicated perceptual load, with high load at short lags and low load at the long lag. Confirming this, an AB effect was found. To test PLT in Experiment 2, congruent or incongruent flankers were introduced beside T2. The AB effect occurred again, but no flanker effect was found. Experiment 3 made the task easier, but flanker effects were still absent. These results suggest that perceptual load effects may be most amenable to visual search.
Acknowledgments

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Chapter 1
Introduction

1 Background

1.1 Perceptual Load Theory

In everyday life, it is necessary for humans to select for task-relevant information in the visual environment to accomplish their goals. Distractors within the visual environment can oftentimes pose threats to this ability by drawing attention away from processing task-relevant information. A common example would be unwanted website advertisements that often appear during web browsing; these advertisements essentially serve as distractors that attempt to pull attention away from one’s primary task. However, it is possible that such distractors are less effective in the case where one’s attention is fully dedicated to primary task at hand on the webpage. This interplay of attending to the visual information of one task in the face of distracting visual information is the topic of the present study.

One possible approach to understand and address the issue of when and how task irrelevant distractors influence performance on a primary task is through perceptual load research. This research began with Lavie (1995), where different manipulations of load were used to make a task more or less difficult, in order to test the hypothesis that perceptual load accounts for the locus of selection (Lavie & Tsal, 1994). To do so, in Experiment 1, Lavie (1995) displayed a target letter and a compatible (same response as target), incompatible (different response as target), or neutral (unrelated to response to target) distractor letter to create a low load condition. The target, one of the three possible distractors, and five additional nontarget letters were displayed to create a high load condition. Participants had to search for the target letter, which was easy in the low load condition (search set of one) and hard in the high load
condition (search set of six), and identify it with a choice keypress response (see Figure 1). In Experiment 2, a go/no-go task was used where a target, distractor, and shape were presented in each trial. Under low load, participants were told to respond to the target identity only when the shape was of a certain colour. The instructions under high load were identical, except they were told to respond only when the shape was of a certain colour and shape conjunction. Experiment 3 consisted of another go/no-go task, where each trial displayed a target and distractor letter, and a third letter. Under low load, participants had to respond the target identity when the third letter was present. However, under high load, they could respond only when the third letter was of the right size and position. The overall pattern of data across these experiments showed that reaction times to the target were slower when distractors were incongruent under low load conditions (although there are some exceptions that will be noted later). Under high load conditions, distractor interference was not found. Thus, distractor interference was present when the primary task was easy to complete and absent when the primary task was hard to complete. On the basis of these data, the perceptual load theory was formed.

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Figure 1. Schematic adapted from Lavie’s (1995) Experiment 1, involving visual search. If the target is the letter “x”, its compatible flanker would be “X”, whereas its neutral flanker would be “P” and its incompatible flanker would be “Z”.

According to perceptual load theory, all perceptual processing has capacity limits (Lavie, Beck, & Constantinou, 2014). The basic premise of the theory is that perceptual processing is first allocated to the visual stimuli relevant to one’s current task, and then any spare processing capacity is automatically allocated to task-irrelevant stimuli (Lavie, 1995). This provides a good account for the now well-replicated finding that visual distractors create less interference in relatively difficult (high load) tasks relative to easier (low load) tasks. Perceptual load theory argues that this finding occurs because under high load, perceptual processing is fully allocated to task-relevant stimuli, thus blocking the irrelevant distractors from being processed (Lavie, 1995). Perceptual load itself may be increased by increasing the number of different items in a visual display, or by increasing the number or complexity of perceptual operations in a task while maintaining the same number of stimuli (Lavie & Torralba, 2010). Lavie and Tsal (1994) suggest that the locus of selection is at least partly determined by perceptual load, and that evidence supporting early or late selection are due to results obtained under high or low perceptual load, respectively. They concluded that early selection only occurs when relevant information takes up much of the available capacity resources. If this does not occur, leftover capacity will be given to irrelevant information, which prevents early selection from occurring (Lavie & Tsal, 1994).

Since the publication of the influential Lavie and Tsal (1994) paper, the effect of perceptual load has become a major research topic and has proven to be a robust phenomenon. For example, Lavie, Lin, Zokaei, and Thoma (2009) examined whether the effect could also
apply to objects across the same or different viewpoints. To examine this, participants were required to perform a letter search task under low or high load, and to ignore task-irrelevant distractors. After this search task, a surprise recognition-memory task was conducted, where two objects were presented and participants were asked to indicate which object was presented as a distractor in the prior task. Distractors were either presented in the same viewpoint as the search task, or in a differently rotated viewpoint. This study confirmed that high perceptual load reduces distractor recognition levels even when these distractors were presented in the same view, since accuracy rates were lower and reaction times were faster in the high load condition. In a similar work, Ho and Atchley (2009) presented a visual search task that included a spatial precue. A target would then appear alongside distractors, and the precue would either be consistent or inconsistent with the target. The target could vary by either shape or colour. Perceptual load was manipulated so that either a colour or shape discrimination task represented low load, whereas a colour/shape conjunction discrimination task represented high load. The authors found that perceptual load can modulate object-based attention because as perceptual load increased, attention was restricted to target locations near the cued location.

Another example of the perceptual load effect can be found in the working memory literature, where researchers concluded that perceptual load can affect how working memory contents influence visual searches (Koshino, 2017). This author used two conditions. In the dual task condition, participants were required to keep a response-related distractor in memory, perform a high or low load visual search task, and then indicate what the item was. The single task condition was identical, except it did not contain the memory component. The author found the typical compatibility effect in the single task condition. However, for the dual task condition,
this effect was only found for high perceptual load, which was interpreted in that the distractor held in working memory interfered with target processing.

Perceptual load theory has also been extended to fields of study not directly within the realm of visual cognition, such as in emotion research, where it was demonstrated that aversely conditioned face distractors only capture attention under low perceptual load (Yates, Ashwin, & Fox, 2010). In this study, participants were presented with angry faces that were either conditioned with white noise or not at all. Perceptual load was manipulated using the flanker task, where the target in the low load display was flanked by a single neutral letter, or flanked by five neutral letters under the high load condition. Participants had to search for the target letter in the display. Under low load, conditioned angry face distractors disrupted performance more than unconditioned angry faces, but this effect was not found under high load. These results conform to perceptual load theory’s prediction that distractor interference is greater in low load.

Though perceptual load effects have been found in numerous studies, there are some criticisms regarding whether the effect found is actually due to low and high load processing (i.e., as explained by Lavie’s perceptual load theory). Dilution theory, originally proposed by Tsal and Benoni (2010), suggests that distractors are processed to the same degree in both low and high load conditions, which is unlike Lavie’s (1995) notion because perceptual load theory claims that distractors are processed to a greater degree in low load conditions. In dilution theory, the interference from peripheral distractors in high load conditions is diluted by the presence of neutral stimuli, where the target is typically embedded within. This is because neutral stimuli in either a high load or dilution display compete with an incongruent distractor, which then degrades the quality of the distractor’s visual representation. For example, in Experiment 1b of this paper, the search displays consisted of a target and distractor (for low load
trials), or a target embedded within neutral letters and a distractor (for high load trials). The dilution display, however, was identical to the high load display, except the target was a red singleton. Due to the differences in displays, the authors claim the dilution display was representative of both low load and high dilution because the target was coloured red whereas the neutral stimuli remained white. In Experiment 1b, participants had to respond to the target quickly, and results showed that no interference was present under the dilution condition. The dilution display was classified by the authors as low in perceptual load since reaction times were identical between the dilution and low load conditions. From these results, dilution theory asserts that distractor interference is determined by the dilution produced by the neutral stimuli, which can be reduced to merely low level visual interference, and is not due to perceptual load.

In response to the Tsal and Benoni (2010) findings, Lavie and Torralbo (2010) raised a counterpoint to dilution theory by arguing that in low load and high set size displays, distractors still compete with search non-target stimuli for any leftover capacity. To support their argument, they conducted a search experiment identical to Tsal and Benoni (2010). However, they included a condition where response-competing distractor letters replaced two of the neutral letters, while the peripheral distractors remained response neutral to the target. The authors found that under these low load and high set size displays, items closest to the target are perceived. The authors predicted that if neutral letters were replaced with response-competing distractors, the distractor interference effect should be restored, which is what they found. This evidence supports the perceptual load theory, which predicts that spare capacity permits spillover of attentional resources to irrelevant information (Lavie & Torralbo, 2010).

Although dilution theory is perhaps the most prominent theory arguing against perceptual load theory, other alternatives have also been suggested, such as from Benoni and Tsal (2013),
and Chen and Cave (2016). In a review paper, Benoni and Tsal present a number of criticisms directed towards perceptual load theory. The authors state that “perceptual load” as a term has never been clearly defined or operationalized, which leads to a circularity in the way low and high loads are characterized. For instance, perceptual load is often confounded with both sensory and cognitive loads as it is not well-defined. Benoni and Tsal also criticize some researchers, particularly Lavie, for not performing manipulation checks to verify whether different displays can meaningfully represent low or high load. Specifically, they mention that the level of perceptual load should be determined by perceptual processing itself, not the stimuli used. For example, if a target letter were cued, a high load display would not necessarily be highly demanding since neutral letters can be filtered out.

The experiments conducted by Chen and Cave (2016) also suggest that an attentional zoom lens, or how narrowly or broadly attention is allocated, is what accounts for the different degrees of distractor processing in high and low loads. In this study, the stimuli presented were the target, a distractor that was either congruent or incongruent to the target, and a go/no-go response cue. These stimuli were arranged in a way that allowed participants to either narrow their attention to exclude the distractor, or broaden their attention include the distractor. Since the study used a go/no-go task, participants identified the target only when the response cue was a particular colour (for low load trials) or when it was a particular colour and shape conjunction (for high load trials). Half of participants started with the low load block, and half started with the high load block, varying search history. It was found under this go/no-go paradigm, those who performed the low load block first had a greater distractor congruency effect. This result was not present among those who performed the high load block first, which perceptual load theory cannot account for. Chen and Cave concluded it is possible that participants use a broader
attentional zoom in low load trials, which would increase distractor processing, and a narrower zoom under high load. For those who started the experiment with a high load block, and therefore a narrower zoom, distractor processing for both high and low load blocks would be minimal, since this narrow zoom strategy would be effective for both types of load. This may at least partially account for the typical effects found in perceptual load research.

Regardless of which account, or accounts, ultimately proves to be the most complete explanation(s), the basic perceptual load effect discovered by Lavie and Tsal (1994) and Lavie (1995) has become an extremely well-known and well-replicated phenomenon. More importantly for the present proposal, their basic paradigm, centered on easy or hard visual searches, has become the standard methodology for almost all subsequent studies. This raises the question of whether the perceptual load effect can be generalized to instances beyond simply visual search tasks, and this is the focus of the present study. Along these lines, it is worth noting that in both Experiments 2 and 3 of Lavie (1995), the results were partially inconsistent with what perceptual load theory would predict. Specifically, in Experiment 2, the compatible distractor (relative to the neutral distractor) did not significantly alter reaction times under low load, but did under high load, in a go/no-go task. Experiment 3 showed similar results in that under low load, compatible distractors did not result in significantly faster reaction times in another go/no-go task. Interestingly, both these experiments (relative to Experiment 1) are not strictly search tasks, providing further impetus to our question.

Visual search also includes a cognitive component, so it is not strictly a measure of only perceptual load (Benoni & Tsal, 2013). Some visual search models suggest that visual working memory is important for operations used during search (Benoni & Tsal, 2013). For example, working memory has been proposed to underlie the use of attentional templates in selecting
objects (Desimone & Duncan, 1995). If perceptual load theory is viable as a general theory of perceptual processing (as it is advertised), then it should apply to more situations than just visual search, and testing this is the focus of the current proposal.

1.2 The Attentional Blink

To accomplish the goal of testing perceptual load theory beyond the realm of visual search tasks, the current proposal will use an adaptation of the attentional blink (AB) paradigm. The AB paradigm uses a rapid serial visual presentation (RSVP) task in which a stream of short-duration items (e.g., 50-200 ms) are sequentially presented at a single location (usually fixation). Within this stream are two targets (T1 and T2), and the relative position of T2 compared to T1 is called lag. Thus, a lag of 1 is when T2 immediately follows T1 while a lag of 8 is when there are 7 items between T1 and T2. In the original AB paradigm of Raymond, Shapiro, and Arnell (1992), the RSVP stream consisted of black letters, with the exception of a single white letter (T1) followed by a specific black letter (T2) that participants had to detect. Each item appeared for 90 ms. The authors demonstrated a marked decrease in the ability to identify T2 when it was presented at lags 2 through 5 (180-430 ms) after T1 is presented. This deficit has become universally known as the attentional blink. Interestingly, identification of T2 may not be impaired if it is presented at lag 1 (known as lag 1 sparing), though this is not necessary for an AB effect to be present (MacLean & Arnell, 2012).

The basic AB effect is quite robust, having been found in a variety of different types of stimuli (McLaughlin, Shore, & Klein, 2001). For example, an AB effect was found when words are used as stimuli (Keil & Ihssen, 2004). This study used the typical AB paradigm, except all stimuli consisted of either pleasant, neutral, or unpleasant verbs. T1 and T2 were coloured green and all other stimuli were black. Affectively arousing T2 words, regardless of whether it is
pleasant or unpleasant, resulted in greater T2 identification rates in the condition where there is a 232-ms SOA between T1 and T2. Another study demonstrating the AB effect used image stimuli, specifically of faces and scenes (Marois, Yi, & Chun, 2004). Participants took part in both single- and dual-task experiments. In the dual-task experiment, they were required to search for T1 and T2 within a typical RSVP stream, in which T1 consisted of one of three possible faces and T2 consisted of a scene. The rest of the stream was made up of scrambled scenes.

Participants then indicated which face had been presented, then responded whether they were presented with no scene, an outdoor scene, or an indoor scene. In the no-scene trials, a scrambled scene was shown. In the single-task experiment, participants were told to only pay attention to T2. Results showed that T2 detection was worse in the dual-task compared to the single-task experiment. Additionally, in the dual-task experiment, T2 detection rates increased as the SOA between T1 and T2 also increased, signifying an AB.

For the purposes of the current proposal, the key feature of the AB paradigm is that at various points in the RSVP stream, T2 is easier (minimum AB at lag 1 and lags greater than 5) or harder (maximum AB at lags 2 through 5) to identify. Thus, the item-locked magnitude of the AB can be used to test perceptual load theory (low load at minimum lags, high load at maximum lags) in a non-visual search task. Indeed, the deficit in T2 identification found in the AB effect has been theorized to be due to a capacity-limited attentional process (Dux & Marois, 2009), thus making it potentially similar to what perceptual load theory proposes. This theory, a two-stage model of the AB, states that a stimulus must be encoded into working memory or it will be overwritten by subsequent stimuli (Chun & Potter, 1995). The model posits that when T2 is presented closely in time to T1, it is more susceptible to decay because T1 must first be encoded into working memory, a process which has limited capacity (Chun & Potter, 1995). This is in
contrast to Raymond et al.’s (1992) gating hypothesis, which predicts that the AB is caused by inhibition of post-T1 stimuli at a perceptual level. There is evidence against this gating hypothesis, however, given that the N400, a component associated with semantic processing, has been found for unreported T2s (Luck, Vogel, & Shapiro, 1996). Nonetheless, because the RSVP task only requires fixation onto a single spatial location where T1 and T2 always appear, there is no need to perform a visual search to find the targets. Unlike the typical AB task, however, distractors will have to be added to the T2 display in order to generate the distractor-compatibility effects that are the measure of perceptual load.

There is one study in the literature that has previously discussed perceptual load theory in the context of the AB (Jiang & Chun, 2001). In particular, their third experiment presented an RSVP stream where T2 was flanked by response compatible or incompatible distractors. These flankers were either the same or different colour as T2, which introduced perceptual interference. Additionally, a two-to-one response mapping was used so that distractors either shared the same (congruent) or different (incongruent) response key as T2. Only lags 2 and 6 were used, and participants were required to identify T1 and T2. The authors found greater distractor interference in the short lag than in the long lag condition when accuracy for T2 was measured. In the long lag condition for both same and different T2-distractor colours, accuracy was equivalent between the T2-distractor colours, and both were very close to ceiling.

It is important to note that the Jiang and Chun (2001) study was designed primarily to examine how temporal selection affects spatial selection and distractor interference; it was not designed to test perceptual load theory. However, in the discussion section, it was briefly noted that their paradigm produced a situation where perceptual load theory might apply (which seems to be a post-hoc comment added by a request of a reviewer). That is, when AB was greatest (i.e.,
T2 is difficult to identify) there could be a high perceptual load situation, and when AB was smallest (i.e., T2 is easy to identify) there could be a low perceptual load situation. Looking back onto their data, the authors ultimately concluded that their results are incompatible with perceptual load theory, given that distractors had a greater interference effect in the short lag condition.

Although testing perceptual load in an AB paradigm was not the explicit goal of the Jiang and Chun (2001) study, I believe they had the right paradigm (AB) to test the question but used the wrong measure (accuracy). To test the effect of distractors on T2, the typical AB paradigm will be adapted from measuring T2 accuracy to measuring T2 identification reaction times (RTs) as the primary dependent variable in the current proposal. As MacLean and Arnell (2012) state, using ceiling performance as a baseline tends to overestimate the AB effect, making it difficult to determine individual differences in T2 identification performance if performance estimates are restricted by the ceiling. Due to this issue, when Jiang and Chun (2001) examined distractors on T2, accuracy ceiling effects may have resulted in their largely null results.

While T2 accuracy has been the overwhelmingly dominant measure for previous AB experiments, there is one example of a RT-based AB task. Lagroix, Di Lollo, and Spalek (2018) asked participants to respond to T2 as quickly as possible to determine whether measuring RT affects lag 1 sparing. Lag 1 sparing is the accurate identification of T2 at lag 1 relative to a longer lag such as lag 3 (when the AB is greatest). Lags 1, 3, and 7 were used in this study. T1 was a vowel, T2 was a consonant, and all other stimuli were digits. The masking of T2 was also an independent variable, where T2 was either masked or not masked. Results showed that in both the masked and not-masked conditions, the AB can be found with RTs.
1.3 The Current Study

The goal of the current proposal is to determine if perceptual load effects can be found in a paradigm other than one involving visual search. In Experiment 1, and before testing perceptual load effects with AB, it is important to first determine the correct experimental parameters for an adapted AB RT paradigm. Unlike a typical AB paradigm where both single and dual task conditions are used, participants will only take part in a dual task condition, where responses must be made to both T1 and T2 instead of only T2. The single task condition will not be used because the main purpose of Experiment 1 is to determine the appropriate stimuli to use for Experiment 2. In Experiment 1, it is hypothesized that a lag-reaction time effect consistent with the AB will be found, so that when the AB effect is greatest, RT will be longest. In Experiment 2, the perceptual load effect will be tested using the non-visual search AB RT task. This will involve presenting the same RSVP stream and stimuli as the first experiment but now perceptual load effects will be tested by flanking T2 with either compatible or incompatible distractors similar to the original load task of Lavie (1995). If perceptual load effects occur beyond visual search tasks, large distractor compatibility effects should be found where RTs are fastest (i.e., low loads; lags 1 and 7) and small distractor compatibility effects should be found where RTs are slowest (i.e., high load; lag 3). If perceptual load effects require visual search tasks, then no modulation of distractor compatibility effects should be found across lags. Experiment 3 follows up the second experiment by using the T2 flankers but with longer display times in the RSVP stream.
Chapter 2
Method & Results

2 Experiment 1

The purpose of this first experiment was to determine whether a RT-based AB can be found in a RSVP stream. Following the findings of Lagroix et al. (2018) in generating a RT-based AB effect, lags of 1, 3, and 7 will be used.

2.1 Method

2.1.1 Participants

Thirty-two participants from the University of Toronto were recruited in Experiment 1. Participants were recruited using the PSYNUP pool or through an email listing, and were compensated either 1.0 credits if recruited through the PSYNUP pool, or $10 if recruited through the email listing. Participants were required to have normal or corrected-to-normal vision, and not have colour blindness.

2.1.2 Apparatus & Procedure

The experiment was programmed and run using E-Prime 2.0. Participants were seated and placed in a chin rest 57 cm away from a computer screen with the room lights turned off. The stimuli for the RSVP stream in this experiment consisted of the digits 2, 3, 4, 5, 6, 7, 8, and 9, and the letters P, U, H, and S, presented on a grey background. All the digits were presented in black except for T1, which was a white digit whose identity was chosen at random. T2 was a black letter that was equally likely to be any of the four letters. A mask was presented at the end of the stream, and consisted of the digits 3, 4, and 7 overlaid in a manner to prevent detecting any particular digit within the mask. All the stimuli were sized to fit into an imaginary box that was 1 degree of visual angle square. Letter stimuli were responded to with a two-to-one response
mapping, where two of the letters corresponded with the left arrow key, and the other two corresponded with the down arrow key. Participants were randomly assigned one of three possible response mappings (left arrow/down arrow): PU/HS, PS/UH, PH/SU.

The experiment began with an instruction screen, which told participants to identify T2 as quickly and accurately as possible with a speeded choice keypress, and then indicate what digit T1 was with an unspeeded response. Each trial began with a fixation cross at the center of the screen, where the spacebar must be pressed to begin the RSVP stream (Figure 2). An RSVP stream of between 5 and 8 black digits, each presented at fixation for 50 ms followed by an interstimulus interval (ISI) of 50 ms, was then presented. This was followed by a T1 (white digit), then either 0, 2, or 6 more black digits (lags 1, 3, and 7, respectively), and then T2 (black letter). The mask was presented immediately after T2, and the responses to T2 (speeded) and T1 (unspeeded) were recorded. The intertrial interval after the T1 response was 50 ms. Trials where participants did not respond for over five seconds resulted in a screen notifying the participant that they did not respond quickly enough.
Figure 2. Example of an Experiment 1 trial, where T2 (black “P”) is presented at lag 1 after T1 (white “9”), then masked.

The experiment consisted of 24 practice trials and 336 experimental trials. For the experimental trials, the lags (1, 3, and 7) and T2 identities (P, S, H, U) were counterbalanced, whereas the number of black digits preceding T1 (between 5 and 8) and the identity of T1 (between 1-9) were randomized. Filler digits (i.e., non-T1 or T2 digits) were randomized so that no two digits of the same identity repeated consecutively. Practice trials were exactly the same as experimental trials except for the counterbalancing.

2.2 Results & Discussion

Thirty-two participants were recruited for Experiment 1. Eight participants were removed for having low T1 identification rates (scoring below 33% on T1 after collapsing across all
conditions) and/or low T2 identification rates (scoring below 65% on T2 after collapsing across all conditions). Median RTs from remaining 24 participants were calculated once RTs below 100 ms and greater than 2 standard deviations were removed. This resulted in 5% of trials being removed. The remaining RTs were then analyzed with a one-way analysis of variance (ANOVA) (Figure 3). A statistically significant difference between the lags was found, $F(2, 69) = 3.543, p < .05$. Post hoc t-test comparisons using Bonferroni corrections indicated that RTs in lag 1 were significantly different from RTs in lag 7 ($p < .05$). However, RTs in lag 1 were not significantly different from those of lag 3, ($p = 1.00$) and RTs in lag 3 were not significantly different from those of lag 7 ($p = .286$).

Figure 3. Median RT data for Experiment 1. Error bars represent the standard error of the mean for each condition. The asterisks (*) indicate that a significant difference between the means was obtained, $p < .05$. 
Similar to Lagroix et al. (2018), Experiment 1 demonstrated that it is possible to obtain an AB effect while using RT as the dependent variable. A lag effect at lags 1 and 7 indicate that low and high perceptual load conditions were successfully created, so now distractors may be added in the next experiment.

3 Experiment 2

In this experiment, the perceptual load effect was tested using a non-visual search paradigm. The paradigm was essentially the same as in the initial experiment, but now compatible and incompatible distractors were presented alongside T2. It was predicted that smaller distractor compatibility effects would be found under high load (i.e., lag 3), and larger compatibility effects would be found under low load (i.e., lags 1 and 7).

3.1 Method

3.1.1 Participants

Thirty-four participants were recruited for Experiment 2. The criteria for recruiting participants for Experiment 2 was the same as that of Experiment 1. However, the number of experimental trials increased to 384.

3.1.2 Procedure

The stimuli and procedure used for Experiment 2 was the same as that of Experiment 1 except for one key difference; in order to test for perceptual load (Figure 4), T2 was flanked by two distractors each located approximately 3 degrees to the left and right of the RSVP stream location. These distractor stimuli were twice the size (2 degrees) of the other stimuli. On half the trials, compatible distractors consisting of a letter that corresponded with the same response key as T2 were presented, while on the other half of the trials incompatible distractors consisting of a
letter that did not correspond with that key where presented. Compatible and incompatible distractors were counterbalanced. Participants were instructed to ignore the distractor, respond to the identity of T2 as quickly and accurately as possible, and then identify T1.

Figure 4. Example of an Experiment 2 trial, where T2 (black “P”) is presented at lag 1 after T1 (white “9”), then masked. T2 is flanked by two distractors (black “H”).

3.2 Results & Discussion

Thirty-four participants were recruited for Experiment 2, and 9 participants were removed for having low T1 and/or T2 identification rates using the same criteria defined in Experiment 1. 5.7% of trials were removed. After removal, the median RTs (calculated as in Experiment 1) of the remaining 25 participants were included in a 2 (congruent vs. incongruent) X 3 (lag 1 vs. 3 vs. 7) within-subjects ANOVA (Table 2). A significant main effect of lag was
found, $F(2, 48) = 32.432, p < .0001$, with slower RTs at the shorter lags, consistent with the full dataset from Experiment 1. Unexpectedly, no main effect of congruency was found, $F(1, 24) = 2.725, p = .112$, nor was a significant interaction was found, $F(2, 48) = 1.856, p = .167$.

The most unusual aspect of the preceding analysis was the lack of a congruency effect. After questioning participants on their task strategy, some indicated that they relied more on response mappings provided on paper at the beginning of the task. This could potentially inflate RTs at the beginning of the experiments due to participants looking down to remind themselves of the assigned mapping. Thus, I then separately analyzed trials from the second half of each session. For this latter half of the dataset, the same 9 participants were removed, leaving 25 participants included in the analyses (Table 2). A 2 (congruent vs. incongruent) X 3 (lag 1 vs. 3 vs. 7) within-subjects ANOVA was conducted. Consistent with the full dataset, a significant main effect of lag was found, $F(2, 48) = 20.469, p < .0001$, with slower RTs at the shorter lags. No effect of congruency was found, $F(1, 24) = 1.68, p = .207$, nor an interaction between lag and congruency, $F(2, 48) = .912, p = .408$.

Table 1

Mean RTs and Congruency Effect for Experiment 2 Separated into Full and Half Datasets

<table>
<thead>
<tr>
<th>Lag</th>
<th>Full Data</th>
<th>Half Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Congruent (M)</td>
<td>Incongruent (M)</td>
</tr>
<tr>
<td>1</td>
<td>1410</td>
<td>1385</td>
</tr>
<tr>
<td>3</td>
<td>1292</td>
<td>1249</td>
</tr>
<tr>
<td>7</td>
<td>1229</td>
<td>1243</td>
</tr>
</tbody>
</table>

Note. CE = congruency effect. CE was calculated by subtracting the mean RT for incongruent trials from the mean RT for congruent trials.
Experiment 2 showed an RT-based AB effect both when the full dataset and the latter half of the dataset were analyzed. Participants were slower in responding to T2 at the shorter lags. However, a flanker congruency effect was unexpectedly not found, nor was an interaction between lag and flanker congruency found.

4 Experiment 3

Experiment 3 was conducted because Experiment 2 did not reveal a congruency effect that differed across the three lags. The task in Experiment 2 could have been too difficult, with median RTs over 1000 ms, which may have prevented any flanker interference effect. A number of changes were made to reduce the task difficulty, which includes slowing down the RSVP stream, removing the masks, and presenting T2 until a response is made. The lags used in this experiment will remain 1, 3, and 7.

4.1 Method

4.1.1 Participants

Thirty-two participants were recruited for Experiment 3. The criteria for recruiting participants for Experiment 3 will be the same as that of Experiment 2.

4.1.2 Procedure

The stimuli and procedure were the same as that of Experiment 2 except that each stimulus was presented for 100 ms, with an ISI of 100 ms. The masks were also removed, and T2 and its flankers were presented until a response is made (Figure 5).
Figure 5. Example of an Experiment 3 trial, where T2 (black “P”) is presented at lag 1 after T1 (white “9”). T2 is flanked by two distractors (black “H”).

4.2 Results & Discussion

Thirty-two participants were recruited for Experiment 3. 5 participants were removed using the same criteria described in Experiment 1, which consisted of having low T1 and/or T2 identification rates. 5% of trials were removed. After removing these trials, a 2 (congruent vs. incongruent) X 3 (lag 1 vs. 3 vs. 7) within-subjects ANOVA was conducted using median RTs from the remaining 27 participants (Table 3). In terms of the full dataset, a significant main effect of lag was obtained like in Experiment 2, $F(2, 52) = 25.300, p < .0005$. However, no main effect of congruency was found, $F(1, 26) = 3.036, p = .093$. Additionally, no interaction between lag and congruency was found, $F(2, 52) = .069, p = .933$. 
As in Experiment 2, I separately analyzed the second half of the data set for each participant. For this latter half of the dataset, 5 participants were removed resulting in 25 participants remaining for the analysis (Table 3). Median RTs for trials starting from 192 and above were analyzed in a 2 (congruent vs. incongruent) X 3 (lag 1 vs. 3 vs. 7) within-subjects ANOVA. Once again, a significant main effect of lag was found, $F(2, 52) = 20.880, p < .0005$. A main effect of congruency was not found, $F(1, 26) = 2.009, p = .168$. No lag x congruency interaction was found either, $F(2, 52) = 1.045, p = .359$.

Table 2

<table>
<thead>
<tr>
<th></th>
<th>Full Data</th>
<th></th>
<th>Half Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lag</td>
<td>Congruent</td>
<td>Incongruent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(M)</td>
<td>(M)</td>
</tr>
<tr>
<td>1</td>
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<td>3</td>
<td>870</td>
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</tbody>
</table>

Note. CE = congruency effect. CE was calculated by subtracting the mean RT for incongruent trials from the mean RT for congruent trials.

As demonstrated in Experiment 2, Experiment 3 found an RT-based AB effect, with slower RTs to T2 at the shorter lags. Despite making the task easier, and hopefully inducing both high and low perceptual loads, a significant flanker congruency effect was not found. This was the same for both the full set of RTs and RTs drawn from the latter half of trials.
Chapter 3
General Discussion

The purpose of this study is to examine whether perceptual load theory can be viewed as a theory of general processing that is not limited to visual search tasks. To do so, a non-visual search task was implemented in three experiments, where the timecourse of the AB effect (greater difficulty in target identification at certain lags) was used as a proxy for the set size manipulation seen in visual search tasks. In Experiment 1, I used an adapted RT-based AB task (based on the accuracy task used by Jiang & Chun, 2001) and found a RT equivalent AB effect. Using the paradigm developed in the first experiment, Experiment 2 implemented flankers alongside T2 to test perceptual load theory, but did not find a main effect of congruency nor an interaction between congruency and lag. This result was replicated when only the latter half of RTs were analysed, presumably when participants had fully learned the response mappings. Experiment 3 used longer stimuli presentation times but the data mirrored that from Experiment 2 for both the full data set and the latter half dataset. Overall, across the three experiments, an RT-based AB effect was found consistently, though neither a congruency nor a lag x congruency interaction effect was present. The meaning and implications of these results are examined in the present discussion, with particular relevance to perceptual load theory.

Using the paradigm outlined in this work, flanker compatibility effects were not found in Experiments 2 and 3, something which is completely unexpected. There are at least three possibilities for this lack of flanker effects. One possible interpretation of the present findings is that perceptual load theory’s claim that perceptual load effects should apply to general processing, is unsupported. In other words, the lack of flanker effects found in this study could be because perceptual load effects require visual search tasks. As noted previously, Experiments
2 and 3 in Lavie’s (1995) seminal paper found incomplete flanker interference effects. Specifically, both Experiments 2 and 3 lacked compatibility effects under low load, whereas perceptual load theory would predict finding compatibility effects under low load. This finding differed from Lavie’s results from Experiment 1, in which both distractor compatibility and distractor interference effects were found. However, before this strong conclusion can be accepted, two other possibilities for the present results must be considered.

Another possibility for the lack of flanker effects is that the paradigm chosen in the present study is simply not conducive to testing perceptual load, in that lags 1 and 7 do not reflect low load and lag 3 does not reflect high load. That is, perceptual load effects may extend beyond search tasks, but not in particular to variations of AB tasks. Supporting this, Jiang & Chun (2001) concluded that the same paradigm they used reflected cognitive load as opposed to perceptual load. In particular, they state that the load imposed by the AB reflects a capacity limitation for working memory consolidation. There are also a number of AB theories that posit that the effect is the result of the encoding or consolidation of T1 into working memory, which then inhibits consolidation of T2 into working memory (Dux & Marois, 2009). Data from event-related potentials agree with these theories: it has been shown that the P3 component, which is tied to working memory updating, becomes suppressed during the AB (Vogel, Luck, & Shapiro, 1998). As a result, even though using RT as a dependent measure may resolve the issues with hitting a ceiling in accuracy performance, perhaps ultimately the AB RSVP stream itself does not induce perceptual load demands. In selecting RT as the dependent measure, it was hoped that measuring RT would avoid the downside of measuring T2 identification accuracy rates, but distractor interference effects were still unable to be found.
A third possibility is that perceptual load effects were alive and well in this paradigm, but the AB task was overall so difficult that all the lags fell into the high load category and thus no distractor interference was found. Indeed, even with the adjustments made in Experiment 3 to make the task easier, RTs were quite high across all three experiments, indicating that it was a difficult task. This is true even when data from the final half of trials were analyzed, with the assumption that by then participants had grown comfortable with the T2 response mappings and thus were in lower load situations. As perceptual load theory would hypothesize, under high load, distractor interference should not occur. In Experiment 3 of Jiang & Chun (2001), prior to the RSVP task, participants first completed a speeded flanker task using the same stimuli from the RSVP task. The purpose of this was to familiarize participants with the response mapping assigned to them. Average RTs in this speeded flanker task ranged from 664-695 ms, which is much quicker than the average RTs found in the present study’s Experiment 3 for both the full and half datasets. The slower RTs in Experiment 3 in the present study could also reflect a speed-accuracy trade off, since accuracy rates for T2 reached 90%+.

When the present data are taken in the light of the data from Jiang and Chun (2001) and Lavie (1995), it seems the most likely possibility is the first one; perceptual load effects are indeed limited to visual search tasks. In other words, compatibility effects, and their modulation, seem to be tightly linked to visual search. In line with this conclusion, Roper, Cosman, and Vecera (2013) explored what factors influence the perceptual load effect by altering target-distractor and distractor-distractor similarity, a frequent manipulation in visual search. In Experiment 2, the authors found that lower target-distractor similarity resulted in significant flanker effects, whereas higher target-distractor similarity (i.e., relatively higher load) did not. This is consistent with what perceptual load theory would predict. It appears that perceptual load
effects are influenced by search efficiency, a significant contributor to visual search performance. They concluded that perceptual load likely shares at least some of the same mechanisms as visual search, at least when perceptual load is manipulated with a search paradigm.

Future research should further refine the non-visual search paradigm to test perceptual load theory. One limitation of the present study that is only one non-visual search task was used to test perceptual load theory – the RT-based AB. The lack of effects found here is merely a single counterpoint to the many visual search-based findings that support the theory. Results from the present study, along with those Jiang & Chun (2001) and Lavie’s (1995) Experiments 2 and 3, show that perhaps perceptual load requires a task that relies heavily on visual search before distractor interference effects may be revealed. To determine whether perceptual load theory can truly be generalized to other non-search processes, it will be important to test multiple types of load-inducing tasks before a solid conclusion can be reached.


McLaughlin, E. N., Shore, D. I., & Klein, R. M. (2001). The attentional blink is immune to


