Psychonomic Bulletin & Review
In press

Attentional Capture Under High Perceptual Load

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Attentional capture by abrupt onsets can be modulated by several factors, including the complexity, or perceptual load, of a scene. We have recently demonstrated that observers are less likely to be captured by abruptly appearing, task-irrelevant stimuli when they perform a search that is high, as opposed to low, in perceptual load (Cosman & Vecera, 2009), consistent with perceptual load theory. However, recent results indicate that onset frequency can influence stimulus-driven capture, with infrequent onsets capturing attention more than frequent onsets. Importantly, in our previous task an abrupt onset was present on every trial, and consequently attentional capture might have been affected by both onset frequency and perceptual load. In the current experiment we examined whether onset frequency influences attentional capture under conditions of high perceptual load. When onsets were presented frequently, we replicated our earlier results; attentional capture by onsets was modulated under conditions of high perceptual load. Importantly, however, when onsets were presented infrequently, we observed robust capture effects. These results conflict with a strong form of load theory and instead suggest that exposure to elements of a task (e.g., abrupt onsets) combine with high perceptual load to modulate attentional capture by task-irrelevant information.

Scenes contain a tremendous amount of information, often more than an observer can process at one time. As a result, selective attention mechanisms have developed that allow us to focus only on the information most relevant for carrying out our goals. For example, when attempting to read a newspaper in a crowded coffeehouse, we focus on the words on the page and ignore the irrelevant sights and sounds around us. Such goal-directed attentional control allows us to focus on the task at hand without interruption from extraneous information. However, sometimes our attention is captured by salient information in the environment regardless of its relevance to our goals. This type of stimulus-driven attentional capture is ubiquitous and can cause us to shift away from our primary goals and attend to information outside of our current focus.

In recent years there has been a great amount of debate regarding the nature of such stimulus-driven attentional capture. Whereas some believe that stimulus-driven control is automatic, occurring independently of our goals (e.g., Theeuwes, 1994), others have posited that attentional capture is under the top-down control of the observer (e.g., Folk, Remington, Johnston, 1992). This debate is ongoing, with evidence in favor of both purely stimulus-driven capture (Schreij, Owens & Theeuwes, 2008; Christ & Abrams, 2006), and evidence in favor of the top-down ‘contingent’ control over capture (Leber & Egeth, 2006; Folk & Remington, 2006; 2008). As a result, there has been a great deal of focus on the particular types of stimuli and the parameters that allow for each mode of control.

One class of stimuli that have been shown to capture attention in a stimulus-driven manner are items that appear abruptly within a visual scene (Yantis & Jonides, 1984; Christ & Abrams, 2006). For example, when participants are asked to search for a target item in a scene, reaction times (RTs) to the target are faster when that item is an abruptly appearing object than when it is not (Christ & Abrams, 2006; Yantis & Jonides, 1984). This onset capture during search occurs even when onset status does not predict which item will be the target (i.e., the target and distractor items are equally likely to be defined by an abrupt onset), and as a result some have suggested that abrupt onsets can capture attention in a stimulus-driven manner (Schreij et al., 2008; Christ & Abrams, 2006). Several other types of visual events also appear to capture attention potently, including motion onsets (Abrams & Christ 2003), looming motion (Franconeri & Simons, 2003), and, perhaps, the offset, or disappearance of an object (Pratt & McAuliffe, 2001; but see Cole & Kuhn, 2010).

However, under some circumstances these various forms of attentional capture can be attenuated, demonstrating that such capture is not entirely stimulus-driven but is under the top-down control of the observer. For example, under some circumstances, onset capture only occurs when participants have an attentional control setting for onset stimuli (Folk et al., 1992; Gibson & Kelsey, 1998). Also, if a target’s location is precued by a 100% valid cue, an abruptly appearing distractor loses its potency to capture attention (Yantis & Jonides 1990). Finally, some of our recent work indicates that onset capture is modulated by the perceptual load of a display (Cosman & Vecera, 2009). In high-load displays that contained a target and several distractors, we found that salient onsets failed to capture attention. Onset capture only occurred in low-load displays that contained a target but no distractors (also see Cosman & Vecera, submitted, for similar results regarding attentional capture by motion).

A straightforward interpretation of our results is that abrupt onsets do not capture attention automatically.

Instead, in demanding, high-load situations, observers have fewer attentional resources to "spill over" to a task-irrelevant onset distractor, and as a result onsets do not interfere with search performance. We based our interpretation on Lavie's (1995; Lavie & Tsal, 1994) 'load theory,' which proposes that attentional resources are exhausted when performing a demanding, high perceptual load search. Load theory explains a wide range of attentional phenomena, and our application of load theory to onset capture indicates that perceptual load is critical factor in attentional capture.

Despite the foregoing evidence suggesting that onset capture can be abolished under certain conditions, recent findings have demonstrated that presentation frequency affects the potency of abruptly appearing stimuli to capture of attention. Neo and Chua (2006) re-examined the claim that observers can override onset capture when target location is known in advance. Using a cuing paradigm, Neo and Chua (2006) showed that the frequency of an onset distractor item affects attentional capture by that distractor. Task-irrelevant onset distractors were presented either frequently (75% of trials) or infrequently (18.75% of trials) at a non-target location, and target location was 100% validly cued prior to the presentation of the onset distractor. When task-irrelevant onsets were presented frequently, onsets lost their ability to capture attention, replicating previous findings (e.g., Theeuwes, 1991; Yantis & Jonides, 1990). However, when task-irrelevant onsets were presented infrequently, the onset distractor produced significant interference on target identification, indicating that the onsets retained their ability to capture attention. Based on these results, the authors suggested that to capture attention, abrupt onsets need to be 'novel' (i.e., infrequent), and top-down control over onset capture might only occur when onsets appear frequently (see also Horstmann, 2002; Horstmann & Ansorge, 2006, for related effects of novelty on capture by color singletons).

One direct implication of Neo and Chua's (2006) findings is that onset frequency, not perceptual load alone, may determine attentional capture. In our previous work, an abruptly appearing flanker appeared on every trial, and it is therefore possible that these frequent onset distractors gave participants sufficient exposure to effectively control onset capture during high-load search. In the current experiment, we tested between a frequency account of onset capture and a load-modulated account of capture.

Here we used a paradigm similar to that in Cosman & Vecera (2009), but we varied the frequency with which onset distractors appeared. Participants searched high-load displays for a known target among visually similar distractors. A task-irrelevant flanking distractor appeared either above or below the search array, and the flanker appeared as either an onset or an offset. The flanker's identity was either incompatible or compatible with respect to the target, allowing us to measure the extent to which the flanker interfered with responses to the target. Typically, no response interference occurs in high-load displays because attention is exhausted by the search task and is unable to be allocated to the flanker (Lavie, 1995).

To distinguish a frequency account of capture from the predictions made by load theory, we manipulated the frequency of the onset flankers. In the 80% Onset condition, an onset flanker appeared frequently (80% of trials) and the offset flanker appeared infrequently (20% of trials). In the 20% Onset condition, we switched the frequency of the distractors such that the flanker now appeared as an onset infrequently (20% of trials) and an offset frequently (80% of trials).

Load theory would predict no effect of our frequency manipulation on onset capture because all displays involve high perceptual load; thus, our displays exhaust the capacity of perceptual-level attention, and onset distractors should not interfere with performance regardless of their frequency. In contrast, a frequency account predicts that experience with onset flankers would determine attentional capture. Consequently, frequently appearing onsets in the 80% Onset condition should fail to capture attention. But, importantly, the infrequently appearing onsets in the 20% Onset condition should capture attention, despite the high perceptual load displays.

METHOD

Participants

Twenty-eight University of Iowa undergraduates participated for course credit, twelve in the 80% Onset condition and twelve in the 20% Onset condition. All had normal or corrected-to-normal vision.

Stimuli and Procedure

A Macintosh mini computer displayed stimuli on a 17-inch CRT and recorded responses and response latencies. The experiment was controlled using MATLAB and the Psychophysics toolbox (Brainard, 1997).

Aside from onset/offset frequency, the stimuli and procedure were identical for the 80% Onset and 20% Onset conditions. Observers sat 75 cm from the monitor in a dimly lit room. We used a task nearly identical to the high load condition in Cosman and Vecera (2009). A sample trial appears in Figure 1. A fixation point measuring 0.35° by 0.35° appeared for 1000 ms, followed by a placeholder array for 1000 ms. The placeholder display contained a central array of six figure-eight placeholders subtending 7.50° x 1.60° of visual angle, with each placeholder measuring 1.50° x .75°, with a distance of 0.45° between each placeholder. The placeholder for the offset flanker (1.90° by 0.90°) appeared either above or below the six, centrally-located placeholders. The center of the flanking placeholder (and the flanker letter itself in both onset and offset flanker conditions) was positioned 3.0° from the fixation point and 4.5° from the center of the most eccentric placeholders in the central array.

Next, line segments disappeared from the placeholders. Simultaneously with the offset of the line segments, a flanker letter appeared either in the position of the flanker placeholder (i.e., segments were removed from the flanker placeholder to generate an "offset" flanker) or opposite this placeholder (i.e., a new object appeared as an "onset" flanker). Flankers were either compatible or incompatible with respect to the target on a given trial. The resulting high load displays contained a single flanker letter and six centrally-located, task-relevant letters containing a target and five distractors. This search array and flanker item remained visible for 100 ms, too brief a duration to permit eye movements during search. Observers' task was to report the identity of a target letter, which was either an E or an H embedded within an array of five distractor letters U, L, P, C, or J. Each letter was equally likely to appear in any of the six different positions in the search array.

The flanker letter was either an E or an H that was either compatible or incompatible with the target letter on a given trial. Observers reported the target's identity by pressing either the "z" or "/" keys, with response keys for the E and H targets being counterbalanced between observers. Following 48 practice trials, observers responded to 288 experimental trials. Each block contained 48 trials, and participants completed 6 blocks of trials. We informed observers that the flanker letters were not relevant to the task and stressed that they should be ignored. We also informed observers to maintain fixation throughout the duration of the experiment. With this design it was possible to examine the effects of task-irrelevant onset and offset flankers presented with varying frequency on search performance under conditions high perceptual load.

RESULTS

Only correct trials were analyzed. In both conditions, RTs less than 150 ms or greater than 2500 ms were excluded from the analyses; this trimming eliminated less than 2% of the data in both the 80% Onset and 20% Onset conditions. Observers' mean correct reaction time (RT) and error rate data for each condition are shown in Figure 2. A combined analysis was performed to test for differences in capture across the two frequency conditions. Reaction time data from both experiments was entered into a 2 x 2 x 2 mixed ANOVA, with onset frequency (80% Onset vs. 20% Onset) as a between subjects factor and onset status (onset vs. offset) and congruency (compatible vs. incompatible) as within subjects factors. Of primary interest in this analysis was the interaction between onset capture and presentation frequency. The combined analysis yielded significant two-way interactions between onset frequency and onset status, $F(1,24) = 21.8$, $p < .01$, and between onset frequency and congruency, $F(1,24) = 6.7$, $p < .05$. Importantly, the three-way interaction between onset frequency, onset status, and congruency was significant, $F(1,24) = 4.9$, $p < .05$, indicating that the ability of onsets to capture attention and drive a flanker effect depended on the frequency with which onsets were presented.

Both accuracy and RT data for each frequency condition were also analyzed individually with separate 2 x 2 repeated measures ANOVAs, with flanker type (frequent onset vs. infrequent offset), and flanker congruency (compatible vs. incompatible) as factors. For the 80% Onset condition, no main effects or interactions were significant, Fs $(1,13) < .05$, ps $> .83$. This indicates that reaction times in the onset flanker condition were similar between compatible (732 ms) and incompatible (725 ms) flankers, reaction times in the offset flanker condition were similar between compatible (723 ms) and incompatible (728 ms) flankers, and the overall reaction times between onset (729 ms) and offset (726 ms) conditions were similar. Furthermore, no main effects or interactions were observed for the accuracy data, Fs < 0.6, ps $> .46$. These findings replicate the effect of perceptual load on onset capture observed in Cosman & Vecera (2009) and suggest that when onsets are presented frequently during high-load search tasks observers can effectively attenuate distraction by task-irrelevant onsets.

In contrast to the 80% Onset condition, analysis of the data from the 20% Onset condition revealed a main effect of onset status on RTs, $F(1,13) = 7.8$, $p < .01$, where reaction times in trials in which the flanker was an onset where significantly slower (828 ms) than those in which the flanker was an offset (721 ms). In addition, there was a main effect of congruency, $F(1,13) = 11.3$, $p < .01$, and the interaction between onset status and congruency was also significant, $F(1,13) = 15.8$, $p < .01$. Planned comparisons revealed that this interaction was driven by a significant flanker effect in the onset condition, with RTs on trials in which the flanker was incompatible were significantly slower (859 ms) than those in which the flanker was compatible (796 ms), $t(13) = 4.7$, $p < .01$. Error rates did not differ significantly between onset and offset flanker conditions, although there was a trend toward higher error rates in the onset flanker condition, $F(1,13) = 4.3$, $p < .06$, but error rates did differ between compatible and incompatible flanker conditions $F(1,13) = 9.4$, $p < .01$. The interaction between onset status and congruency was also significant, $F(1,13) = 15.8$, $p < .01$.

GENERAL DISCUSSION

Our results indicate that the frequency with which an onset appears affects attentional capture in high perceptual load search displays. Frequently presented onsets fail to capture attention when participants search through high perceptual load displays, replicating Cosman & Vecera (2009). Perhaps more important, our current results indicate that infrequently occurring onset flankers captured attention, even though participants were performing a high-load search. These results suggest that frequency and high perceptual load combine to determine whether or not capture will occur, supporting a frequency account of capture (Neo & Chua, 2006), but challenging load theory (Lavie, 1995).

Although our results have implications both for theories of attentional capture and perceptual load, one potential concern is our use of compatible and incompatible flankers. Given that load effects are often calculated using incompatible minus neutral reaction times (Lavie, 1995; Lavie et al., 2004), and furthermore it has been demonstrated that the use of incongruent minus congruent RTs in assessing load effects tends to underestimate flanker interference (see Gibson & Bryant, 2010), it is possible that the current results may have been influenced by our measure of flanker interference and not onset frequency. To exclude this possibility, we conducted a supplementary experiment with 24 new participants (12 in each frequency condition) that was identical to that presented above, except that the flankers were either neutral or incompatible. The results from this supplementary experiment are shown in Figure 3, and the findings replicated the results of our main experiment. This indicates that our conclusions hold irrespective of the types of flankers used.

We should note that there are two possible measures of onset capture in our experiment[1]. First, the difference between compatible and incompatible flankers provides a measure of flanker processing (i.e., identification), and flanker identification is clearly abolished for frequent onset flankers but not for infrequent onset flankers. Second, in the infrequent onset condition, the onsets cause a general slowing of RTs regardless of their compatibility. This finding would seem to suggest that under high load conditions attentional capture by frequent onsets is initially automatic but is attenuated with sufficient experience, given that a similar slowing of RTs is absent in the high-load, frequent onset condition. Taken together with the results of our previous work showing that even frequently presented onsets cause interference in displays that are *low* in perceptual load (Cosman & Vecera, 2009), it appears that capture by abrupt onsets may proceed automatically unless displays are both sufficiently high in perceptual load and abrupt onsets are presented frequently. Such an interpretation is tentative, however, given that in the current experiments and in our previous work our primary assay of capture was the presence or absence of a flanker effect, and not overall RTs in each condition.

Regardless of the nature of the effect of load on capture by onsets, these results challenge perceptual load theory because perceptual load effects are typically described as a resource limitation in perceptual level attention: To the extent that resources are exhausted by the demands of the primary task, there will be no resources left over to process task-irrelevant visual information (Lavie, 1995; 2004). Given the results of the current study, it would seem that perceptual load effects reflect the combination of higher-level attentional control settings (e.g., Folk et al.1992; Theeuwes, Kramer, & Belopolsky, 2004, Neo & Chua, 2006) and lower-level perceptual effects such as the competition between items in a search array (e.g., Torralbo & Beck, 2008). Thus, future conceptualizations of perceptual load theory must account for the effects of non-perceptual, top-down control mechanisms that appear to influence distractor interference.

In line with this interpretation, other recent results show that load effects depend on prior experience with a task (Theeuwes, et al., 2004; Couperus, 2009). For example, Theeuwes et al. (2004) showed that intermixing high and low perceptual load trials affected capture: When observers performed a high-load search on the current trial, a task-irrelevant distractor produced an interference effect if the previous trial had been low in perceptual load. They explained their result in terms of the scale of attention, suggesting that participants configured the size of their attentional "window" on a trial-by-trial basis. On low load trials, participants adopted a wide scale of attention, such that when the subsequent trial was high in perceptual load the peripheral distractor was processed.

Likewise, Couperus (2009) showed using ERPs that the visual cortical response to parafoveally presented, task-irrelevant probe items is modulated by learned expectancies regarding the load of the primary task. If the trial type (high vs. low load) could be predicted based on learned expectancies (i.e., sequences of particular trial types), there was a diminished P1 response to a task-irrelevant probe item in high load trials and an increased P1 response in low load trials – what may be considered a "typical" load effect. However, when the trial type was random with respect to load, such an effect was not observed. This effect was interpreted in the context of the results of Theeuwes et al. (2004), and it was suggested that the anticipation of particular types of stimulus arrays (high vs. low load) can lead to changes in attentional scale and thus the extent of distractor processing.

Taken together with the current results, it appears that task experience combines with high perceptual load to modulate the processing of task-irrelevant information, with a critical factor being the frequency with which the task-irrelevant attributes appear. This suggests that efficient suppression of task-irrelevant information reflects the combined influences of bottom-up and top-down processes, and that future conceptualizations of perceptual load theory must take top-down control processes into account when explaining the effect of load on attentional selection.

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[1] Thanks to Fook Chua for raising this point

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FIGURE CAPTIONS

Figure 1. Sequence of events and timing parameters for the task used in both conditions. Following presentation of a fixation point for 1000 ms, a six-item placeholder array flanked by a cortically scaled flanker placeholder was presented for 1000 ms. Directly after this, a high-load search array and a single flanker item (onset or offsets) appeared for 100 ms. In the "Onset Frequent" condition, the frequency of onset flankers was held at 80% (20% offset flankers), whereas in the "Onset Infrequent" condition the frequency of onset flankers was decreased to 20% (80% offset flankers). The trial depicted above is a "neutral onset flanker" trial.

Figure 2. Mean reaction times for high-load search when flankers were compatible or incompatible onsets or offsets in the "Onset Frequent" condition (left panel) and the "Onset Infrequent" condition (right panel). Error rates for each condition are indicated at the base of the graph. Error bars represent 95% within-subject confidence intervals for the flanker effect in each condition (Loftus & Masson, 1994).

Figure 3. Mean reaction times for high-load search when flankers were incompatible or neutral onsets or offsets in a supplementary experiment using incompatible and neutral flanker letters (see General Discussion). The methods employed in this experiment were identical to those in Experiment 1, except for the use of incompatible and neutral flankers. Error rates for each condition are indicated at the base of the graph. Error bars represent 95% within-subject confidence intervals for the flanker effect in each condition.

Figure 1

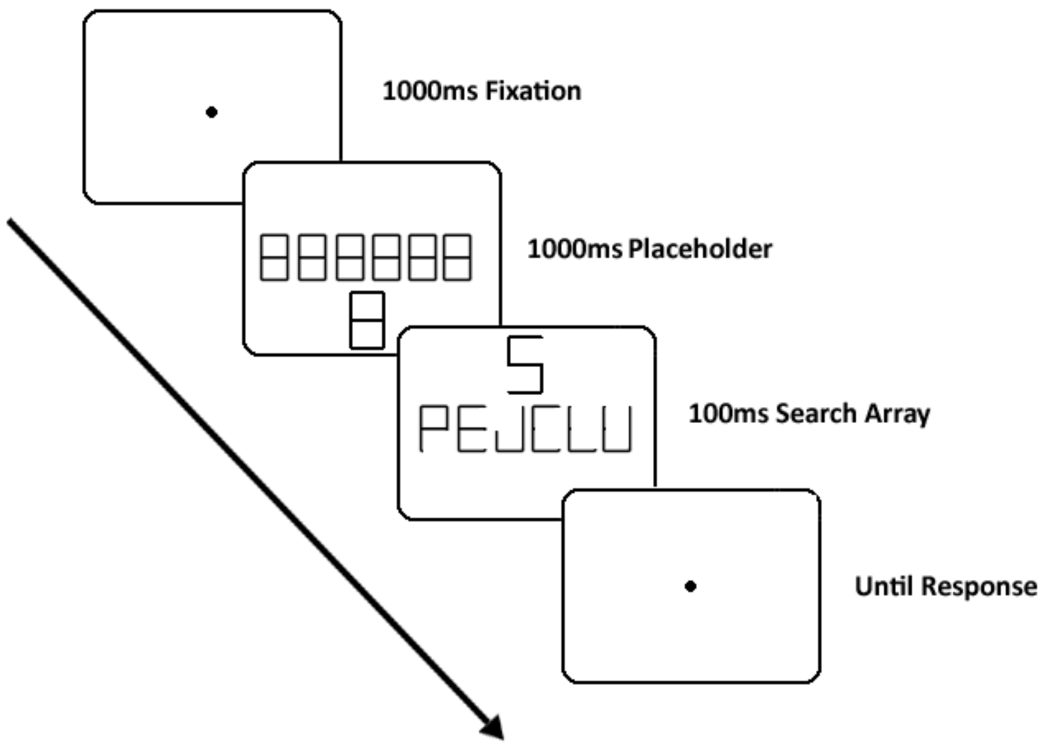

1000ms Fixation
1000ms Placeholder
5
PEJCLU
100ms Search Array
Until Response

Figure 2

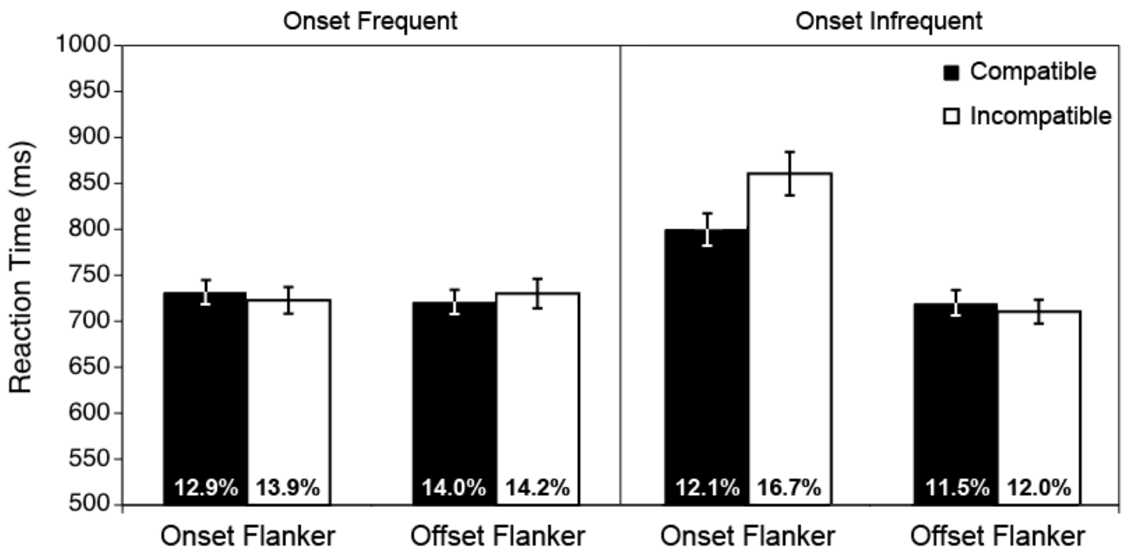
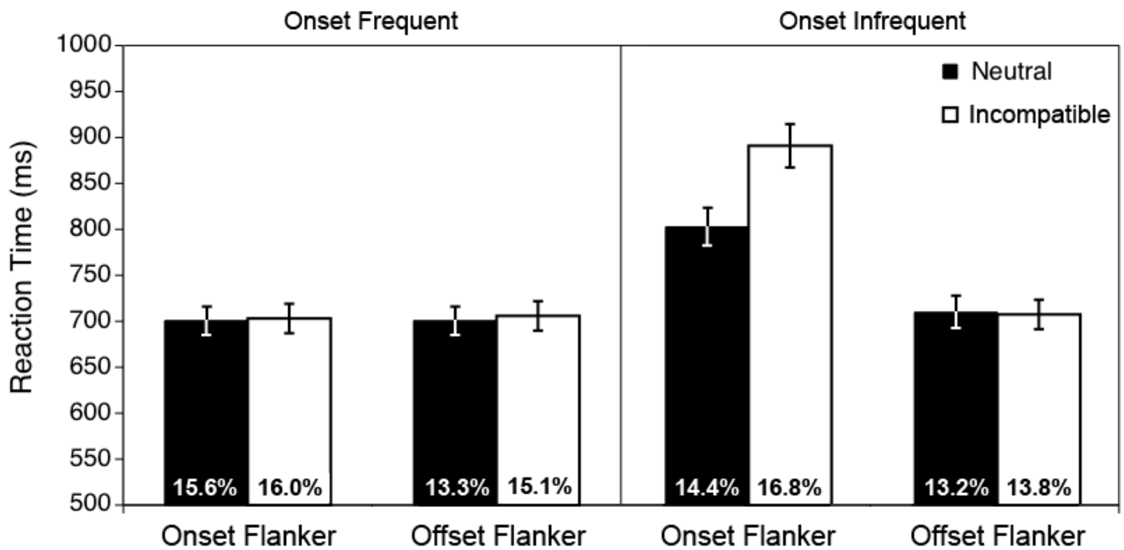

Onset Frequent
Onset Infrequent
Compatible
Incompatible
Reaction Time (ms)
1000
950
900
850
800
750
700
650
600
550
500
12.9% 13.9%
14.0% 14.2%
12.1% 16.7%
11.5% 12.0%
Onset Flanker
Offset Flanker
Onset Flanker
Offset Flanker

Figure 3


Onset Frequent
Onset Infrequent
Neutral
Incompatible
Reaction Time (ms)
1000
950
900
850
800
750
700
650
600
550
500
15.6%
16.0%
13.3%
15.1%
14.4%
16.8%
13.2%
13.8%
Onset Flanker
Offset Flanker
Onset Flanker
Offset Flanker