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Perceptual load and the capture of spatial attention by color singletons

Nicholas Gaspelin

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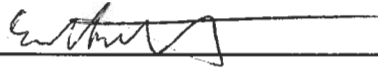
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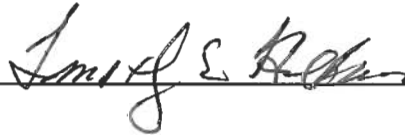
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**PERCEPTUAL LOAD AND THE CAPTURE OF SPATIAL
ATTENTION BY COLOR SINGLETONS**

BY

NICHOLAS W. GASPELIN

**PREVIOUS DEGREES
B.A., Psychology, University of Iowa, 2008**

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

Master of Science

Psychology

The University of New Mexico
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ABSTRACT

Recent experiments have cast considerable doubt upon the ability of color singletons to capture spatial attention in a stimulus-driven manner. Despite the lack of evidence for it in the laboratory, there are many anecdotal reports of stimulus-driven capture in real-world settings. Perhaps a critical difference between laboratory and real-world visual scenes is the amount of relevant information, or perceptual load. Scenes with low perceptual load (as when one is focused on a single visual object) might free attentional resources, allowing them to be more easily captured by color singletons. To test this hypothesis, we manipulated perceptual load in a visual search task with irrelevant flanking letters that were sometimes color singletons. If reduced perceptual load increases susceptibility to capture by color singletons, then the presence of a color singleton should slow responses and increase flanker-target compatibility effects. Contrary to this prediction, we found no evidence of capture under high or low perceptual load.

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Chapter 1

Introduction

Spatial Attention

Our visual systems represent basic features over the entire visual field. However, we deeply process only a very small subset of this visual information provided to us. This selectivity is accomplished via several mechanisms. Some mechanisms of our visual systems, such as eye movement, direct processing resources overtly, in a manner that is viewable to others. However, our visual systems also direct resources covertly, in a manner that is not viewable by others. This latter covert mechanism, known as spatial attention, can rapidly redirect processing resources across a visual scene and can do so independently of eye movement (Posner, 1980).

Movements of spatial attention can be divided broadly into two distinct forms: voluntary and involuntary. Voluntary shifts of attention refer to when a person exerts deliberate control over the allocation of their spatial attention. For example, you may purposely shift your spatial attention in an attempt to track an approaching, potentially dangerous stranger on a city street at night. However, some shifts of spatial attention are beyond the control of the viewer, or involuntary. For example, your attention may automatically shift to an advertisement because it is brightly colored. The present study will focus on how these involuntary shifts of spatial attention are guided.

Stimulus-Driven and Goal-Driven Attention

An active debate exists as to whether involuntary attentional capture is due to goal-driven or stimulus-driven factors. Goal-driven, or top-down, capture of attention refers to when an observer's deliberate strategies and intentions related to goals at hand guide spatial attention. For example, while looking for your friend in a crowd, your

attention may be captured by other people with the same color of shirt your friend is wearing (e.g., red). Stimulus-driven, or bottom-up, attentional capture refers to when salient features of stimuli capture an observer's attention irrespective of his or her goals. Referring to the previous example, the only person in the crowd wearing a bright green sweater might attract your attention despite the fact that you know your friend is not wearing that color of shirt. It has generally been accepted that goal-driven attentional capture is possible. However, it remains unclear whether spatial attention can be guided in a stimulus-driven manner and what types of salient stimuli capture spatial attention (Folk, Remington, & Johnston, 1992; Franconeri, Simons, & Junge, 2004a).

Color singletons seem to be an inherently salient type of stimuli. A color singleton is simply an object that differs in color from a homogeneously colored background of a visual scene. For example, a single red car parked amongst twenty green cars would be considered a color singleton. Some evidence suggests that color singletons are not capable of capturing spatial attention in a stimulus-driven manner (Bacon & Egeth, 1994; Folk et al., 1992; Jonides & Yantis, 1988). Jonides and Yantis (1988) had participants search arrays of letters for a specific target letter. In all of the trials, a letter varied from the rest on some feature (e.g., color or luminance). The location of this unique letter, or *feature singleton*, was uncorrelated with target location. In other words, it could appear in any potential position in the array with equal likelihood (including the target location). This experiment yielded no evidence of capture by feature singleton distractors. That is participants' reaction times (RT) were no faster when the feature singleton was a target rather than a distractor.

Other researchers have taken the opposite stance, concluding that, in early stages of visual processing, involuntary capture of spatial attention is stimulus-driven

(Theeuwes, 1991a, 1991b, 1992, 1994). Thus, any salient stimulus, such as task-irrelevant color singletons, can capture attention. This conclusion is based upon studies using a visual search task in which participants searched arrays for a target with an unique feature (color, shape or onset) and reported the orientation (horizontal or vertical) of a line within this object (Theeuwes, 1992). In some of the trials, a distractor of a different unique feature appeared along with the target. For example, participants might search a circular array for a green circle amongst distractor squares. Sometimes a distractor square would also be a red color singleton. Despite the fact that participants were told the relevant dimension of the unique target object, participants were still captured by distractors with unique features that did not match the target. In light of these results, stimulus-driven capture by irrelevant color singletons seems plausible.

However, it has been argued that the results above do not demonstrate purely stimulus-driven shifts of spatial attention. Folk and colleagues (1992), for example, have argued for a *contingent capture theory* that postulates that when an observer adopts a strategy of searching for a particular feature, only distractors sharing that feature will capture attention. In other words, stimulus-driven capture is contingent upon observers' goal-driven attentional control settings.

Expanding upon this idea, Bacon and Egeth (1994) noted that, in many experiments demonstrating stimulus-driven capture, participants were required to search for a singleton. These researchers proposed the existence of a *singleton detection mode* -- if asked to search for a one kind of feature singleton, participants will simplify their search by merely looking for any type of feature singleton. For example, if participants were instructed to search for a shape singleton, singleton detection mode would predict that an irrelevant color singleton would capture attention.

These studies cast considerable doubt regarding the existence of *pure* stimulus-driven capture by color singleton (Bacon & Egeth, 1994; Folk et al., 1992). Despite the lack of convincing laboratory evidence for it, so far, stimulus-driven capture by color singletons still seems intuitively plausible. One can think of countless personal examples in which stimulus-driven attention was exploited in real-world situations (e.g., brightly colored billboard advertisements). Yet, for some reason, difficulties arise when trying to replicate this phenomenon in laboratory settings. This begs the question of what might distinguish these experiments from “real-world” environments.

Perceptual Load Theory

Perhaps, a critical difference between laboratory and real-world environments is the amount of relevant information, or *perceptual load*, in a visual scene. A large amount of evidence suggests that the perceptual load of visual scenes can strongly influence attentional processes (Cosman & Vecera, 2009; Lavie, 1995; Lavie & Tsal, 1994). To explain these findings, Lavie and Tsal (1994) introduced the perceptual load theory of visual attention, which proposes an attentional mechanism that is designed to always work at full capacity. When little information relevant to the task at hand is available, the attentional mechanism processes irrelevant information until it is filled to capacity (Lavie, 1995; Lavie & Tsal, 1994).

Perceptual load theory offers a compromise between early- and late-selection theories of spatial attention. Early-selection theories state that at a very early stage of processing, irrelevant information is discarded. Late-selection theories, on the other hand, postulate that it is not until a very late stage of encoding (after identification) that irrelevant information is discarded. For high perceptual load scenes, attention operates in a manner consistent with early-selection theories, directing processing only to task-

relevant information. Under conditions of low perceptual load, attention operates in a manner consistent with late-selection theories, with some task irrelevant information being deeply processed as well.

Perceptual load theory is supported primarily by data collected in a flanker task (Figure 1) in which participants search an array of letters for a target letter ('z' or 'x') with one of two potential identities (Lavie, 1995; Lavie & Tsal, 1994). Meanwhile, another letter, known as the *flanker*, appears outside of this array. In a given trial, this flanking letter can either have a compatible, neutral or incompatible identity with the target letter. Referring to Figure 1, the 'X' in the rightmost display is incompatible with the target 'z'. However, in the left display we can see that the flanker is compatible with the target identity, because both are a 'z'. If the flanker was an 'A', it would be neutral because 'A' is not a potential target identity. Prior research has demonstrated that compatible flanker trials yield shorter reaction times than neutral flanker trials and incompatible flankers yield longer reaction times (RTs) than neutral flanker trials (B. A. Eriksen & C. W. Eriksen, 1974; C. W. Eriksen & Hoffman, 1974). This difference between mean RTs on trials with incompatible, compatible and neutral flankers is known as the compatibility effect.

Results with the flanker task demonstrate that large, complex arrays (high load) produce small effects of the flanker. However, when participants search smaller arrays (low load) for a target, compatibility effects are more robust (Lavie, 1995). The explanation is that high perceptual load arrays leave few attentional resources to process the identity of the flanker, leading to little interference. On the other hand, when perceptual load is low and the attentional mechanism is not filled with relevant

information, leftover attentional resources process the flanker identity, resulting in larger compatibility effects.

Recently, Cosman and Vecera (2009) demonstrated that perceptual load modulates stimulus-driven capture by irrelevant abrupt onset flankers. In a series of experiments, participants performed a flanker task in which the flanking letter could either be an offset or abrupt onset. Compatibility effects were only observed in low perceptual load displays with an abrupt onset flanker. These findings suggest that stimulus-driven capture by abrupt onsets is only possible under conditions of low perceptual load, when attentional resources are available to process irrelevant information (Lavie, 1995; Lavie & Tsal, 1994).

The Current Study

The goal of the current study is to determine whether stimulus-driven capture by color singletons depends on the perceptual load of a visual scene. As noted above, perceptual load might help explain the discrepant results between laboratory studies on color singletons and anecdotal instances of capture by such stimuli in the real world. Indeed, recent experiments have suggested that perceptual load plays an important role in the involuntary capture of spatial attention. More specifically, there is evidence that abrupt onsets capture spatial attention only under low perceptual load (Cosman & Vecera, 2009). However, no studies have yet examined the effects of load on color singletons. It should be noted that viewers often respond differently to color singletons than they do abrupt onsets and other feature singletons (Boot, Brockmole, & Simons, 2005; Franconeri & Simons, 2003; Jonides & Yantis, 1988). As will be seen in the following experiments, the impact of perceptual load on capture by color singletons does in fact differ from its impact on abrupt onsets.

Chapter 2

Experiment 1

The purpose of the first experiment is to determine how perceptual load influences stimulus-driven capture by color singletons. To manipulate perceptual load, we will use a flanker paradigm similar to one used in previous studies of perceptual load (Cosman & Vecera, 2009; Lavie, 1995). However, unlike previous studies, the flanking letter will also be a color singleton on some trials.

If low perceptual load trials free processing resources, spatial attention may be allocated to flankers, leading to an increased ability of color singletons to capture spatial attention. This result would be analogous to previous findings with abrupt onsets (Cosman & Vecera, 2009). Under these circumstances, participants would show increased RTs on neutral identity, singleton flanker trials compared to neutral identity, nonsingleton flanker trials. Participants might also show greater compatibility effects on singleton trials compared to nonsingleton trials under low perceptual load.

On the other hand, contingent capture theory posits that no task-irrelevant feature singletons are able to capture attention in stimulus-driven manner. According to this theory, little to no costs should be observed on singleton flanker trials compared to nonsingleton flanker trials, regardless of perceptual load. Similarly, no differences in compatibility effects should be present between singleton and nonsingleton trials.

Method

Participants. Fifty-one students from the University of New Mexico participated for class credit. All participants had normal color vision and normal or corrected-to-normal visual acuity.

Apparatus. A Dell personal computer was used to display stimuli on a 19-inch CRT monitors and record responses and response latencies.

Stimuli. GIMP (GNU Image Manipulation Program) open-source software was used to create stimuli and E-Prime Studio software was used to present stimuli. The elements displayed were all letters in the English alphabet in Arial font, except M and W. Letters were either green (0, 210, 50) or red (255, 0, 50), designed to be roughly equal in luminance. Letters inside the array were 2.1° in width and 2.5° in height. Flanking letters were 3.4° in width and 3.8° in height. Letters were arranged in circular arrays 12.1° in diameter, as shown in Figure 2. In high load conditions, the circular arrays consisted of a target letter and 5 distractor letters. In low load conditions, the circular arrays consisted of a target letter with O's in the remaining five positions. In all trials, a flanking letter appeared outside of the circular array on either the left or right side (1.9°). All stimuli were presented on a white background at a viewing distance of approximately 43 centimeters.

Design. The critical independent variable was the relationship between the flanker and the target (incompatible, compatible, neutral). Half of the trials had a neutral flanker (A or B). In 25% of the trials however, the flanker identity was compatible with (or the same as) the target identity. For example, if an E target was presented, an E flanker was presented. In the remaining 25% of trials, the flanker had an identity that was incongruent with (or the opposing identity of) the target identity. For example, if an E target was presented an H flanker was presented.

We counterbalanced array and singleton color between participants. Roughly half of the participants searched red arrays (with occasional green singletons) while the other half search green arrays (with occasional red singletons). This approach ensured that all

effects of color singletons could be attributed to their identity as a singleton rather than to a specific hue.

In half of the trials, the flanker was the same color as the items in the circular array. In the other half, the flanker was a color singleton that differed in color from the array. In all trials of high load conditions, distractor letter identity (all letters in the English alphabet, except E, H, M and W) and target identity (E or H) were varied randomly. Similarly, across trials, target identity and location were varied randomly. Each participant performed 768 trials divided over 12 blocks.

Procedure. In all trials, participants identified the target letter and responded by pressing, respectively, keys labeled either “E” or “H”. Before they began, participants were told that color singleton letters would never predict the target letter identity or location and should be ignored. Each trial began with a fixation cross appearing for 1000 ms. The circular array appeared for 100 ms and disappeared. A new trial did not begin until a response was made. At the end of each block, participants were given feedback regarding their performance accuracy and speed.

Results. Two participants were excluded from analysis because of low accuracy (less than our criterion of 91%, which is 2.5 SDs below the mean accuracy of 97%). Trials with response latencies greater than 1200 ms and less than 200 ms (1.9% of all trials), or with inaccurate responses, were excluded from RT analyses. Mean RTs were computed for each participant as a function of perceptual load, flanking letter compatibility and flanking letter color (Figure 3 and Table 1).

A three-way repeated measures analysis of variance (ANOVA) with perceptual load (high versus low), flanker singleton status (singleton versus nonsingleton) and flanker-target compatibility (incompatible, compatible or congruent) was conducted on

the mean RTs. A significant main effect of perceptual load revealed that participants performed low load trials (528 ms) faster than high load trials (606 ms), $F(1,48)=354.91$, $p<.001$. This finding suggests that our manipulation of perceptual load was effective. The main effect of singletons was also significant, with singleton trials (571 ms) being performed slightly faster than nonsingleton trials (578 ms), $F(1,48)=12.91$, $p<.001$. This result is opposite of what one would expect if participants were captured by color singletons. The main effect of compatibility was significant as well, with incompatible trials (588 ms) slowing participants compared to neutral trials (564 ms), $F(2,47)=83.65$, $p<.001$.

A significant two-way interaction of perceptual load and flanker-target compatibility revealed that compatibility effects were reduced in high load trials relative to low load trials, $F(2,47)=4.06$, $p<.05$. This decrease is consistent with previous studies, although our decrease was less pronounced than is usually found (Lavie, 1995). Giving a flanking letter singleton status was more beneficial to search (decreasing RTs) on high perceptual load trials than on low perceptual load trials, as demonstrated by the significant two-way interaction between perceptual load and flanking letter singleton status, $F(1,48)=5.59$, $p<.05$. Results also demonstrated that the effect of singleton status depended on their compatibility with the target, $F(1,48)= 3.99$, $p<.05$; whereas singleton status slightly facilitated search for incompatible and compatible flanking letters, singleton status had virtually no effect on trials with neutral flanker identities. There was a marginally significant trend towards a three-way interaction between all three variables, $F(2,47)=2.98$, $p=.056$.

Pre-planned repeated measures t-tests were conducted on mean RTs to see whether flanker singleton status influenced performance in each sub-condition of the

design (load X compatibility). The only sub-condition that showed a significant influence of singleton status was the condition with high load and incompatible flankers, $t = 4.56$, $p < .001$; that the effect was -10 ms, in the opposite direction to what one would expect if singletons actually captured attention. All other sub-conditions showed non-significant differences.

A three-way repeated measures analysis of variance (ANOVA) with perceptual load (high versus low), flanker singleton status (singleton versus nonsingleton) and flanker-target compatibility (incompatible, compatible or congruent) was conducted on the mean error rates as well. A significant main effect of perceptual load revealed that participants performed low load trials (1.7%) with fewer errors than high load trials (3.1%), $F(1,48)=4.089$, $p < .05$. This finding also suggests that our manipulation of perceptual load was effective. The main effect of singletons was nonsignificant. The main effect of compatibility was significant, with participants making more errors on incompatible trials (4.4%) compared to compatible trials (1.6%), $F(2,47)=36.78$, $p < .001$. All two-way comparisons (perceptual load X compatibility, perceptual load X singleton status, compatibility X singleton status) were nonsignificant. The three-way interaction (flanker compatibility X perceptual load X singleton status) was also nonsignificant.

Discussion

These results suggest that color singletons were not capable of capturing spatial attention in a stimulus-driven manner. If anything, giving a flanker singleton status (571 ms) aided search, compared to nonsingleton trials (578 ms). Making a flanker a color singleton made the flanker identity easier to ignore (especially in high load conditions, where the difference was statistically significant). This is unusual, as feature singletons

in irrelevant locations rarely make searches *more* efficient (Bacon & Egeth, 1994; Folk et al., 1992; Jonides & Yantis, 1988).

This lack of capture of involuntary attention by color singletons may have been a result of varying array color between participants. Because color singletons were always the same color for a given participant (red for some participants, green for others), this manipulation potentially confounds color singleton status with set for a specific color (ignored/attended). Although it seems unlikely that participants would use color (it provides no benefit in locating or identifying the target, since almost all display items are the same color), participants could have set spatial attention to ignore the color of the singleton flanker. Nevertheless, to strengthen the case that color singletons are not capturing attention, it seems worthwhile to vary array color by trial rather than between participants (see Experiment 2). This approach would prevent participants from being able to ignore any specific color because target color and singleton color would be unpredictable.

Also, it is somewhat puzzling as to why flanker-target compatibility effects (calculated as incompatible-compatible to increase sensitivity) in high perceptual load nonsingleton trials (31 ms) were so large. Previous research suggests that high load trials should show much lower compatibility effects (e.g., ~15 ms in Lavie, 1995). It is possible that potential target locations were spaced further apart in our circular arrays than in the linear arrays used in previous research (Cosman & Vecera, 2009; Lavie, 1995). This increased dispersion of potential target locations might have reduced the perceptual load of our “high perceptual load” displays. A simple solution to this problem, therefore, would be to use linear arrays (as in most previous studies of perceptual load), which are more compact.

Chapter 3

Experiment 2

This experiment addresses two problems discussed in the previous section: 1) to increase perceptual load, 2) to prevent participants from setting spatial attention to ignore specific colors. To accomplish the first goal, we used linear arrays, which decrease the dispersion of potential target locations (to increase the effective perceptual load in high load trials). We also varied array color by trial rather than by participant, strongly discouraging participants from setting themselves to ignore specific colors.

Method

Participants. Forty-six new students from the University of New Mexico participated for class credit. All participants had normal color vision and normal or corrected-to-normal visual acuity.

Apparatus. A Dell personal computer was used to display stimuli on a 19-inch CRT monitors and record responses and response latencies.

Stimuli. GIMP (GNU Image Manipulation Program) open-source software was used to create stimuli and E-Prime Studio software was used to present stimuli. The elements displayed were all letter of letters in the English alphabet in Arial font, except M and W. Letters were either green (0, 210, 50) or red (255, 0, 50), designed to be roughly equal in luminance. Letters inside the array were 2.1° in width and 2.5° in height. Flanking letters were 3.4° in width and 3.8° in height. Letters were arranged in horizontal linear arrays 20.9° in width. In high load conditions, the linear arrays consisted of a target letter and 5 distractor letters. In low load conditions, the linear arrays consisted of a target letter with O's in the remaining five positions. In all trials, a

flanking letter appeared either above or below the linear array (.7°). All stimuli were presented on a black background at a viewing distance of approximately 43 centimeters.

Design. As in Experiment 1, the critical independent variable was the relationship between the flanker and the target (incompatible, compatible, neutral). Each type of flanker identity had an equal likelihood of appearance on a given trial (~33.33%). Array and singleton color were varied by trial. In half of the trials, the flanker was the same color as the items in the circular array. In the other half, the flanker was a color singleton that differed in color from the array. In all trials of high load conditions, distractor letter identity (all letters in English alphabet except E, H, M and W) and target identity (E or H) were varied randomly. Similarly, in all trials, target identity and location were varied randomly. Each participant performed 328 trials divided over 8 blocks.

Procedure. In all trials, participants identified the target letter and responded by pressing, respectively, keys labeled either “E” or “H”. Before they began, participants were told that red letters would never predict the target letter identity or location and should be ignored. Each trial began with a fixation cross appearing for 1000 ms. The circular array appeared for 100 ms and disappeared. A new trial did not begin until a response was made.

Results. One participant was excluded from analysis because of low accuracy (less than 81.2%; 2.5 SDs from the mean accuracy of 93.5%). Trials with response latencies greater than 1200 ms and less than 200 ms (2.8%) or in which inaccurate responses were given were excluded from RT analyses. Mean RTs were computed for each participant as a function of perceptual load, flanking letter compatibility and flanking letter singleton status (Figure 6 and Table 2).

As in Experiment 1, a three-way repeated measures analysis of variance (ANOVA) was conducted on the mean RTs. The analysis revealed that the main effect of perceptual load was significant; low load trials (569 ms) were faster than high load trials (645 ms), $F(1, 44)=125.2$, $p <.001$. This finding suggests that our manipulation of load was effective. The main effect of flanking letter compatibility was also significant, with incompatible trials (620 ms) slowing participants compared to compatible trials (593 ms), $F(2,43)=33.64$, $p<.001$. Flanking letters with singleton status (605 ms) did not significantly slow RTs compared to nonsingleton flanking letters (609 ms), $F(1,44)=2.82$, $p>.05$. This lack of a main effect suggests that flanking letters were not able to capture attention.

The two-way interaction of perceptual load and flanking letter compatibility was also significant, with flanking letter compatibility effects being smaller on high load trials (17 ms) than low load trials (36 ms), $F(2,43)=5.26$, $p<.01$. This finding is similar to those found in previous studies with perceptual load (Lavie, 1995; Lavie & Tsal, 1994). All other two-way interactions were nonsignificant (perceptual load x singleton status, $F(1,44)=2.97$, $p>.05$, and flanking letter compatibility x singleton status, $F(2,43)=.29$, $p>.05$). The three-way interaction of all the variables was also nonsignificant, $F(2,43)=.67$, $p>.05$.

Analysis of only low load trials revealed no significant main effect of singleton status. However, analysis of only high load trials revealed a main effect of flanking letter singleton status with singleton flankers slowing RTs (648 ms) compared to nonsingleton flankers (640 ms), $F(1,44)= 5.93$, $p<.05$. However, this effect is modest (only 8 ms difference). Pre-planned repeated measures t-tests were conducted on mean RTs to see whether flanker singleton status influenced performance in each sub-condition of the

design (load X compatibility). All of these comparisons were nonsignificant. Overall, these findings suggest that color singletons were incapable of capturing attention.

A three-way repeated measures analysis of variance (ANOVA) with perceptual load (high versus low), flanker singleton status (singleton versus nonsingleton) and flanker-target compatibility (incompatible, compatible or congruent) was conducted on the mean error rates as well. A significant main effect of perceptual load revealed that participants performed low load trials (4.3%) with fewer errors than high load trials (6.1%), $F(1,43)=7.24$, $p<.01$. This finding also suggests that our manipulation of perceptual load was effective. The main effect of compatibility was significant as well, with participants performing more errors on incompatible trials (6.7%) compared to neutral trials (4.6%), $F(2,42)=11.597$, $p<.001$. The main effect of singletons was nonsignificant. This also suggests that color singletons were not capturing attention. All two-way comparisons (perceptual load X compatibility, perceptual load X singleton status, compatibility X singleton status) were nonsignificant. The three-way interaction (flanker compatibility X perceptual load X singleton status) was also nonsignificant.

Discussion

Firstly, compatibility effects in nonsingleton, high perceptual load trials were smaller with linear arrays in this experiment (19 ms) than they were with circular arrays in Experiment 1 (31 ms). Participants were also slower on high load trials in Experiment 2 (645 ms) than in Experiment 1 (606 ms). It should be noted that both of these effects were nonsignificant in one-way ANOVA analysis. These nonsignificant effects are most likely a result of the letters being closer together than in the circular arrays used in Experiment 1, increasing the effective perceptual load.

According to perceptual load theory, attentional resources are freed under conditions of low load. We hypothesized that these freed attentional resources under low load could be captured by task-irrelevant color singletons. If this were the case, participants should have shown increased RTs on neutral identity, singleton flanker trials compared to neutral identity, nonsingleton flanker trials. Participants should also have shown greater compatibility effects on singleton trials compared to nonsingleton trials under low perceptual load. However, neither of these predictions was confirmed.

As in Experiment 1, the results also demonstrate no evidence of capture by color singletons in low or high perceptual load trials. Giving a flanking letter singleton status did not significantly increase RTs compared to nonsingleton trials. Unlike Experiment 1, however, giving a flanking letter singleton status did not decrease RTs compared to nonsingleton trials. This finding is more consistent with previous literature demonstrating a lack of stimulus driven capture by color singletons (Bacon & Egeth, 1994; Folk et al., 1992; Franconeri & Simons, 2003).

Chapter 4

General Discussion

While there are many anecdotal reports of color singletons capturing attention in real-world environments, a wide range of laboratory experiments suggest the opposite conclusion. The present research explored whether this apparent discrepancy is due to differences in the perceptual load of the visual scenes. Perceptual load has been previously shown to strongly influence attentional processes, so it therefore seemed entirely plausible that perceptual load could modulate capture by color singletons (Lavie, 1995; Lavie & Tsai, 1994).

Specifically, one might expect that under conditions of low perceptual load, processing resources will be freed, leaving task-irrelevant color singletons to be processed. In our modified flanker task, we would therefore expect to see increased RTs on singleton neutral trials compared to nonsingleton neutral trials under low perceptual load. We might also expect to increased flanker-target compatibility effects from singleton flankers under low load. In our experiments, however, giving flanking letters singleton status did not significantly increase RTs (compared to trials with nonsingleton flanking letters), both under low perceptual load and under high perceptual load. Nor did singleton status increase compatibility effects from that flanker onto target responses. These results further strengthen the case against the existence of *pure* stimulus-driven capture by color singletons (Folk et al., 1992; Franconeri & Simons, 2003; Jonides & Yantis, 1988).

Anecdotal Capture by Color Singletons

So, from where do anecdotal reports of stimulus-driven capture of spatial attention by color singletons come? These reports may be a result of viewers being

unaware of their perceptual goals at hand (what they are searching for), making capture by objects with color singleton status *seem* stimulus-driven to the viewer. However, this form of capture is actually contingent upon the viewer's goals. In other words, viewers may not always be aware of what they are searching for. For example, when sitting in a coffee shop, one's spatial attention might be captured by a passing cyclist. It might be tempting to consider this form of capture to be purely stimulus-driven, because one has no reason to attend to a cyclist. However, it is possible that this person has a low-level (unconscious) attentional set for any type of motion that may signal danger. In this case, capture may seem stimulus-driven, when it is actually contingent upon the viewer's goal of finding moving objects that might represent danger.

When tested in a controlled laboratory environment, we attempt to manipulate participants' attentional set by giving them a specific target to find (e.g., search for a given shape). Having a specific goal, participants might drop all other goals, at least temporarily. Accordingly, task-irrelevant feature singletons would be truly irrelevant to the current task goals in working memory and thus fail to capture attention (as demonstrated in the experiments above).

Behaviorally Urgent Stimuli

These results with color singletons differ from previous findings with abrupt onsets, where scenes of low perceptual load yielded attentional capture (Cosman & Vecera, 2009). Again, abrupt onsets are often able to capture attention under circumstances where color singletons do not (Franconeri & Simons, 2003; Jonides & Yantis, 1988). Although both kinds of stimuli are perceptually salient, it appears that they have fundamentally different effects on the attentional system. One intriguing

hypothesis is that only dynamic, or behaviorally urgent stimuli, are capable of capturing attention in a stimulus-driven manner (Franconeri et al., 2004; Jonides & Yantis, 1988).

Certain stimuli often require immediate action in real-world settings, making them behaviorally urgent. For example, a looming stimulus indicates that an object is rapidly approaching the viewer (e.g., an oncoming automobile). This would require the immediate action of moving out of its path. Abruptly appearing or moving stimuli might also represent stimuli requiring action. One can imagine that stimulus types as such might be prioritized and cause an automatic shift of processing resources to develop a response.

However, color singletons might also be considered behaviorally urgent. One could certainly imagine situations where a color singleton might signify some sort of event requiring immediate action. For example, a brightly colored red reptile in a homogenously green colored background of foliage might signify some sort of threat. One explanation might be that color singletons do not represent behaviorally urgent information frequently enough to be prioritized by the human attentional system. Other information, such as looming stimuli and abrupt onsets, might signify behaviorally urgent information more frequently

Differing Paradigms Yield Differing Results

Research on stimulus-driven attentional capture by abrupt onsets has been very inconsistent. Some evidence indicates that abrupt onsets and other dynamic stimuli can capture attention in a purely stimulus-driven manner (Cosman & Vecera, 2009; Franconeri & Simons, 2003; Franconeri, Simons, & Junge, 2004; Jonides & Yantis, 1988; Theeuwes, 1994). Other research has reached the opposite conclusion (Bacon &

Egeth, 1994; Folk et al., 1992; Folk, Remington, & Wright, 1994; Lien, Ruthruff, Goodin, & Remington, 2008).

These conflicting results may stem from the use of different paradigms. In capture research, three types of paradigms are commonly used: the additional singleton paradigm, the irrelevant feature search paradigm and the pre-cueing paradigm. I will briefly review each paradigm, then speculate on what the key differences might be.

In the additional singleton paradigm, participants simply perform a search task. Occasionally, a distinctive feature singleton appears in the search display but is never the target. For example, participants would search a circular array for either an L or T. On some trials, a single distractor letter would be a different color than the rest of the array. Elevated RTs on feature singleton-present trials compared to feature singleton-absent trials would be taken as evidence of stimulus-driven capture. The present experiments used this paradigm.

The irrelevant feature search paradigm is very similar to the additional singleton paradigm. The main difference is that the feature singleton can appear in any location - including the target location - with equal likelihood. Stimulus-driven capture is indicated by shorter RTs on trials when the target is the singleton. Both of the aforementioned paradigms (additional singleton paradigm and irrelevant feature search paradigm), consistently yield stimulus-driven capture by dynamic stimuli (Franconeri & Simons, 2003; Jonides & Yantis, 1988; Theeuwes, 1991a, 1991b, 1992, 1994).

In a pre-cueing paradigm, the irrelevant feature singleton is presented before the search display. For example, participants might be instructed to search an array for a T or L. On a given trial, this array would be preceded by a pre-cue display containing the feature singleton (e.g., a motion cue). In this paradigm, attentional capture is indicated

by longer RTs on trials where the feature singleton cue is invalid (appears in a position where a subsequent distractor appears). Unlike the other two paradigms, the pre-cuing paradigm rarely yields evidence of purely stimulus-driven capture (Folk et al., 1992; Folk et al., 1994; Lien, Ruthruff, & Cornett; Lien et al., 2008). Instead, involuntary capture is dependent on viewers' top-down goals. For example, if one is searching for a color singleton, only color singleton cues will capture attention.

The reason for these discrepant results with differing paradigms is unclear. It appears that the feature singleton must be present in the search array, for some as yet unknown reason. Some researchers have suggested that top-down control can affect capture only after the first feedforward sweep of visual information (Stigchel et al., 2009). However, this hypothesis implies that pre-cueing paradigms should show also attentional capture, because the first sweep occurs before the search array. As expressed above, this is not the case.

One detail worth noting is that cuing experiments tend to use a simpler target-finding property (i.e., target defined some simple feature). Many additional singleton and irrelevant feature search paradigms use complicated target property finding features (namely, shape and form). Perhaps both top-down goals and bottom-up stimulus saliency play a role in attentional capture. Thus, when the target is difficult to find (as in most additional singleton paradigms), the contribution of top-down goals are ineffective and thus weakened. This would make the contribution from bottom-up processes more influential which could lead to capture by an irrelevant feature singleton. When the target is easy to find (as in pre-cueing paradigms), top-down goals will override stimulus-driven capture. Because no one has directly compared paradigms in this manner, further

research is needed to understand how difficulty of search affects capture by feature singletons.

Attentional Window and Search Strategies

Although the current research suggests that manipulations of perceptual load are not sufficient to modulate capture by color singletons, other variables might play an important role in the ability of color singletons to capture attention. Recently, Belopolsky and colleagues (2007) manipulated the size of participants' attentional window to see how capture by color singletons was affected. In this experiment, participants were forced to make local or global shape discrimination immediately before searching an array for a target letter. Both the fixation point and search array were triangular. In the diffuse condition, the orientation of the search array determined whether the participant needed to perform the given trial. In the focused condition, participants used the orientation of the fixation point to determine whether the given trial needed to be performed. In both conditions, some trials contained a distractor letter with color singleton status. The results demonstrated that increasing the size of participants' attentional window (global shape discrimination) caused capture by an irrelevant color singleton. The authors liken the diffuse condition to a parallel search strategy in which a visual scene is searched holistically. Thus, stimulus-driven capture, the authors claim, might occur only when participants use a parallel search strategy.

However, this claim that parallel search leads to capture by color singletons is at odds with the current experiments. Our low perceptual load conditions could be likened to a parallel search in which the target "pops out" of the search array. Similarly, our high perceptual load conditions could be likened to a serial search in which participants must search each potential target location individually. We showed no evidence of

capture by color singletons under low or high perceptual load. Currently, we are conducting research that specifically manipulates participants' use of parallel and serial search strategies in a color singleton pre-cueing paradigm.

Concluding Remarks

The present research suggests that color singletons cannot capture attention in a purely stimulus-driven manner. Yet, many questions regarding stimulus-driven capture remain to be answered. Namely, why do different capture paradigms yield conflicting results? What types of stimuli, if any, can capture our attention regardless of our goals at hand? And, ultimately, how much control do high-order processes have over involuntary attentional shifts?

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Table 1. Experiment 1 Data Summary: Mean Reaction Times (in Milliseconds), Standard Errors, and Percentage of Errors as a Function of Distractor Identity and Perceptual Load for Experiment 1. Mean RT=Mean reaction time; NS=Nonsingleton; S=Singleton; % Error=Error rate; SE= Standard error.

Perceptual Load	Distractor Identity					
	Compatible		Incompatible		Neutral	
	NS	S	NS	S	NS	S
LOW						
Mean RT	553	549	589	585	568	575
SE	17.39	16.51	16.76	18.46	17.57	17.15
% Error	4.4	3.23	6.85	5.8	4.16	4.38
HIGH						
Mean RT	632	643	652	658	640	646
SE	16.65	16.6	15.37	17.08	15.87	16.34
% Error	6.3	6.83	9.99	8.76	6.33	6.34

Table 2. Experiment 2 Data Summary: Mean Reaction Times (in Milliseconds); Standard Errors; and Percentage of Errors as a Function of Distractor Identity and Perceptual Load for Experiment 2. Mean RT=Mean reaction time; NS=Nonsingleton; S=Singleton; % Error=Error rate; SE= Standard error.

Perceptual Load	Distractor Identity					
	Compatible		Incompatible		Neutral	
	NS	S	NS	S	NS	S
LOW						
Mean RT	518	514	561	514	529	529
SE	10.7	10.74	11.13	10.88	9.71	10.26
% Error	1.75	1.2	3.47	3.35	1.77	1.7
HIGH						
Mean RT	610	600	642	618	612	612
SE	11.91	10.84	11.11	10.54	10.24	10.53
% Error	1.8	1.77	6.42	4.29	1.95	2.28

Figure 1. *Lavie's Flanker Task (1995)*: Participants search center array for either an 'x' or 'z'. Center array can either be low or high load. Flankers can be neutral, compatible or incompatible with the target identity.

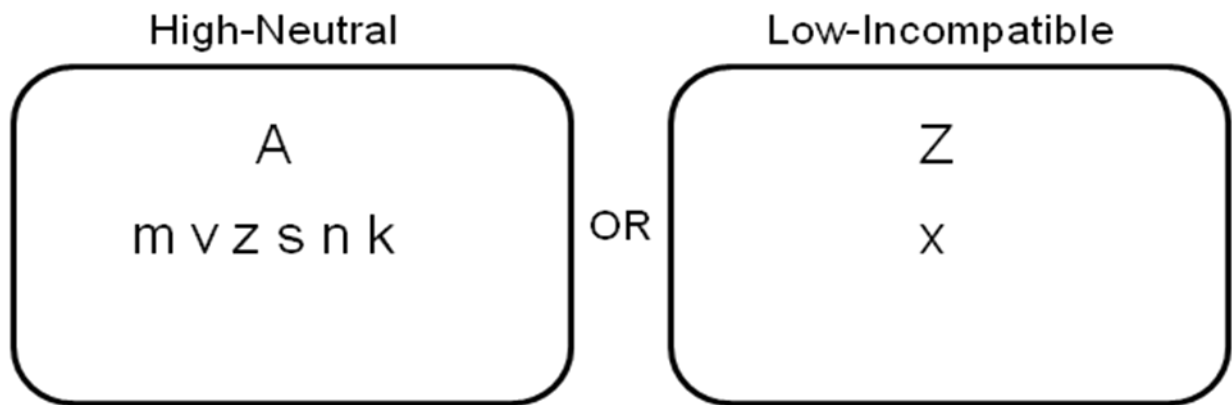


Figure 2. Progression of a Trial in Experiment 1: Participants search the array for either an ‘E’ or ‘H’. Flanking letters can have either a neutral, compatible or incompatible identity with the target. The flanker is a color singleton on half of the trials. The search array on the left is an example of a high load trial with a nonsingleton, compatible flanker. The search array on the right is a low load trial with a singleton, incompatible flanker.

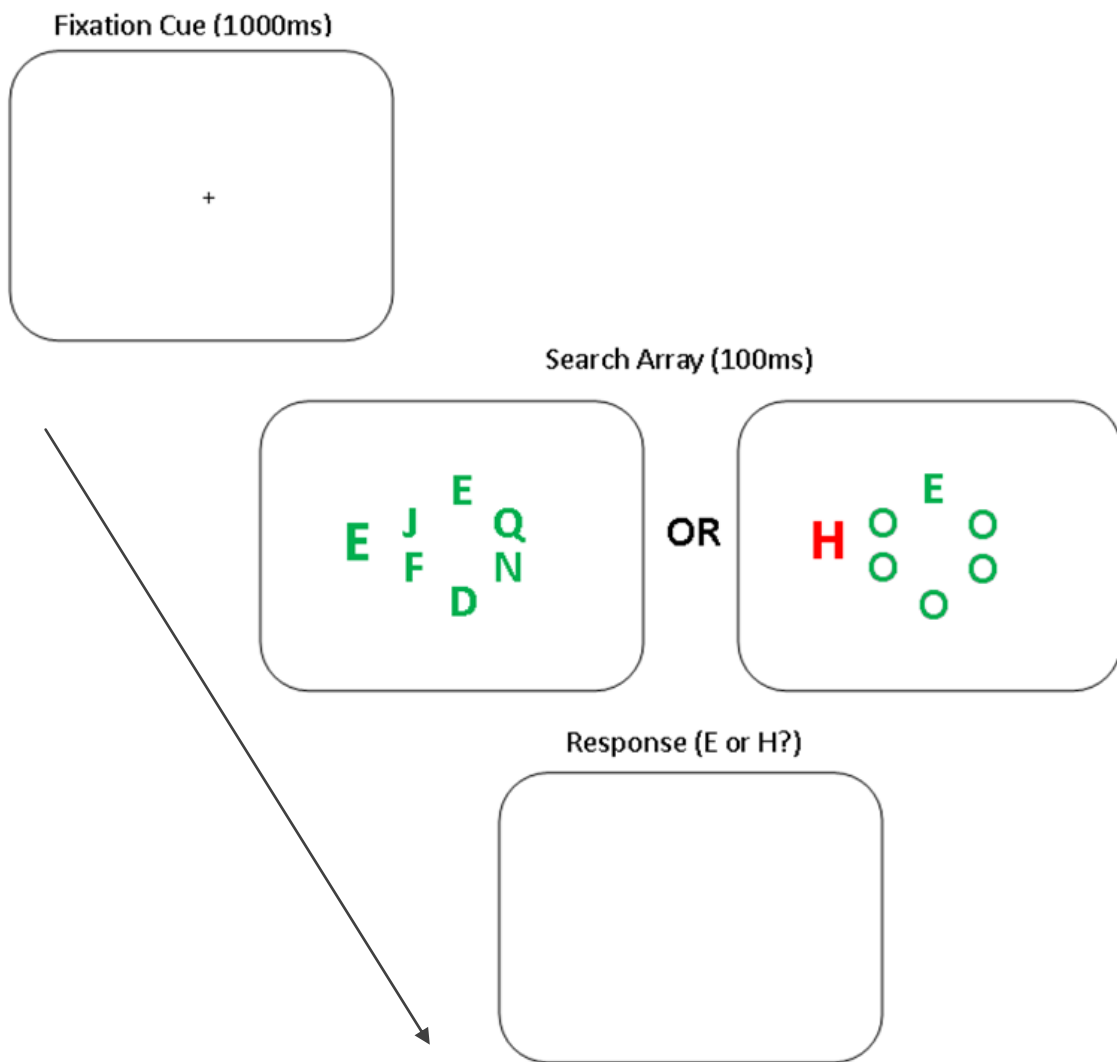


Figure 3. *Mean Reaction Times (RTs) from Experiment 1 by Trial Type.*

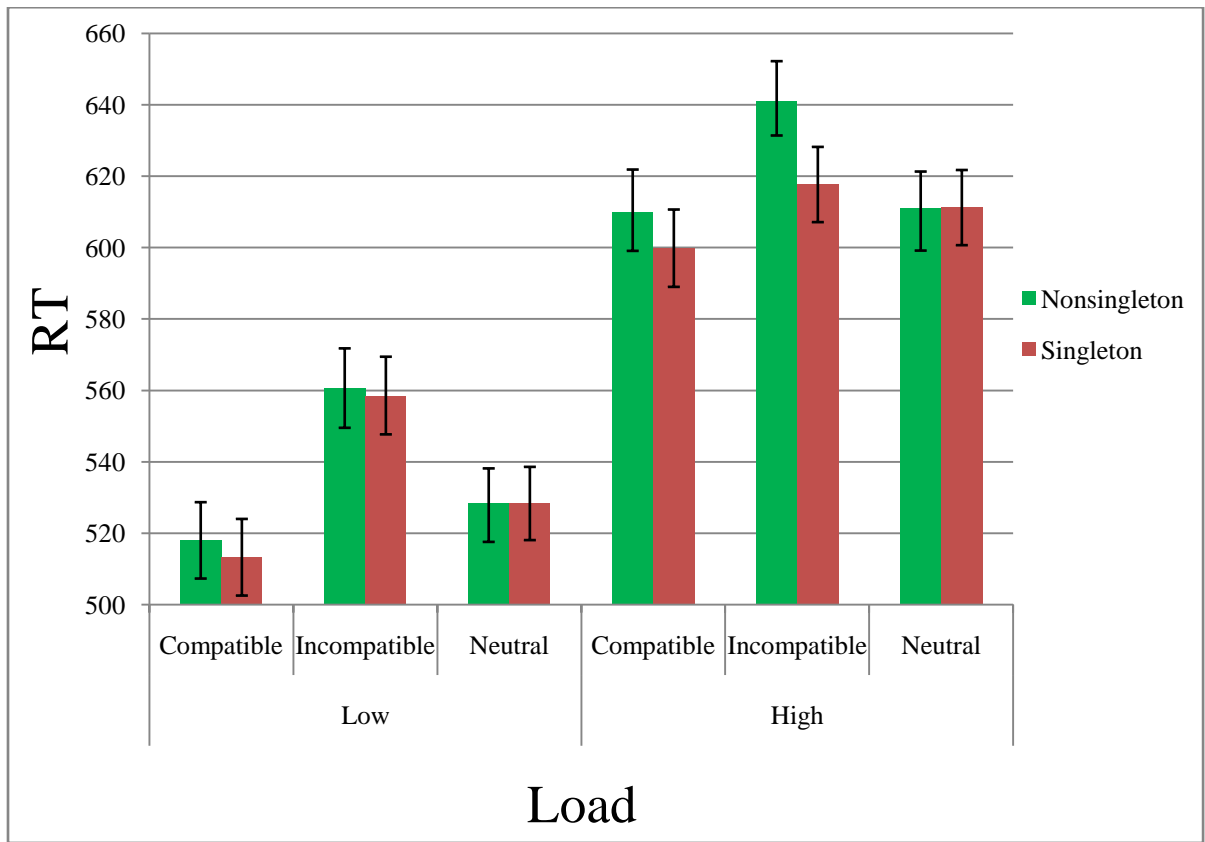


Figure 4. Compatibility Effects Observed in Experiment 1: Calculated as incompatible trials minus compatible trials.

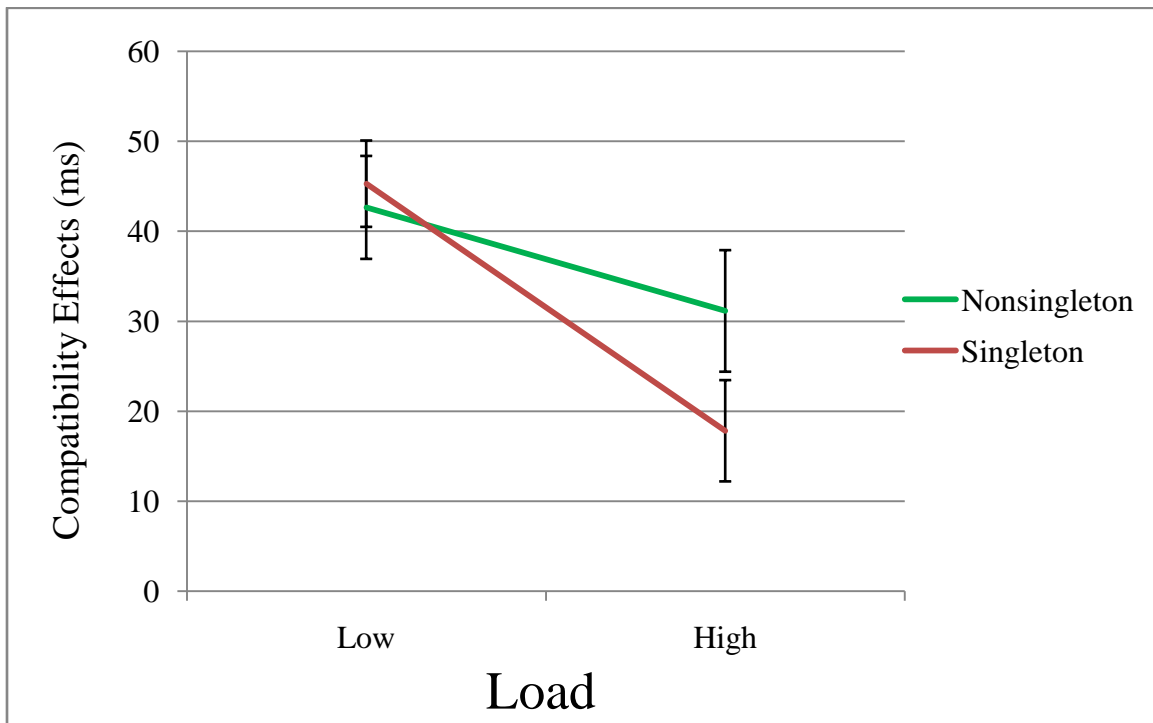


Figure 5. Progression of a Trial in Experiment 2: This experiment is similar to Experiment 1, except that: a) array color is varied by trial b) arrays are arranged into a linear formation.

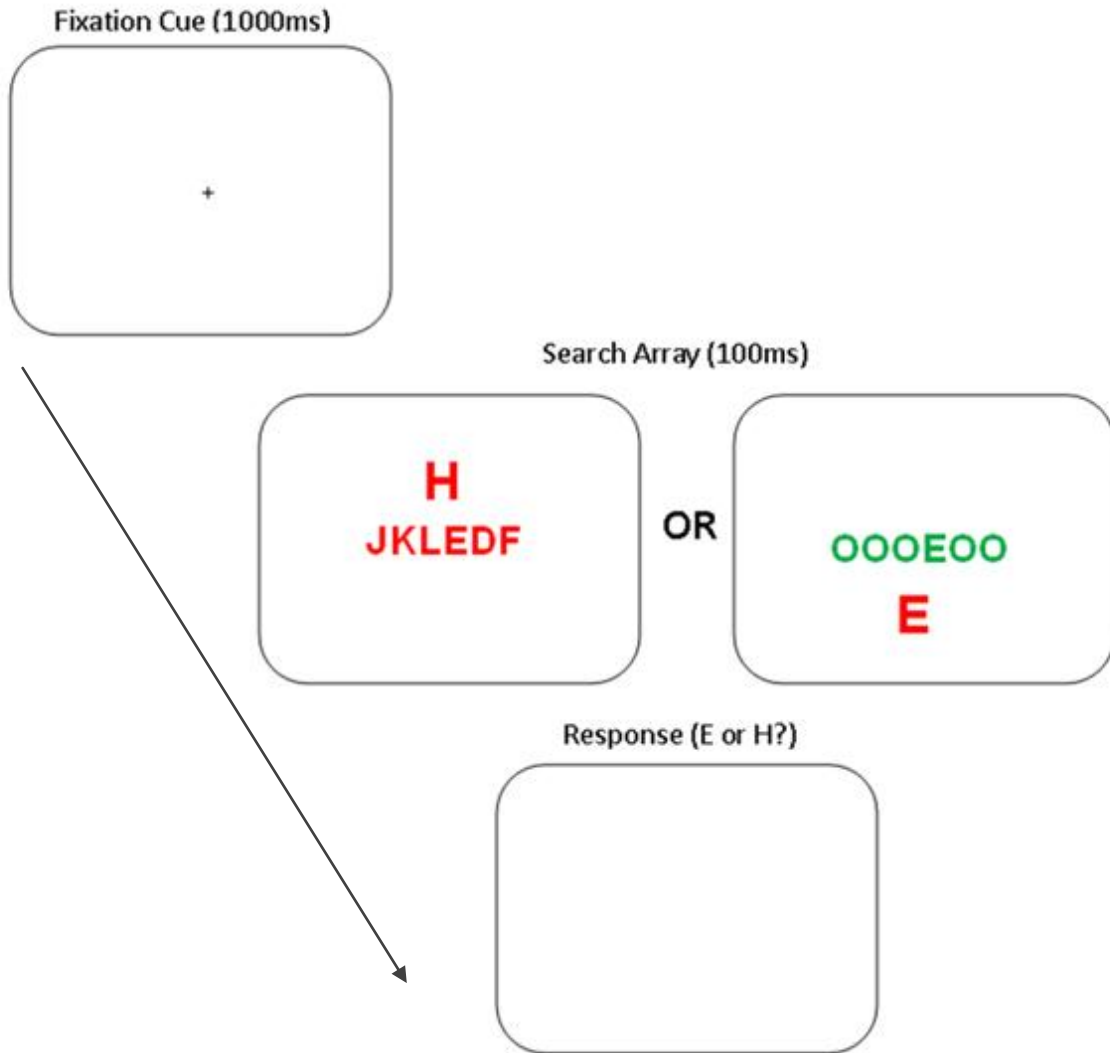


Figure 6. *Mean Reaction Times (RTs) from Experiment 2 by Trial Type.*

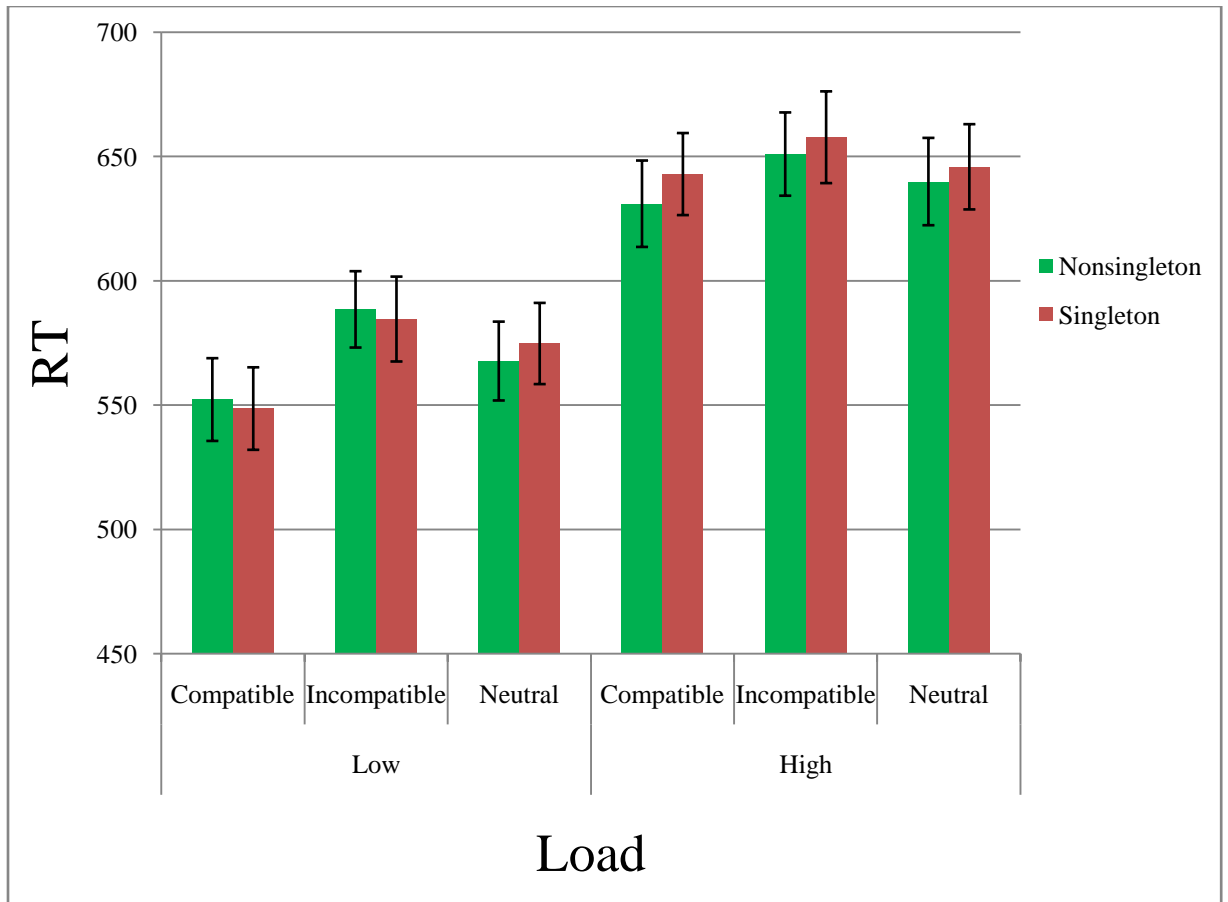


Figure 7. Compatibility Effects Observed in Experiment 2: Calculated as incompatible trials minus compatible trials.

