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Attention Capture by Visual Onsets and the Mediating Power of Attentional Set

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ABSTRACT

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This study examined how attentional set mitigates attention capture by onsets occurring between known spatial locations. In Experiment 1 response times increased with the number of onsets that occurred. In Experiment 2 and 3 color was used instead of onset as the task relevant feature. Data collected at the keystroke-level showed delayed response times for keystrokes in only certain positions following an onset. Typing patterns were also found to affect the costs generated by the onsets, implying that task strategies mediated when onsets captured attention. Experiment 4 manipulated the cue types in a 2 phase spatial cuing task. Cues of the same type in both phases yielded faster responses, even though the blocked nature of the trials alerted participants to the upcoming cue type in each phase. This suggests that participants were unable to rapidly shift attentional set.

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Introduction

It has been well-established that under many conditions the abrupt appearance of new perceptual objects will overtly or covertly capture visual attention. However, the extent to which this capture is mediated by spatial cuing, attentional set, and task relevance is still widely debated. The knowledge that visual onsets have a special place in attention capture is far from new to the psychological community, for example, it was commented on by Titchener when he wrote, "Sudden stimuli and sudden changes of stimulus exert a familiar influence upon attention" (Titchener, 1908, p. 192). This observation has been supported by the findings of numerous studies over the last few decades. For example Todd and Van Gelder (1979) used a search task in which the target and background figures were either rapidly onsetting block letters, or letters revealed from the removal of camouflaging segments of block figure 8's, which they dubbed "no-onset." They found that participants' response times were faster when the target was an onsetting letter. Also, this effect increased with the complexity of the task; i.e., the effect was greater when the participant had to classify the target, rather than merely identify it. Automatic capture has also been shown even when attending to an onset is not beneficial to the goal of the task. For example in Jonides (1981) participants had shorter response times in identifying a target when it happened to appear in a recently cued location, even though the onset was predictive of the target on only at a chance level. That is, the target was just as likely to occur at any position, regardless of it being cued by an onset or not. Other studies with similar findings include Lambert, Spencer & Mohindra (1987) and Theeuwes (1991). In these paradigms the onsets were not predictive of the target, but they were also not uniformly non-predictive. Therefore, although there was no clear benefit from beginning the search at the location of the onset, there was also no cost in doing so. It is even likely that in these cases the choice to not attend to an onset takes cognitive effort, and possible time cost, thus the strategy of attending the onset first may actually have been beneficial to the task.

As previously mentioned, there are certain conditions, such as spatial cuing, in which abrupt onsets do not automatically capture attention. Experiment 2 of Yantis and Jonides (1984) examined the effect that a central cue in the form of an arrow had in mediating the power of onsets in capturing attention. When this arrow accurately predicted the upcoming location of the target, participants' response times were not affected by the presence of an onsetting letter. That is, the response times were the same regardless of whether the target was an onset or not. This finding implied that the power of abrupt stimulus onset to capture attention could be mediated by the participant attending to a specific visual location. The extent of this mediation was addressed in Yantis and Jonides (1988), in which the participants were asked to identify a target in the cued location, with a response of one of two possible key-press responses. The purpose of this design was to determine if there was an interference effect when the onset was not the cued target, but contained the incorrect response. The experimenters found that such interference did occur, more so than when another, non-onsetting, position contained the incorrect response. Based on this result the authors suggested that the onset might still be capturing attention to some degree, but either covertly or secondarily, subsequent to when the participant shifted attention to the accurately cued target location. This interaction between the experimental paradigm and the mitigation of attention capture by top-down processes motivated further studies.

Folk, Remington & Johnston (1992) examined the effects of manipulating attentional set. They again used a search task, but unlike previous studies, the cue type was examined in relation to the features that distinguished the target. An abrupt flash was presented as a cue around one of four possible target locations. For one group the target was a single abruptly onset character, but for the other it was one of four figures, differentiated by color. They hypothesized that the task would control the features for which the attention of the participant was set, and that the onset cue would affect response times only in trials where the target was specified by onset. The results were compatible with this hypothesis. Valid cues reduced reaction times and invalid cues cost time, but only in the onset target condition. In a second experiment the two features were reversed, with color acting as a cue. The goal was to see if any feature that the participant was monitoring for could involuntarily attract attention. The results supported this notion. The invalid and valid color cues had the expected cost and benefit effects when the target was distinguished by color and had no effect when the target was a single onset figure. The authors concluded that once the attentional set of the participant had been determined by the features of the search task, other stimuli containing the same singleton features would automatically capture attention. On the other hand, any stimuli possessing features for which attention was not set would fail to capture attention. The authors dubbed this the "contingent involuntary orienting hypothesis." In this hypothesis stimulus-driven visual attention capture is completely controlled by top-down, or endogenous, processes. Arguably the onset effects found in previous experiments were due to the nature of the search task, or some default setting favoring onset in the absence of another, non-onset, defining feature. It is important to note that the experimental trials in Folk, Remington and Johnston (1992) were blocked by validity. Participants were informed that the cues they were seeing would be completely predictive, or completely non-predictive of the upcoming target. Surprisingly, even though participants knew that a given cue was going to be predictive or non-predictive of target location, the match between cue and target type was still a powerful factor. For example, even though participants knew that the cues were valid, they failed to take advantage of a valid color cue to attend to the location of a subsequent onset target. Participants were so keyed to attend to onsets that valid color cues were ignored. However, participants were able to use valid onset cues in reducing response times for color targets. This is yet another example of the uniqueness of onset above other stimulus properties.

This distinction is important to the definition of attentional set. If attentional set is formed based on the goal of optimizing task performance, than participants in the valid color-cue, onset-target condition, should have been able to form an attentional set for both color and onset. However, rather than setting attention to the properties that would optimize task performance on the whole, participants' attention seemed to be set for optimizing only the target identification segment. This finding implies either that the participants were not highly motivated to optimize performance, or that the formation of such a complicated attentional set is difficult or impossible.

The contingent involuntary orienting hypothesis was further examined in Theeuwes (1994). The search task in this experiment involved three circular possible target locations, spaced evenly around a central fixation point. In one experiment, the circles began as green and the one containing the target changed to red. In half of these trials another green circle also appeared at the moment of color change. Theeuwes found that the presence of this onsetting figure distracted participants from identifying the target, as evident in response times. He also found this effect when, to control for the target circle being defined as the only one to change, the circles began as gray and all but the target circle turned to red. Theeuwes concluded that the onsets still captured attention, even when attentional set should be limited solely to color change. Therefore, stimuli salience, rather than attentional set, determined which stimuli captured attention, and that onset was a more salient feature singleton than color. However, although an attentional set for onset was not beneficial in these tasks, the onsetting figure still shared some features relevant to the task, specifically shape and color. Since participants were required to identify the target through these features, it is arguable that the onsetting circle distracted attention in so much as it increased the search set, thus requiring that a further judgment be made.

In a summary of the literature to date, Yantis (1993) addressed the conditions under which onsets would capture attention. When a participant is lacking an attentional set for a given singleton, as in (Jonides and Yantis, 1988; Lambert, Spencer and Mohindra, 1987; Theeuwes, 1991b; Yantis and Jonides, 1984, 1990) then onsets will capture attention. Even in search tasks which require an attentional set for a given singleton feature (i.e., the target is distinguished by a single feature), many irrelevant singletons will effectively attract attention: color (Folk et. al., 1992; Theeuwes, 1991a) and motion (Folk & Wright, 1992). In some cases where a task requires the participant to have an attentional set for a specific feature singleton other than onset (e.g., color), onset will fail to capture attention (Folk et. al., 1992). Unlike onset, the following features have been found not to capture attention, in the lack of a specific attentional set: color (Folk, 1990; Jonides and Yantis, 1988; Martin and Benson, 1991), brightness (Jonides and Yantis, 1988) and motion (Folk and Wright, 1992; Hillstrom and Yantis, 1992). Finally, if the participant's attention is already focused on a specific location, as from a cue, that an onset outside of this location will not capture attention (Theeuwes, 1991b; Yantis and Jonides, 1990). As such, Yantis concluded that attentional set, determined by the defining target features in a search task, does play a large role in mediating the capture of attention by various stimuli. However, onset still has the unique ability to capture attention in the lack of a specific task relevant attentional set.

Folk, Remington and Johnston (1993) provided an insightful counterpoint to Yantis's conclusions. The authors proposed that all stimulus driven visual attention capture is dependent both on task demands, which determine how attentional control is set, and the actual stimuli. Therefore, although they agree that onset has a special place in attention capture, they argued against the possibility that a search task can ever produce a total lack of attentional set. They proposed that even outside of a given experiment a participant is sure to have some preconditioned attentional set. The authors also suggested that the search tasks, in the cases cited by Yantis, produce an attentional bias towards onsets. Specifically, the fact that the participants need to locate a target, rather than discriminate it from other figures, creates a search specific attentional set. Along these same lines they hypothesized that "default settings' based on experience or 'long-term ecological based biases' [evolution] may be favorable to onset detection." (p. 638) However, after this semantic debate over the possible existence of an attentional setless state, the authors agree with Yantis, that when there is no other set for a specific feature singleton, onsets will capture attention.

It is readily apparent that the task used to measure the capturing power of onsets plays some role in the observed effect. The type of response made has even been found to be relevant to the debate, such as Ludwig and Gilchrist (2002). This paper discussed the dichotomous findings that stimulus-driven capture is often found in search tasks, while contingent capture is mainly found in attentional cuing tasks. This experiment utilized a search task in which the target would occur in one of four pre-set locations, and would be defined by either onset or color. As expected distractors with the same modality as the target, defined by onset or color, yielded the greatest effect in eliciting eye movements. The interesting finding was that even when the distractor did not elicit a saccade, response times were slower when the distractor was an onset. Apparently the suppression of an overt eye movement to the distractor delayed parallel eye movements to the target. Also of importance, the abrupt onsets interfered with mouse movements to the target, but had no effect when button presses were used to identify the quadrant in which the target was located.

Theeuwes, Kramer, Hahn and Irving (1998) presented participants with a display of six gray circles in a circular configuration around a fixation point. Each circle contained a block-figure 8. All but the circle containing the target changed to red, and participants were asked to make a saccade to the target. At varying locations and times, after the color change, a new red circle onset between the other circles. Participants' eye-movements were captured using an eye tracker. The results showed that, so long as the new circle onset before the participant had completed their saccade to the target, the onset disrupted the saccade. Specifically the participants' eyes were drawn towards the new circle, normally fixating on it briefly, before continuing to the target. This effect was found regardless of the spatial proximity of the onset to the target. These findings imply that attention capture is directly correlated with capture of eye movements.

In a second experiment a central arrow accurately cued the upcoming location of the target. So long as the arrow appeared more than 200 ms before the display change, the presence of the onset circle failed to disrupt saccades to the target. This finding regarding eye movements is compatible with the conclusions of Yantis (1993) regarding attention and supports the idea that visual attention capture and eye-movements are highly correlated.

Experiment 1

It is clear from this review of the literature that there is still debate concerning how attentional set, determined by the properties of the task and stimuli, mediate the attention capturing property of abrupt onset. Current experimental data has come from various forms of spatial cueing, detection or discrimination search tasks. The limited nature of experimental methods is surprising, since the paradigm used may contribute considerably to the effect of onset. Folk, et al. (1993) argues that the nature of a search task is likely to produce an attentional bias for onsets. Also, Vecera and Farah (1994) discuss the different levels of object representations that may be utilized by participants performing simple detection vs. discrimination tasks. Therefore bottom-up attention capture may be highly contingent on the depth of processing required by the task. This experiment hopes to provide a contribution to the debate through the use of a typing / transcription task. This is a high-level discrimination task, and is more similar to a spatial cueing than a search task. Like Folk, et al. (2001) it will examine possible interference effects produced by task similar foils, as evidenced through response times. The nature of the task is such that it should focus participants' attention on a series of locations. This experimental design is unique because it requires a transfer of attention from the locations of the to-be-transcribed characters, and the location where the characters appear when typed by the participants, with the onsetting figures occurring in the space between these two locations. One of the primary questions is therefore if onsets can distract attention when they occur between two goal-relevant locations. Such an attention capture should be evidenced with longer response times and possibly increased errors.

If the hypothesis presented in Theeuwes (1994) is correct, then salient onsets will capture attention regardless of whether they posses task-relevant features. Alternatively if the contingent involuntary orienting hypothesis (Folk, et al. 1993) is correct, then no distraction should be observed when the onsets do not contain any task-relevant features, assuming that the task dictates attentional set for singletons other that onset.

The use of a typing task is also specifically relevant to the growing number of computer and internet applications. Many software programs and web sites utilize onsets as a method to capture their users' attention. This experiment may help determine the validity and costs of this practice. The ability of participants to ignore onsets is also relevant to tasks with other onset-rich environments, such as air traffic control. With this in mind, the temporal positioning of the onsets within the transcription task was also examined.

Method

Participants

Twenty-seven undergraduate students at Rice University, ranging in age from 18 to 21 years old, participated in this study as a requirement for a psychology course. All reported normal or corrected to normal vision, and moderate (>20 words per minute) or better typing ability.

Apparatus and Stimuli

Apple iMac computers and Apple keyboards were used for display and participant input. On each trial the display consisted of a white background and two rows of four boxes each, see Figure 1 below.

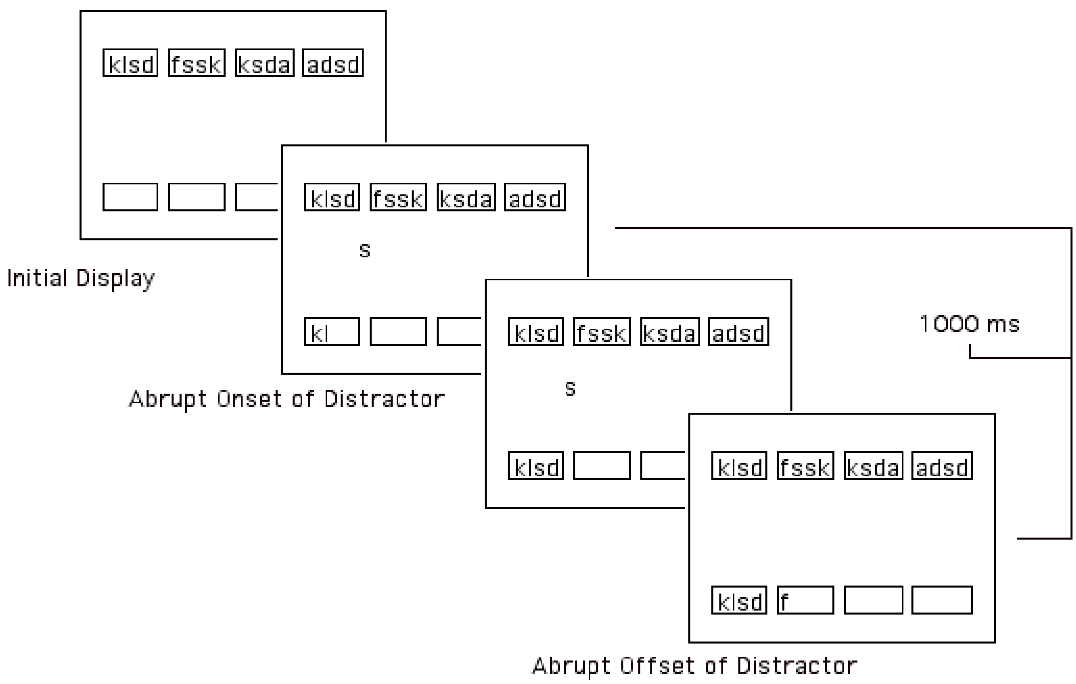

Figure 1: Experiment 1 design layout, with onset.

Each box had a 1 pixel wide black border, was 30 pixels high and 70 pixels long, and was separated from the adjacent box by 60 pixels. The two rows of boxes were separated by 250 pixels. There were 150 pixels of space between each edge of the screen and the outermost edge of the outermost boxes. There were 150 pixels of white space above the top edges of the uppermost boxes, and 140 pixels below the bottom edges of the lower most boxes. The monitors used were 15 inches across diagonally, and were run at a display resolution of 800 x 600, making each box approximately 1 inch in length (65 pixels to an inch). Participants sat with their eyes positioned approximately 18 inches from the screen, meaning each inch of length on the screen was approximately 3.2 degrees of visual angle, or about 20 pixels per 1 degree of visual angle, with the width of the entire display encompassing 40 degrees. At the beginning of each trial the upper row of boxes each contained four capital characters in Courier 20, a 20 pixel, black mono-spaced font. The characters were randomly selected from the home-key finger position: A, S, D, F, J, K, L, ;. The participants transcribed these characters into the corresponding boxes in the lower row.

During some of the transcription tasks, described in detail below, one or more figures abruptly onset and offset in the space between the two rows of boxes. The figure was either one of two types. The first type, task-relevant, was a character selected from the home key characters, identical to those in the boxes. The second type of figure, task-irrelevant, was a geometric shape (square, circle or triangle) of solid black, and was 20 pixels in diameter. The position of these figures was randomly selected within the third of the screen in which the participant was currently engaged. Each figure was presented for 1000 ms.

Design

Participants completed twelve practice trials, containing no onsetting figures, to familiarize them with the task. They then completed four blocks, each consisting of 60 trials, 24 of which contained no onsets. The other 48 trials consisted of an equal distribution of the other onsetting figure variables.

There were four independent variables in the onset conditions. The first was the block in which the trial was completed. The second was the temporal location of when the figure onset: either while the participant was typing within a box or was between boxes. The third was the type of onsetting figure: either a character or a shape. The fourth was the number of figures appearing per trial: either 0, 1, 2, or 3. For within-box onsets the figure(s) appeared while the participant was transcribing within a box, that is, after she entered the first, second or third keystroke in a box. For between-box onsets, the figure(s) appeared while the participant was in between boxes, that is, after she typed the fourth keystroke in a box and before she type the first keystroke in the next box. On any given trial the figures were consistently either characters or shapes, and appeared consistently within or between boxes. The combination of these independent variables created 12 different condition types, each of which was presented 4 times per block. The order of these trial types was randomized within each block of trials.

Total task response time was defined as the time between the participant pressing the space bar to begin the trial and pressing the 16^{th} keystroke to complete the trial. Errors were recorded for each trial as the number of characters in the participant's transcription that did not match the corresponding character in the box above.

Procedure

The participants were asked to transcribe the characters located in the upper row of boxes into the corresponding boxes in the lower row, as quickly and accurately as possible. The participants were also instructed that they were not allowed to correct typing errors, and that anything appearing outside of the boxes would be irrelevant to the task and should be ignored.

After a participant pressed the space bar to begin a trial, the display began with the cursor in the first position of the left-most lower box. Upon the participant's completion of typing four letters in a given box the cursor automatically shifted to the next of the lower boxes. Upon completion of the fourth box the on a trial, the screen changed to a rest screen, where participants were instructed to begin the next trial by pressing the space bar with their thumb, while keeping their fingers in home-key position. The participants were also instructed to rest for a few minutes between each block of trials.

Results and Discusion

Missing Data

None of the 27 data sets were removed from the analysis. Each data set was examined individually, and outlying data points that were more than 3 standard deviations from the participant's individual mean were replaced with the individual mean.

The Total Task Response Time Dependent Variable.

The total task response times for each participant were analyzed using a 4 x 2 x 2 x 3 and a 4 x 4 repeated measures ANOVA. The first ANOVA compared means for trials across the four blocks, the two temporal onset positions (either while the participant was typing within or transitioning between boxes), the two onsetting figure types and either 1, 2 or 3 onsetting figures per trial. The second ANOVA compared means across the four blocks and either 0, 1, 2 or 3 onsetting figures per trial. It was necessary to conduct two ANOVAs because the trials with no onsetting figures obviously did not represent either of the other two figure-relevant dependent variables.

The key finding was that response times increased reliably as the number of onsetting figures per trial increased, as illustrated in Figure 2 below, $F(3, 78) = 5.06$, $p = 0.003$. The presence of these perceptually new figures did therefore exert a cost in the participants' response times. This implies that the onsets captured attention to some degree. In this unique split location-of-focus design the onsets that occurred outside of the locations where attention was focused still produced an effect.

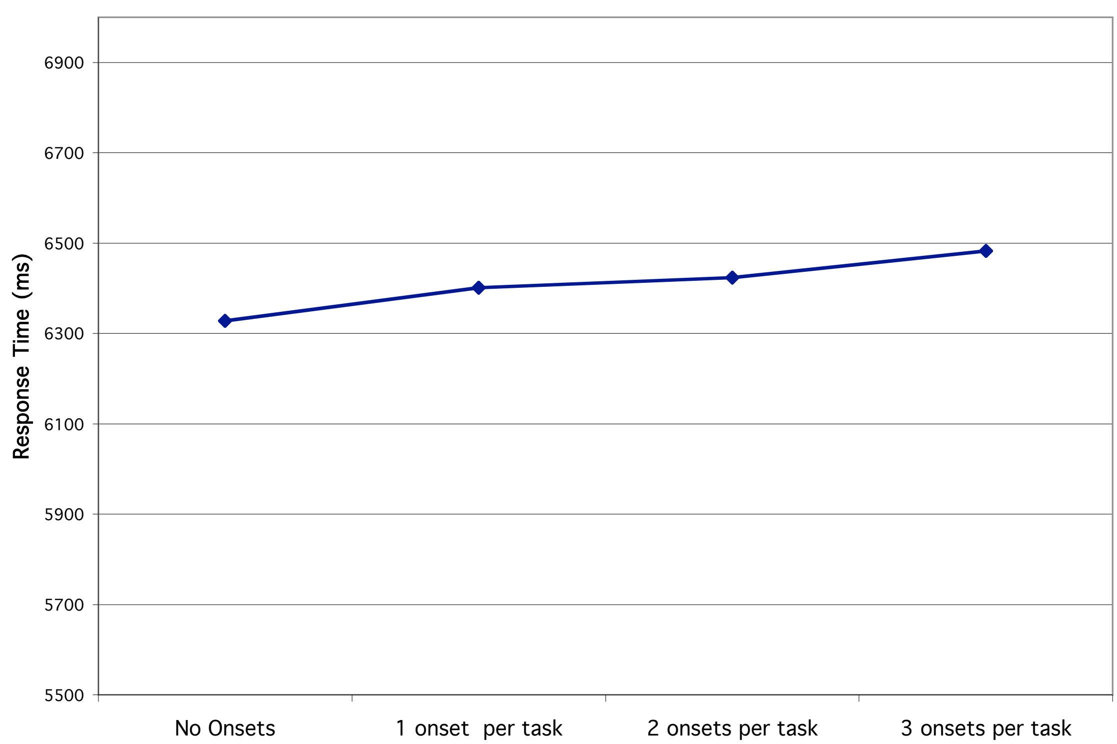

Figure 2: Experiment 1, total task response times, by number of onsets per task.

A main effect was also found across the four blocks of trials with response times decreasing over each block of experimental trials, means decreased from 6853 ms in block 1, to 6538 ms in block 2, 6165 ms in block 3 and 6062 ms in block 4, $F(3, 78) = 20.11$, $p < 0.001$. Such improved performance was expected as participants became more familiar and practiced on the task, especially due to the small number of practice trials. Letter onsets yielded longer response times, 6465 ms, than shape onsets, 6423 ms, though the effect did not reach the 0.05 level, $F(1, 26) = 4.20$, $p = 0.051$. In addition, there was an interaction between the type of figure and where the participant was in the task, within or between boxes, when it onset; see Figure 3 below.

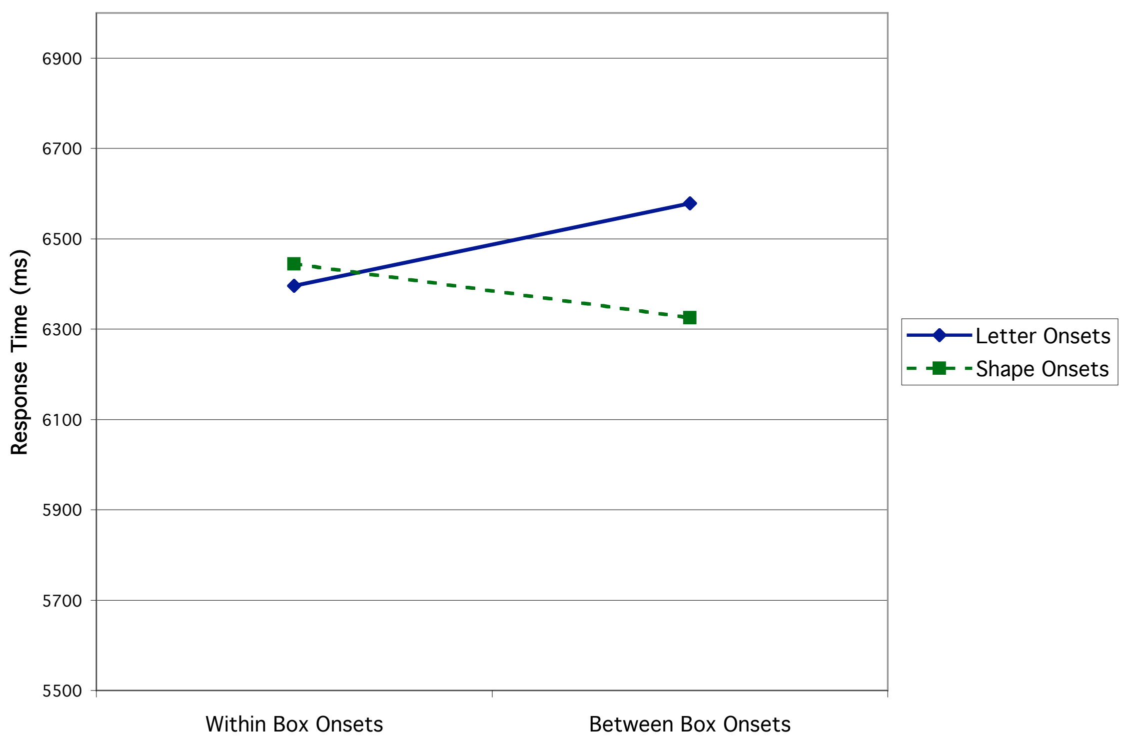

Figure 3: Experiment 1, total task response times by onset position and type.

Trials where the figures onset while the participant was typing within a box had a mean of 6419 ms. Trials where the figures onset while the participant was between boxes had a longer mean response time, 6451 ms, $F(1,26) = 12.4$, $p = 0.0018$. For comparison, trials containing no onsets yielded the fastest mean response time 6328 ms.

The trend of these mean response times suggests that participants were distracted by the appearance of figures which onset in either temporal position. However, figures which onset while the participants were transitioning between boxes may have had slightly greater attention capturing power. The nature of the task was such that participants were more likely to shift their attention from the top to bottom rows while they were between boxes. This made them more susceptible to distraction by removing their spatial attention from a given location, and scanning through the area in which the new figure onset. As predicted in Folk, et al. (2001), if onsets do capture attention then they will be involuntarily processed, in which case the letter or “foil” onsets would cause added interference and yield longer response times.

This interaction between when the onset occurred and the type of figure that appeared clarifies the lack of a main effect for onset position and also explains why the main effect for type of onsetting figure did not reach significance. The target-similar figures, characters, produced significantly different response times from target-dissimilar figures, shapes, only when they onset while the participant was transitioning between boxes.

Accuracy

Analysis of the accuracy data did not yield any significant main effects, though there was a general trend for less errors over the course of the experiment, $F(3, 78) = 1.64$, $p = 0.198$. Accuracy was above 90% throughout all types of trials. A general examination of the error data revealed that errors often came in pairs or longer strings. Since there were no main effects or clear interactions appears that onsetting figures did not decrease accuracy rates, but merely increased response times.

Within-Box Onset Keystroke Analysis

In order to gain a more thorough understanding of the time course of the stimulus-driven attention capture, further analysis was conducted to examine each dependent variable keystroke-by-keystroke. Due to the interplay between box position and position post-onset, separate analyses were conducted for distractors which onset while participants were within or between boxes. The within-box analysis consisted of a 2 x 4 x 4 x 6 ANOVA. The dependent variables examined were the type of figure (letter or shape), the position of the keystroke within a box (1, 2, 3 or 4), the block in which the trial took place (1-4), and the position of the keystroke post when the most recent prior onset took place (0, 1, 2, 3, 4 or 5.) This last variable was examined in an attempt to locate any delay that the onset had in capturing attention; i.e.. did keystrokes 1, 2, 3, 4 or 5 positions after the onset have the longest response time?

One main effect found to be significant in this analysis was the position of the keystroke within the box, with average response times for the first keystroke in each box taking about twice as long as keystrokes in the other 3 positions; first keystroke within a box M = 779 ms, second keystroke M = 341 ms, third keystroke M = 368, and fourth keystroke M = 332, $F(3, 36) = 10.69$, $p < 0.001$. This pattern shows that participants were pausing between each box of letters, presumably to shift their attention from one box to the next. Another main effect was found by the position of the keystroke following an onset, $F(5, 60) = 4.44$, $p = 0.0017$.

However, it is the significant interaction between these two effects, which takes into consideration both the position of the keystroke within a box, and how many places post an onset that keystroke fell, shown in Figure 4 below, that is the most instructive, $F(15, 180) = 8.5$, $p = 0.004$.

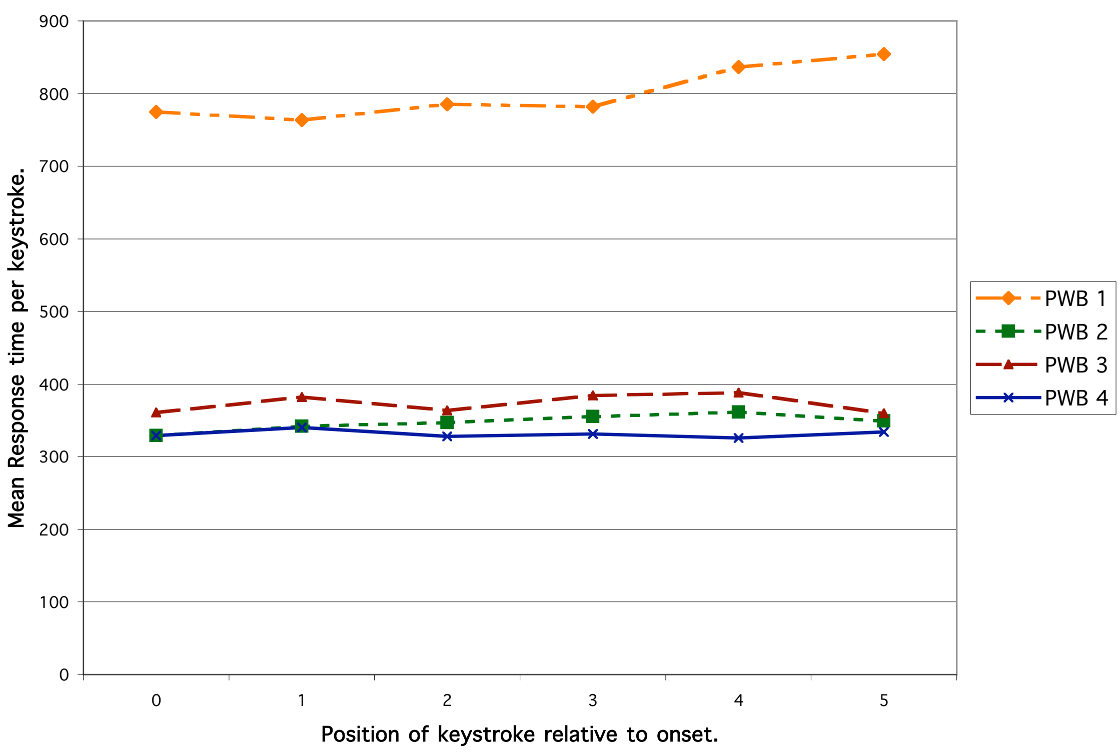

Figure 4: Experiment 1, within box onsets: keystroke response times by position of keystroke within the box (PWB) and position of keystroke following an onset.

Figure 4 shows the extreme difference in reaction times between the first keystroke in each box and the subsequent three. It also shows that the main effect for position of the keystroke relative to the onset is primarily being driven by the fourth and fifth positions post onset, only when these fell on the first keystroke in each box. One possibility is that the increased response times are due to the offset rather than the onset of the figure. Since the figure remained on the screen for 1000 ms it may have been offsetting around the fourth or fifth keystroke post onset. However, were this the case then greater time costs would be expected for the other three box positions. In order to eliminate this possible confound, experiments 2 and 3 utilized a gradual offset of the distractors.

Another interesting possibility is that the participants were treating each box as an individual sub-task, and were delaying examination of figures which onset while they were engaged in a sub-task. This notion that participants perceived each box as a sub-task within a trial is supported by the longer response times for the first keystroke in each box. The data may imply that participants notice a figure while typing in a box but do not examine it until after they finish the task, before moving on to the next box. Since the figures remained visible for such a relatively long time they were often present during the subsequent transition between boxes. A similar hypothesis was raised in Yantis & Jonides (1990). The data from this study support Yantis and Jonides' hypothesis that abrupt onsets may be noticed when attention is focused on another area, but may not be examined until after the participants' initial task has been completed.

Between-Box Onset Keystroke Analysis

For between-box onsets the position of a keystroke within a box, and the position of that keystroke post the most recent onset were always confounded. As such it is difficult to determine the percentage of response time differences that were due to each variable. Therefore, the important comparison is between keystrokes that either followed an onset, or did not. In order to compare onset type effects for between-box onsets, a 4 x 3 x 5 repeated measures ANOVA examined block (1-4), type of onset (shape, letter or none), and the position of a keystroke post onset / within box (1-5). A main effect was found for the type of onset, with letter onsets, M = 541 ms, yielding longer response times than shape onsets M = 518 ms, which in turn were longer than times for keystrokes not following an onset, M = 499 ms, $F(2, 52) = 11.84$, $p < 0.001$. It is important to note that type of onset produced an effect in the direction predicted by the contingent orienting hypothesis, with task-relevant letter onsets yielding longer response times. This is in contrast to within-box onsets that produced no significant differences for onset type. This finding further supports the idea that onsets that occur during transition between sub-tasks are being processed at a deeper level, causing letter onsets to produce greater interference costs. The position post-onset was also found to have an effect, with the trend for longer keystroke times for positions further away from the onset, as shown in Figure 5 below, $F(4, 104) = 74.28$, $p < 0.001$.

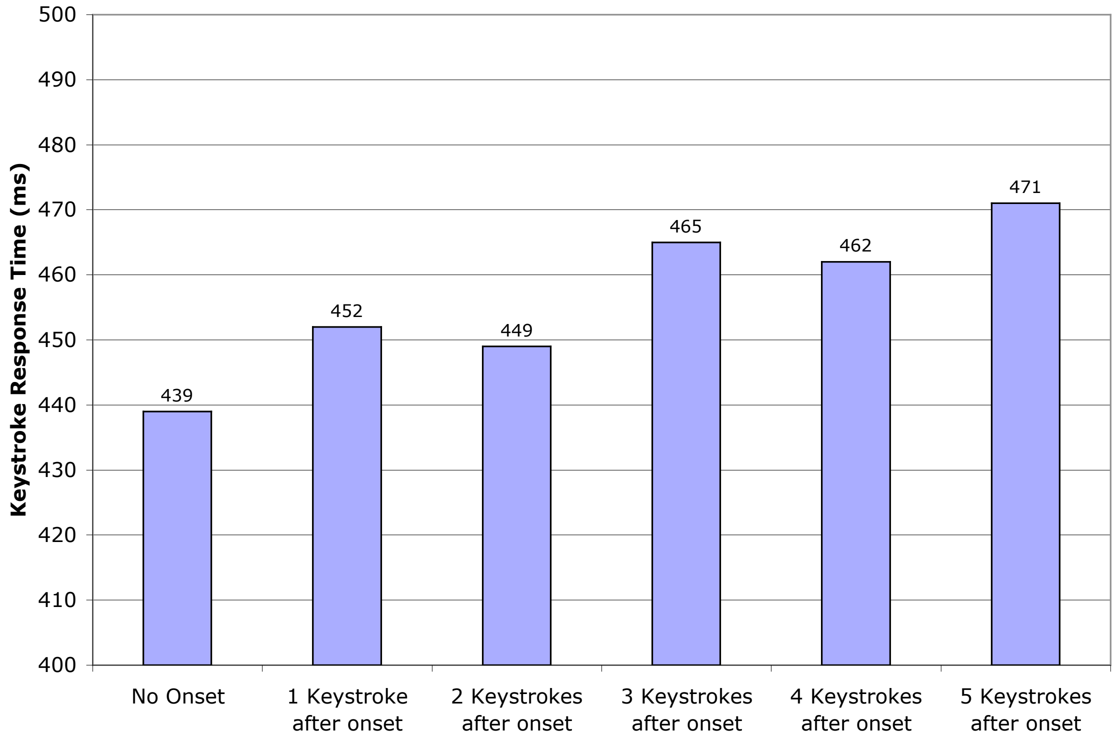

Figure 5: Experiment 1, keystroke response times by position of the keystroke post-onset.

A significant two-way interaction was also found for type by position $F(8, 208) = 3.33$, $p = 0.013$, showing a similar trend to the within-box onsets, in that the greatest variability between types occurred in the fifth position post onset, which is the first position in the next box, shown below in Figure 6.

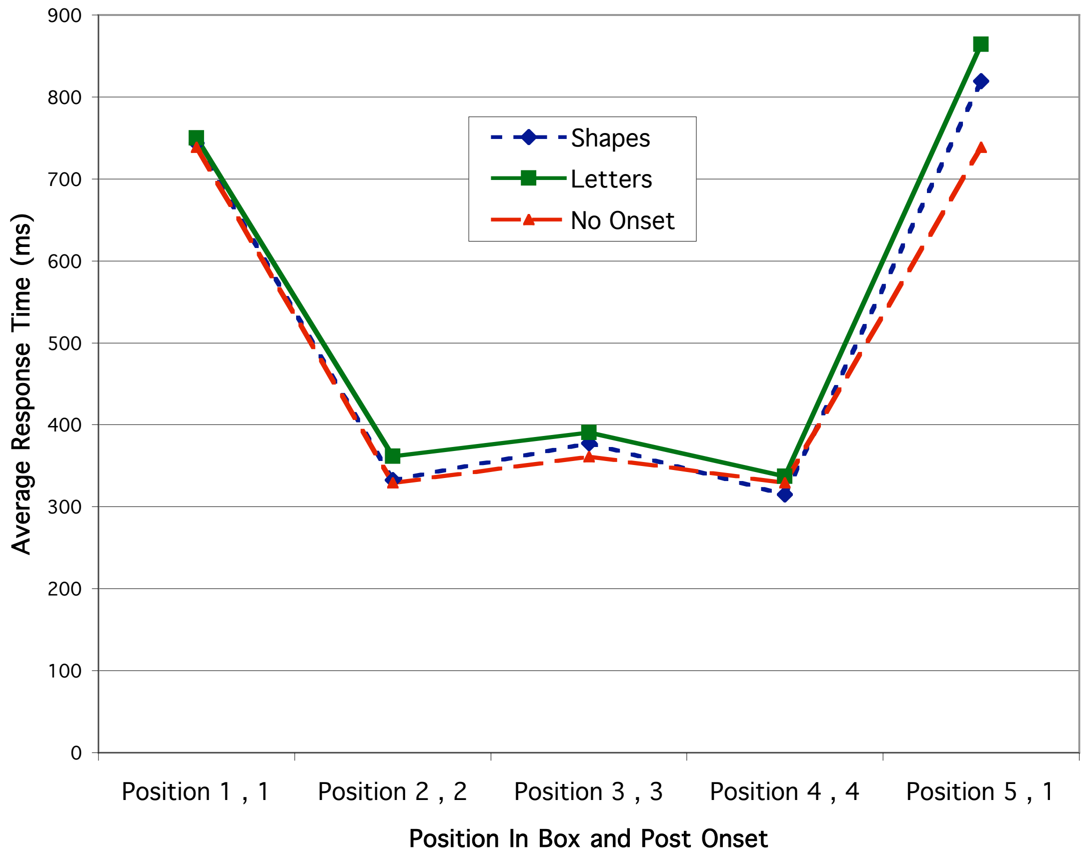

Figure 6: Experiment 1, Between box onsets, keystroke response times by type of onset and position of keystroke within a box / following an onset.

The greater times in the first position in the next box supports a delayed processing hypothesis. Because each box contained only four letters it is assumed that participants could hold all four in working memory, without having to stay fixated on the letters they were currently typing. The between-box onsets were designed to occur shortly after the participant had finished typing in a given box. However, while this was almost always before the participant began typing in the next box it is fair to assume that they would have often already completed a saccade to the new box. In this case the onset would fail to immediately capture attention, but would be attended to as the participant finished typing in that box and transitioned to the next.

The interaction between block and type, $F(6,156) = 3.16$, $p < 0.01$ is not clearly defined. It appears to be driven by the difference between no-onset keystrokes in earlier and later blocks for the first positions within each box. The trend is for a greater reduction in keystroke rates for these positions than the other three box positions, shown below in Figure 7.

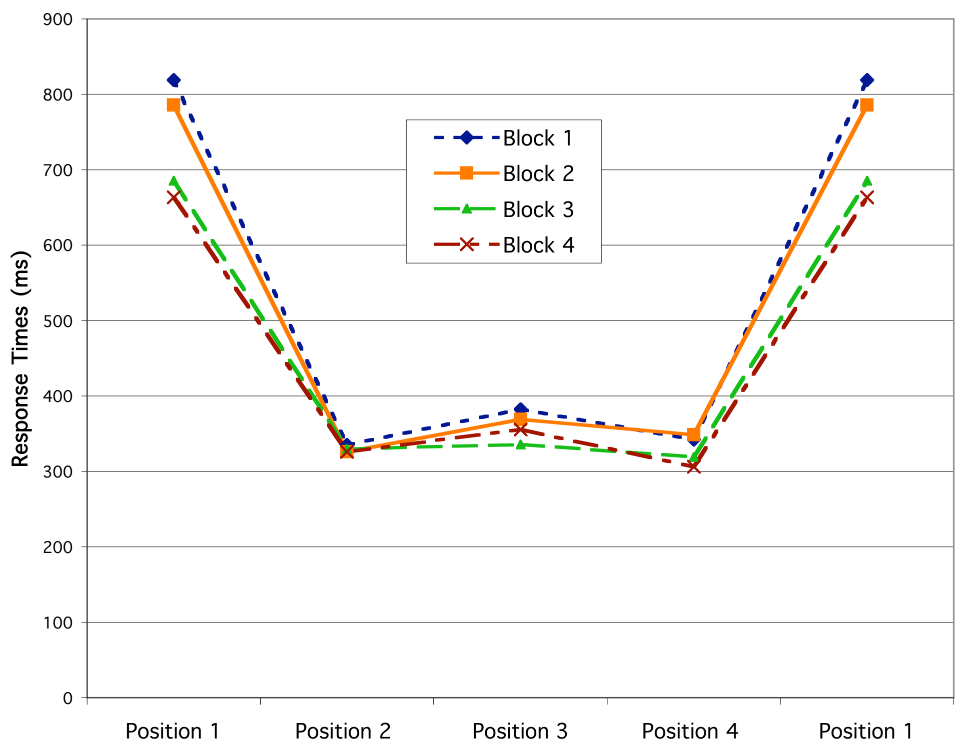

Figure 7: Experiment 1, Between box onsets, keystroke response times by block of trials and position of keystroke within a box / following an onset.

As participants became more practiced in the task they were able to reduce the time spent between boxes, or sub tasks. This transition time difference changes where in the task the participant would be focused when the onset occurred. For example, a quicker transition would make it more likely for a participant to be looking at the second or third letter in the next box when a between box onset occurred. This finding implied that the task strategy employed had an effect how onsets captured attention, and therefore that strategy differences should be examined in future experiments.

Experiment 2

Experiment 1 showed that the typing/transcription task could be a useful paradigm for examining onset-driven attention capture. The transition of attention between spatial locations had proved effective for allowing a window during which the onset of new perceptual figures captured attention, regardless of the participants' goal-directed intentions. Experiment 2 was designed to be as free as possible from instilling an attentional set for onset; in contrast to experiment 1, in which letters appeared abruptly in the bottom row of boxes as participants typed. Since participants were monitoring this row to chart their progress, the design of Experiment 1 likely generated a goal-directed attentional set for onset. In Experiment 2 the layout was altered so that one row of five boxes were positioned in a diagonal, or stair stepping, fashion across the screen. In order for participants to keep their place in the transcription task the letters in the boxes changed from black to red as they were typed; therefore attentional should be set for color change, not onset. If the onsetting figures are still able to capture attention it would be a fairly unique example of stimulus-driven capture overriding attentional set. Such a finding would highlight the unique nature of onsets that occur during transition between visual spatial locations.

Another alteration in Experiment 2 was in the presentation order of the letter onset, shape onset, and no onset trials. These trial types had been randomly interwoven in Experiment 1, and this may have contributed to the lack of finding a main effect on this variable. In Experiment 2 participants were presented with blocks of trials that contained either all shape onsets, all letter onsets, or a mixture of the types. Presentation order of these blocks was controlled for, necessitating a mixed between-within participants design. This design was also intended to allow for an examination of possible presentation order effects.

Method

Participants

Forty-five undergraduate students at Rice University, ranging in age from 18-21, participated in this study as a requirement for a psychology course. All reported normal or corrected to normal vision, and moderate (>20 words per minute) or better typing ability.

Apparatus and Stimuli

Apple iMac computers and Apple keyboards were used for display and participant input. On each trial the display consisted of a white background and five boxes presented diagonally, see Figure 8 below.

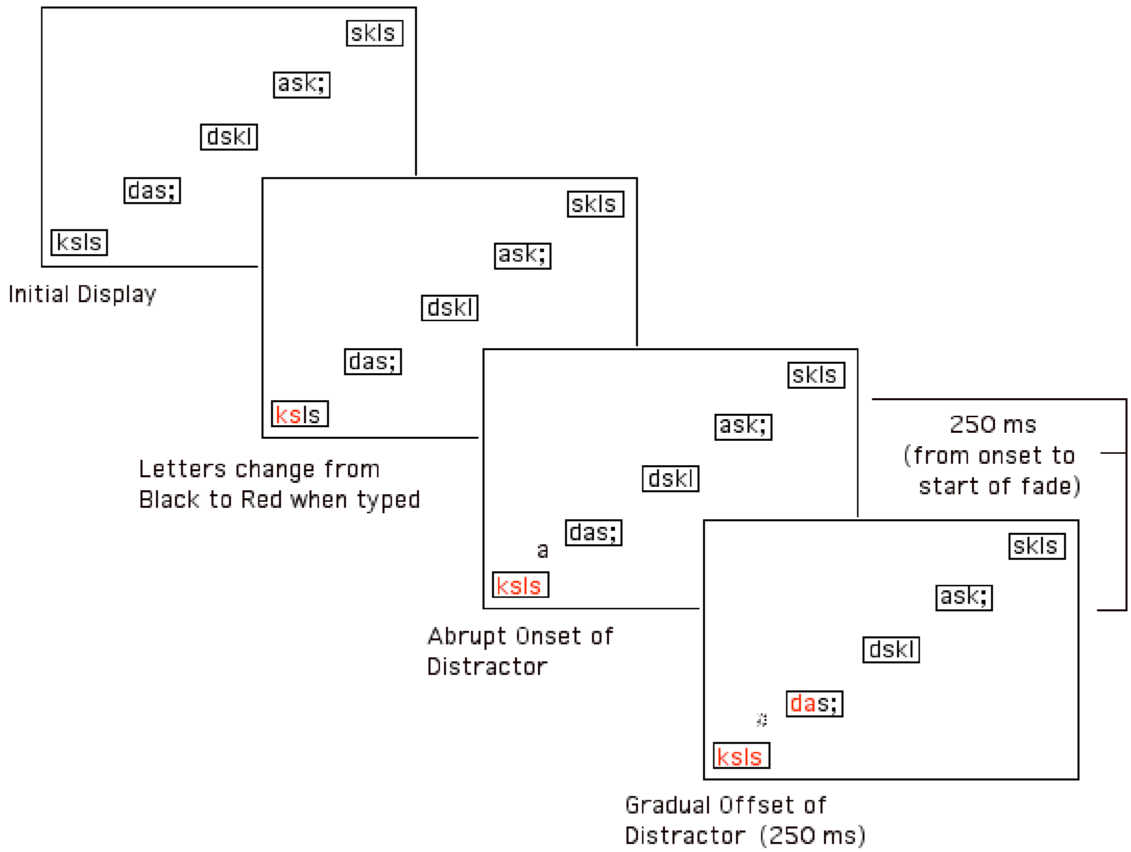

Figure 8: Experiment 2, display of a between box onset trial.

Each box had a 1 pixel wide black border, was 30 pixels high and 80 pixels long, and was separated from the adjacent box by 80 pixels of horizontal and 80 pixels of vertical space. There were 40 pixels of horizontal space and 65 pixels of vertical space between each edge of the screen and the outermost edge of the outermost boxes. At the beginning of each trial the boxes each contained four capital characters in Courier 20, a 20 pixel, black mono-spaced font. The characters were randomly selected from the home-key finger position: A, S, D, F, J, K, L, ;. The first letter in the lower and leftmost box was presented in red. As the participants typed, the next letter to be typed turned from black to red, allowing participants to monitor their position. As in Experiment 1 participants sat with their eyes positioned approximately 18 inches from the screen, meaning each inch of length on the screen was approximately 3.2 degrees of visual angle, or about 20 pixels per 1 degree of visual angle, with the width of the entire display encompassing 40 degrees.

During some of the transcription tasks, described in detail below, one or more figures abruptly onset in the space between the boxes. The figure was either one of two types. The first type, target similar, was a character selected from the home key characters, identical to those in the boxes. The second type of figure, target dissimilar, was a geometric shape (square, or circle) with a black border, and was 20 pixels in diameter. The position of these figures was randomly selected within the space between the box the participant was currently typing in and next box. Each figure was presented for 250 ms and then faded gradually from view over another 250 ms period, to control for possible offset effects.

Design

In each of three conditions the onsetting figures were all letters, all shapes or a mix of each type. To examine the effects of presentation order, and the possible attentional set differences created thereby, participants were assigned to one of six groups, each group receiving the conditions in different orders.

In addition to the presentation order of the letter, shape and mixed blocks there were three independent variables in the onset conditions. The first was the block in which the trial was completed, 1-5. The second was the temporal location of when the figure onset, either while the participant was typing within a box or was transitioning between boxes. The third variable was the type of figure, either a character or a shape.

To help ensure that participants were not able to predict the onsets, the number of figures appearing per trial was varied between 0 through 3. However, the 3rd onset was included only in the space after the last box, for which data was not recorded due to its position in the task. For within-box onsets the figure(s) appeared while the participant was typing within a box, that is, at a random delay between 10 and 400 ms after she entered the first keystroke in a box. For between-box onsets, the figure(s) appeared after a random delay between 10 and 200 ms after the last keystroke in a box. On any given trial the figures were consistently either characters or shapes, and appeared consistently while the participant was within or between boxes. Each block contained an equal amount of trials with 0, 1, 2 or 3 onsets.

Response times were recorded between each keystroke, as well as how long after the most recent onset each keystroke was executed. Errors were recorded as the number of characters in the participant's typing that did not match the corresponding character in the box.

Procedure

The participants were asked to type the characters, beginning in the lower left box, as quickly and accurately as possible. The participants were also instructed that they were not allowed to correct typing errors, and that anything appearing outside of the boxes would be of no use in the task and should be ignored. Participants completed twelve practice trials, containing no onsets, to familiarize them with the task. They then completed the three different conditions, each consisting of five blocks, of 18 trials each.

After a participant pressed the space bar to begin a trial, the display began with the leftmost letter of the leftmost lower box displayed in red, and all the other characters in black. When a participant typed a letter the next letter to be typed changed from black to red. Upon the participant's completion of typing the fourth letter in a given box the cursor automatically shifted to the next box up and to the right. Upon completion of the fifth box the on a trial, the screen changed to a rest screen, where participants were instructed to begin the next trial by pressing the space bar with their thumb, while keeping their fingers in home-key position. Between each block of trials participants were provided with information about the number of errors they had made. If their error rate was less than 0.05 they were presented with the message "Well done!" If their error rate was between 0.05 and 0.1 they saw "That's pretty good." If their error rate was between 0.1 and 0.2 they saw "That's a few errors. Please try to concentrate more on typing the right letters." If their error rate was greater than 0.2 they were prompted with "That's a lot of errors. You really need to concentrate more on typing the right letters." Participants were also encouraged to take a brief rest between each block of trials.

Results and Discussion

Missing Data

Two of the participants' data sets were removed due accuracy rates at a chance level, and seven were removed because they were incomplete, leaving 36 complete sets. Each data set was examined individually, and outlying data points that were more than 3 standard deviations from the participant's individual mean were replaced with the individual mean.

Subtask Completion Times

The completion times for each four-character box were analyzed with a 3 x 3 repeated-measures analysis of variance (ANOVA) with onset type (shape, letter or mixed) and position of the box relative to an onset (first post onset, second post onset, or no prior onset) as within-participants factors. The position of the box post onset was found to affect completion times with the first box following an onset showing the slowest times, M = 1975 ms, in comparison to M = 1906 ms for boxes that did not follow an onset, see Figure 9 below.

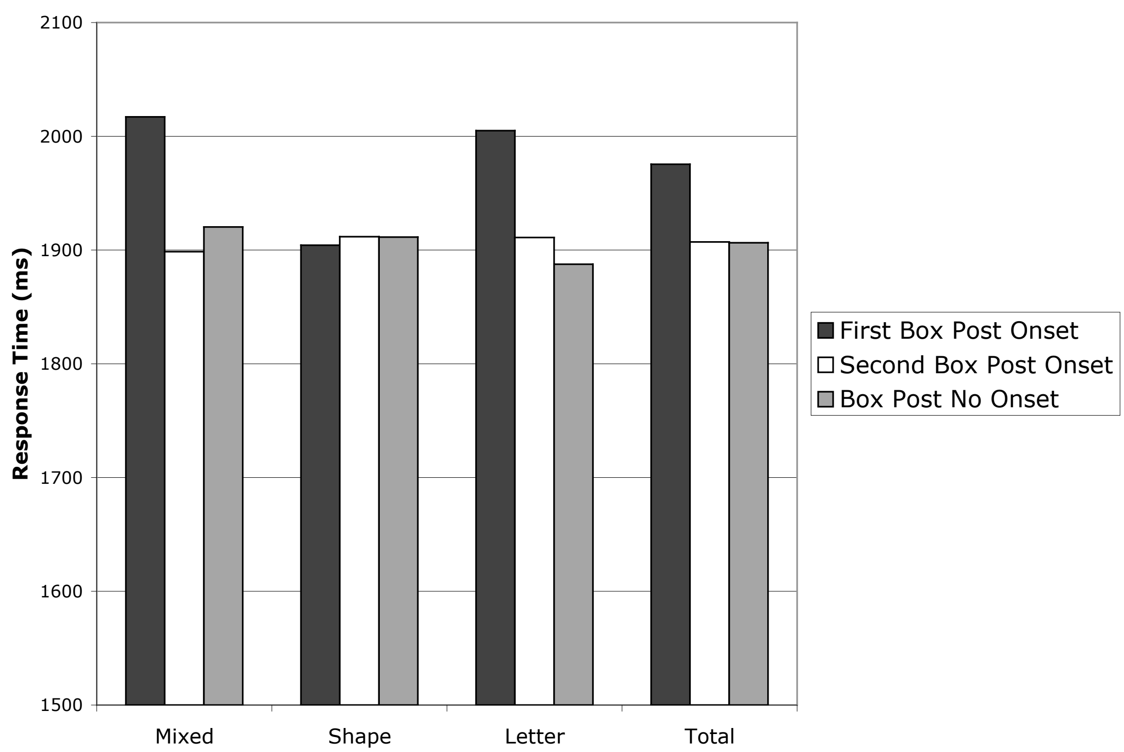

Figure 9: Experiment 2, between box onsets, box completion times by type of onset and position of box following an onset.

Difference scores were calculated for each box position, with boxes that did not follow onsets being used as reference. T-tests on these difference scores confirmed that boxes immediately following an onset were completed more slowly, $t(36) = 3.21$, $p = 0.0028$.

The AVOVA also revealed a significant interaction between box position post onset and the type of onset, $F(4, 144) = 4.75$, $p < 0.01$. This interaction stemmed from differences due to box position in all conditions except the shape-onset condition. T-tests confirmed that the mixed onset and letter onset conditions showed a significant difference between the first box post onset and boxes post no onset completion times, while the shape onset condition did not, mixed $t(36) = 3.17$, $p = 0.003$, letter $t(36) = 3.41$, $p = 0.0016$.

This finding, that the type of onset determined the level of distraction it induced, is very interesting when compared with the contingent orienting hypothesis of Folk, et al. (1992) The onsets were not beneficial, or relevant to the completion of the task in any of the onset conditions, and position within the task was indicated by color change. Therefore the contingent orienting hypothesis would predict that the participants' attention should be set only to monitor for color change, and that onsets would not capture attention. Since the onsets did not contain any goal relevant features they should not have captured attention. However, discriminating and holding the target letters in memory was crucial to the task, inducing a more complicated attentional focus. The fact that any effect was found implies that the criterion for attentional set in complicated tasks may need to be re-thought. The distinction between effects based on the similarity of the onsets and targets falls in the direction that would be predicted by the contingent orienting hypothesis, only if attentional set were expanded to task similar, and not only goal relevant features.

Keystroke Response Times

In order to better understand the time course of the distraction effects, we examined the individual keystroke times using a 6 x 3 x 5 x 4 x 8 ANOVA. This first analysis included onsets that occurred in both task positions; i.e., while the participant was within and between boxes. No main effect was found for the 6 presentation orders of onset type, or for the 3 types of onsets. As in Experiment 1, response times decreased significantly over the blocks of trials $F(4, 124) = 11.28$, $p < 0.001$. The box-position of the letter being typed also showed a similar pattern to Experiment 1, with the keystroke corresponding to the first letter in each box taking about twice as long as those for the other positions, first position within a box M = 781 ms, second position M = 343 ms, third position M = 369 ms, and fourth position M = 332, $F(3, 42) = 84.78$, $p < 0.001$. The position of the keystroke post the most recent onset, also yielded a significant effect, $F(7, 98) = 3.77$, $p < 0.001$. The effect of position post onset did not follow a linear pattern, rather, it was driven by the segmented task structure. This interaction between box position and position post onset was significant $F(21, 294) = 2.94$, $p < 0.001$.

Due to the complex nature of the design it was difficult to determine how the onsets were affecting the typing rates at each position of the task. This was especially true for onsets that occurred while a participant was within a given box, since this yielded 24 different combinations of box position and position post onset. To gain a clearer picture of the post-onset time course, a second ANOVA was therefore conducted with only the between-box onsets. This 6 x 3 x 5 x 8 ANOVA again showed no effect for the presentation order of the onset types, or for the type of onset. The main effects of block $F(4, 124) = 11.28$, $p < 0.001$, and position post onset, $F(7,217) = 138.88$, $p < 0.001$, were still significant.

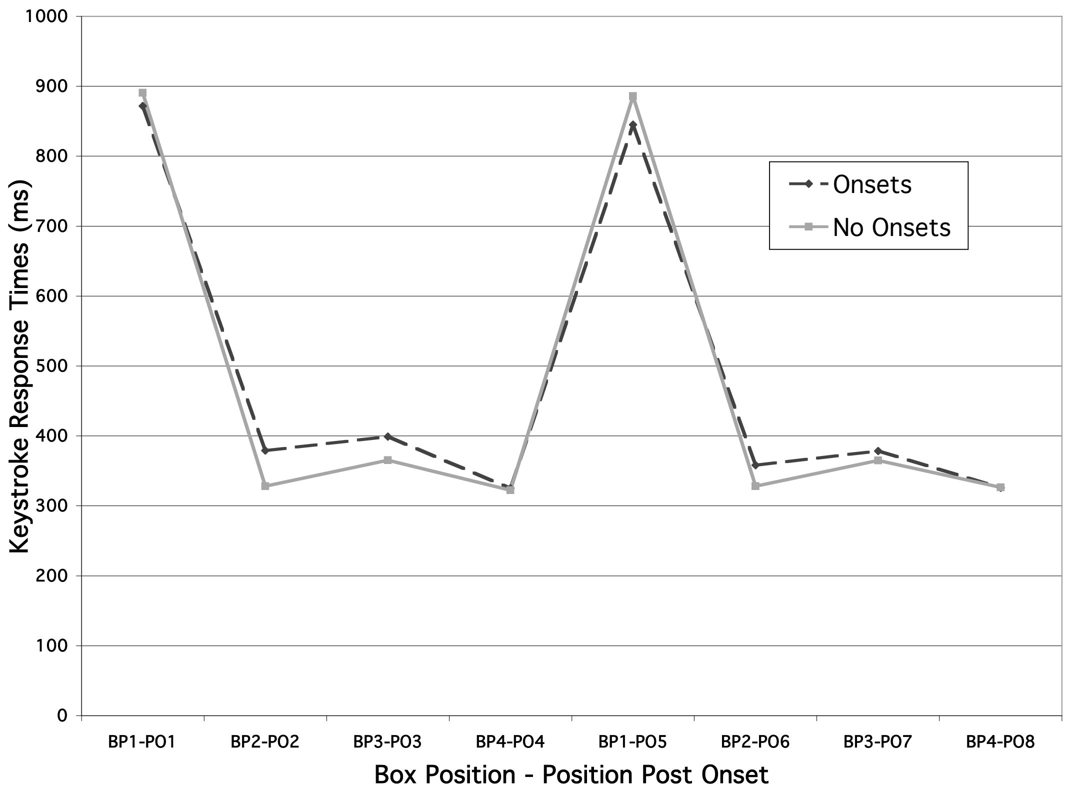

Figure 10: Experiment 2, response times for keystrokes following between box onsets, compared to keystrokes not following onsets, by box position.

As in Experiment 1 the most useful way to understand the data is to compare keystrokes from the same box positions that either followed or did not follow an onset; see Figure 10 above. This comparison was accomplished by conducting independent t-tests on the difference scores for keystrokes post onset or post no onset from each participant, at each position. These response time differences showed that the presence of onsets did affect typing rates. The greatest average difference occurred in the second position post onset, and was in the expected direction, with keystrokes after an onset taking longer, 44.6 ms, $t(36) = 3.9$, $p < 0.001$. It is also not surprising that no difference was found in the first position post onset, since the participants had likely already shifted attention to the next box when the distractor onset. The most surprising difference is the apparent facilitation effect at the fifth position post onset. At this first position in the next box of letters the keystrokes were quicker when a distractor had previously onset. As discussed earlier it is likely that participants were able to hold the four letters in each box in working memory, and move on to the subsequent box while still typing the letters in the last box. However, the color change, which marked their progress, was highly salient and the easiest strategy would be to simply follow along with the progression of letters turning red. Since the presence of an onset distracted participants from the typing task it is reasonable to assume that it may have also distracted them from following the color change progression. In this case they may have skipped ahead to the next box of letters, and allowed their typing, and the color change, to catch up. Therefore they would look at, and be ready to type, the first letter in the next box earlier than if they had followed along with their own typing rate. An important distinction is that this hypothesis does not require the onset to capture attention overtly, but merely to distract the participant enough to change his typing pattern, or alter his general task completion strategy.

Another possibility is that the presence of an onset changed the participant's immediate typing strategy. On a post experimental questionnaire participants answered unanimously that they noticed the onsets. Since the goal was to complete the task as quickly as possible participants may have attempted to compensate for any time cost that they felt the distracting onset imposed by speeding up their transition to the next box.

Overt or Covert Attention Capture

There are two ways in which the onsets may have captured attention; overtly, eliciting a saccade to the onset position, or covertly, not eliciting a saccade. An extra saccade associated with each onset would have produced time costs far greater than those found in the data. Therefore, if the onsets did elicit saccades they did so probabilistically, for example once in every 4^{th} or 5^{th} trial. This hypothesis is supported by recent eye-tracking data, such as Kramer, Cassavaugh, Irwin, Peterson and Hahn, (2001) which has shown that even when onset distractors capture attention, saccades are only made towards the onsets on less than half the trials. It is more likely that the onsets were only covertly capturing attention, by increasing the complexity of the visual scene. In this case participants would not make saccades to the distractors, and the time costs would be due to the effort of ignoring the new figure. The post-experimental questionnaire supported this notion, since participants unanimously answered that they noticed onsets, regardless of whether they believed that the onsets distracted them from the typing task.

Typing Pattern Differences

It was originally hypothesized that the typing abilities of the participants, as evidenced by their typing rates, would mediate the level of distraction that onsets induced during the typing task. This was found not to be the case; however during this examination of the typing rates, we noticed that the typing patterns of the participants tended to fall into one of two groups. The first group was quicker in transitioning between the boxes, but slower in typing the letters within the boxes. This pattern was dubbed the quick shift strategy. The other group took more time transitioning between the boxes, but was faster at typing the subsequent letters within each box. This pattern was dubbed the quick type strategy. To examine any effects that typing pattern differences may have yielded, a transition time ratio was calculated for each participant by dividing the average time spent between the last and first keystroke of each box by the average rate of the subsequent keystrokes. A median split was then used to divide the participants into either the quick shift or quick type groups. A t-test analysis comparing keystrokes either following an onset or not following an onset was then conducted for each of the two groups, see Table 1 below. Since there were two groups, and 8 positions post onset, a significance level of 0.003 (0.05 / 16) was used.

Table 1: Experiment 2, between box onsets, significance levels for difference scores between onset and no onset trials, by typing strategy group.

	Position Post - Onset							
	1	2	3	4	5	6	7	8
Quick Shift	0.093	0.001*	0.001*	0.469	0.001*	0.001*	0.233	0.587
Quick Type	0.786	**0.01**	**0.009**	0.124	**0.118**	0.001*	0.866	0.023

*$p < 0.003$. Bold values represent positions where there was a difference in the quick shift, but not in the quick type group.

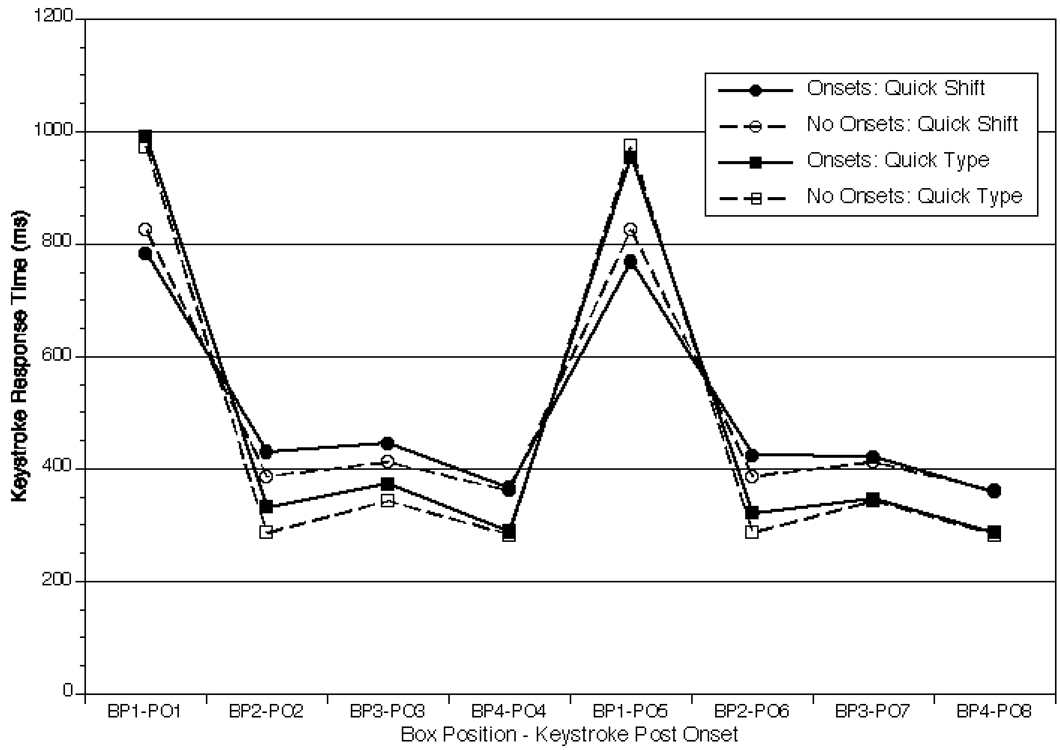

Figure 11: Experiment 2, response times for keystrokes following between box onsets, compared to keystrokes not following onsets, by box position and transition time ratio.

Differences between strategy groups were found at the second, third and fifth positions following an onset. In these cases the presence of an onset yielded a difference in the quick shift group, but not in the quick type group, see Figure 11 above. At the second and third positions the keystrokes following an onset were slower than those not following an onset. However, keystrokes at the fifth position after an onset, which is the first position in the next box, were faster than keystrokes not following an onset. Also, although neither group showed a significant difference between onset and no onset keystrokes at the first position, the difference was greater for the quick shift group. These findings suggest that the task completion strategy of the participant affected where in the task the onsets effected response times.

The overall trend is that the presence of onsets created less of an effect for the quick type group. However, there also seems to be a deferment of where the participants dealt with the onset. The greater transition time in the quick type group seems to have absorbed some of the effect of between box onsets for the first keystroke in each box, whereas, the quicker transition time in the quick shift group helped to shift the effect of the onsets to the second and third positions. This difference was likely driven by where in the task the participant was typing, compared to where their attention was focused when the onset occurred.

These differences are especially interesting because task completion strategies have rarely been examined in modulating the attention costs imposed by onsets. It is unlikely that participants were consciously adopting typing pattern strategies in order to defer the time costs from onsets, but nonetheless these results open up the question of whether such a conscious deferment is possible. If so, then the attentional set of a participant may not be determined solely by the task itself, but also by the strategy that the participant employs to complete the task. The results also suggest that while the effect of the onsets could be deferred, it could not be completely avoided. This hypothesis is ecologically logical in that automatically attending to new objects is usually important to survival, but it is also adaptive to delay processing of the onset in cases where attention is already dedicated to a given task.

Experiment 3

The results of Experiment 2 showed that differences in typing patterns could affect where in the task structure the onsets effected keystroke times. Experiment 3 was conducted as a replication of the between box onset conditions from Experiment 2. Without within box onsets we were able to effectively double the number of between box trials, in order to ensure that there was enough power to detect any differences in post onset keystroke times between the two typing strategy groups.

Method

Participants

Forty-three undergraduate students at Rice University, ranging in age from 18 to 21, participated in this study as a requirement for a psychology course. All reported normal or corrected to normal vision, and moderate (>20 words per minute) or better typing ability.

Apparatus Design and Procedure

The apparatus design and procedure for experiment 3 were the same as experiment 2, except that all onsets were between-box onsets. This design change yielded 180 trials, 45 of which contained no onsets, and the other 135 containing 1, 2 or 3 between box onsets.

Results and discussion

Missing Data

Data from one of the participants was excluded due to an accuracy rate at chance level, and two data sets were removed because they were incomplete, yielding 40 usable data sets. Each data set was examined individually, and outlying data points that were more than 3 standard deviations from the participant's individual mean were replaced with the individual mean.

Subtask Response Times

As in Experiment 2, the completion times for each four-character box were analyzed with a 4 x 3 ANOVA, with onset type (shape, letter, mixed shape, or mixed letter) and position of the box relative to an onset (first after an onset, second after an onset, or not following an onset) as within-participants factors. The position of the box following an onset was found to effect completion times, with the first box following an onset showing the slowest times, 2049 ms, in comparison to 2015 ms for boxes that did not follow and onset, $F(2, 78) = 9.24$, $p < 0.001$. see Figure 12 below. This trend was similar to the data in Experiment 2, with the exception that response times for the second box following an onset was consistently faster than those for boxes that did not follow onsets, which supports the notion that participants may have tried to compensate for the distraction from the onset by increasing their typing rate in the following box.

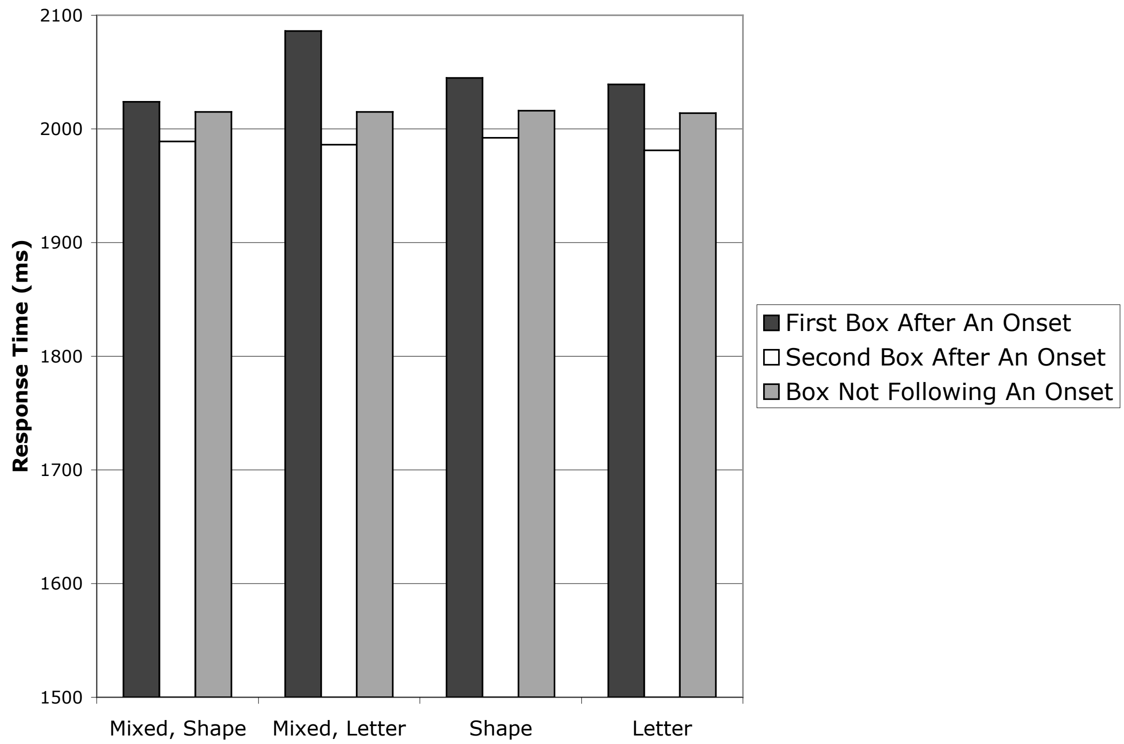

Figure 12: Experiment 3, box completion times for between box onsets by type of onset and position of box following an onset.

Overall the task completion times in Experiment 3 were greater than those in Experiment 2. Also, the differences between keystrokes following an onset or not, were smaller in Experiment 3. The only procedural difference between the experiments was the removal of within box onsets, which was not expected to raise typing rates. However, since the rates were greater for all conditions the longer times are most likely based on individual differences between the participants in the group.

Keystroke Response Times

A 6 x 5 x 3 x 8 x 2 ANOVA was conducted, comparing the 6 presentation orders of the onset types (shapes, letters and mixed). Also the 5 blocks of trials for each onset type, the 3 types of onsets, the 8 positions of keystrokes post onset, and the two groups based on transition time ratio. The typing strategy groups were calculated in the same manner as in Experiment 2. Response times again decreased over the blocks of trials, with block 1, M = 514 ms, block 2, M = 533 ms, block 3, M = 477 ms, block 4, M = 488 ms, and block 5, M = 497 ms, $F(4, 152) = 6.98$, $p < 0.001$. The position post an onset also showed a similar pattern to the between box onset results from experiment 2, $F(7, 266) = 207.19$, $p < 0.001$. Also significant were the interactions between position after an onset and typing strategy, $F(7,266) = 23.65$, $p < 0.0001$, and position after onset and block, $F(28,1064) = 1.85$, $p = 0.018$. To better examine the interaction between position after onset and typing strategy, we conducted a t-test comparison of keystrokes after an onset or with no prior onset, at each position, for each typing strategy group. These t-tests were based on the difference scores for each participant's post onset and post no onset keystrokes, at each position. And as in experiment 2 a significance level of 0.003 was employed, see Table 2 below.

Table 2: Experiment 3, significance levels for difference scores between onset and no onset trials, by typing strategy group.

	Position Post - Onset							
	1	2	3	4	5	6	7	8
Quick Shift	0.001*	0.001*	0.001*	0.002*	0.001*	0.001*	0.688	0.87
Quick Type	**0.99**	**0.13**	**0.06**	**0.2**	**0.65**	**0.3**	0.211	0.97

**p* , 0.003, bold values represent positions where there was a difference in the quick shift, but not the quick type group.

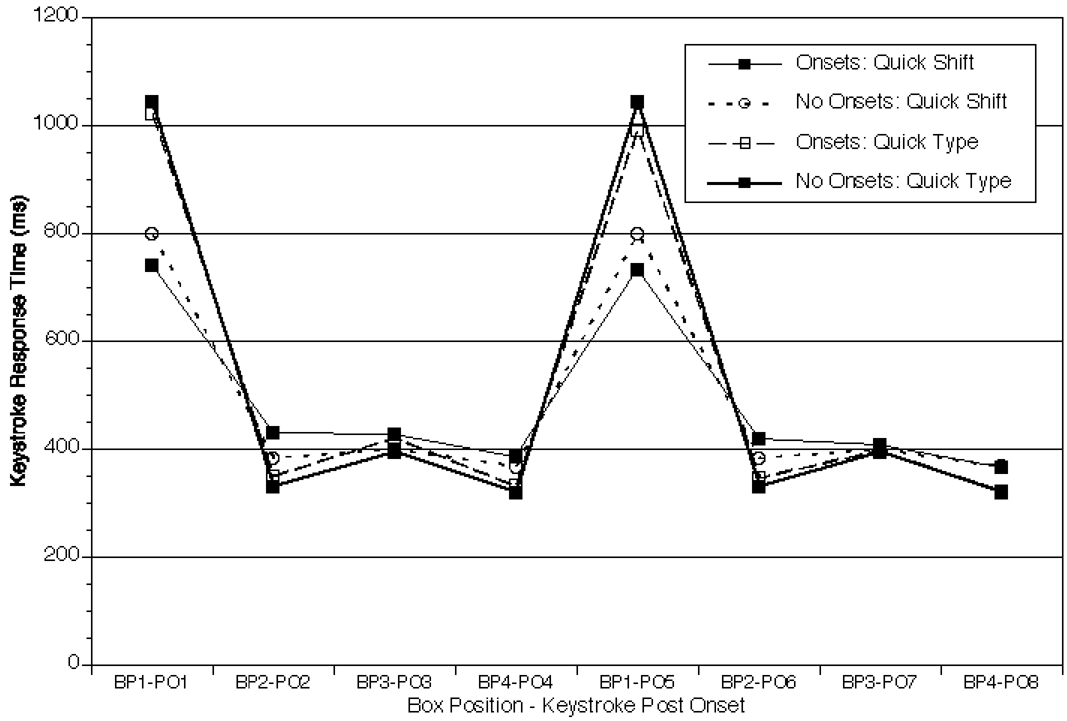

Figure 13: Experiment 3, response times for keystrokes following between box onsets, compared to keystrokes not following onsets, by box position and transition time ratio.

The differences present in Experiment 2, at the second, third and fifth positions, were also present in Experiment 3, see Figure 13 above. In addition differences were found at the, fourth and sixth positions. These differences were in the expected direction, with onset vs. no onset differences present for the quick shift group and not present for the quick type group. The direction of the differences for post onset or post no onset keystrokes were the same across the two typing strategy groups, but the differences were less reliable in the quick type group at nearly every position. This replication therefore supports the findings from Experiment 2 and clearly shows that the task completion strategy adopted by the participant determined the extent to which onsets effected keystroke response times.

Experiment 4

Experiments 2 and 3 revealed the relevance of position within task structure as a relevant factor in mediating the attention capturing power of onsets. Both of these experiments were also designed to examine if onsets could capture attention during shifts of visual attention, even when the onsets were irrelevant to completing the goals of the task, and did not share any features for which the participant's attention was set. Experiment 4 is designed to address the interaction between the phase of the task, and the features for which attention is set. Specifically it sets out to address the question of how the effectiveness of an attentional set in one phase of a task can be influenced by the attention set from the prior phase.

Experiment 4 again utilized distractors which onset while participants are transitioning between known visual locations. However, unlike in the prior experiments, the to-be-shifted-to location was not known prior to the presentation of a cue. The physical layout of the display is adapted from earlier experiments, such as Kramer, et al., (2001) in which six circles surround a central circle around an invisible ring, see Figure 14 below for an example.

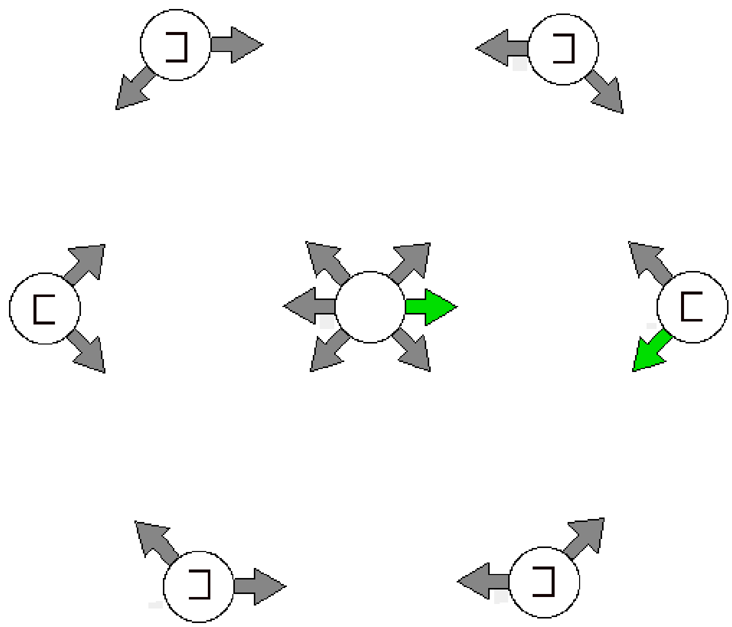

Figure 14: Experiment 4, phase 1 color, phase 2 color, no distractor condition.

In phase 1 of the task a central cue, either color change or onset of a directional arrow, directed the participant to shift their attention to one of the six outer circles. At the same time block figure 8 premasks within the outer circles changed to become forwards or backwards C’s. Participants completed phase 1 by responding with a keypress identifying the direction of the target C. Phase 2 of the task began upon the keypress response completing phase 1, and a new cue radiating from the outer target circle, again a directional arrow changing color or onsetting, directed the participant to again shift their attention to one of two neighboring outer circles. Phase 2 was completed when the participant responded with a keypress indicating the direction of the C in the new target circle. Distractors occurred within the first 50 ms of phase 2, and were either the color change, or onset of, a directional arrow on one of the non-target outer circles. In this sense the distractor was highly similar to the relevant task completion cue, and either shared or did not share features, color or onset, necessary for completion of phase 1.

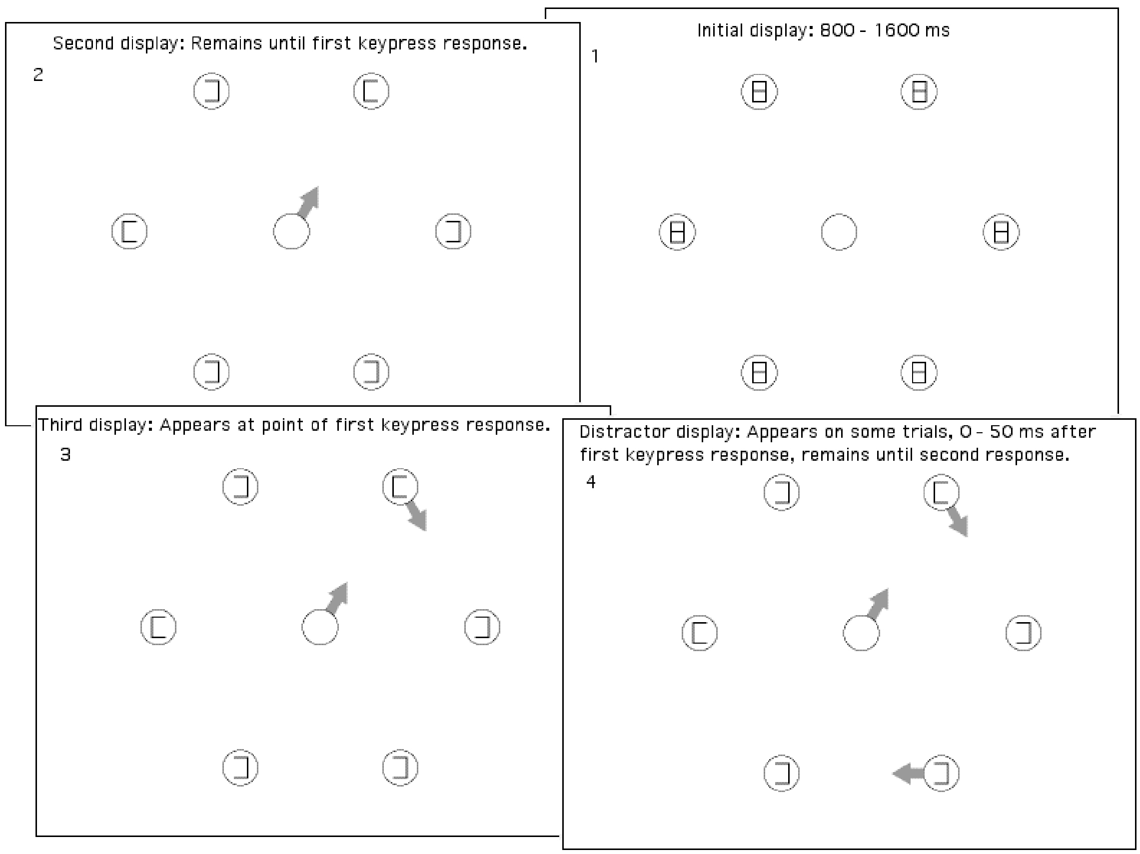

Figure 15: Experiment 4, example of a phase 1 onset cue, phase 2 onset cue trial with a distractor.

The contingent orienting hypothesis of Folk, et al. (1992) predicts that distractors sharing task relavant features will distract attention, however, it does not address the dynamic changing attentional sets that are required in a multi-phase task. In fact some of the results from Folk, et al. (1992) imply that participants may not be able to create a dynamic attentional set. The task they used manipulated the similarity of cue and target as well as the validity of the cue in predicting the location of the target. If attentional set is formed based on the goal of optimizing task performance, than participants in the valid color-cue (100% predictive of location), onset-target condition, should have been able to form an attentional set for both color and onset. However, rather than setting attention to the properties that would optimize task performance on the whole, participants' attention seemed to be set for optimizing only the target identification segment. This fact implies either that the participants were not highly motivated to optimize performance, or that the formation of such a complicated attentional set is difficult or impossible. Therefore, in addition to the relationship between cues and targets, attentional set may need to be examined in terms of task structure. For example, the task in Folk, Remington and Johnston, (1992) led participants to form an attentional set in the target discrimination segment of the task, mediating which features captured attention in the cueing segment. Also, this effect was different for color and onset cues. Experiment 4 was designed to further examine these characteristics of attentional set.

Method

Participants

Twenty-one undergraduate students at Rice University, ranging in age from 18 to 21, participated in this study as a requirement for a psychology course. All reported normal or corrected to normal vision, including color vision.

Apparatus and Stimuli

Apple eMac computers with 17 inch displays and Apple keyboards were used for display and participant input. Participants were seated with their eyes approximately 18 inches from the monitor. The display was set at 800 x 600, meaning each inch of length on the screen was approximately 3.2 degrees of visual angle, or about 18.5 pixels per 1 degree of visual angle, with the width of the entire display encompassing 43 degrees. Each trial screen consisted of a central circle 50 pixels in diameter, surrounded by 6 circles of the same size around an invisible circle 400 pixels in diameter. The outer circles were positioned at clock positions 1, 3, 5, 7, 9 and 11, and each contained a 20 x 10 pixel block figure 8 premask. In the phase 1 color condition the central circle was surrounded by 6 grey arrows, made up of a 20 x 10 pixel rectangle with an equilateral triangle on top, 20 pixels on each side. The arrows pointed to the six outer circles. In the phase one onset condition the central circle did not initially have any arrows around it. In the phase 2 color condition the outer circles all began with 2 grey arrows, which pointed towards the neighboring two outer circles. During half of the trials a distractor appeared as either a non-relevant grey arrow turning green, in the color condition, or abruptly appearing, in the onset condition.

Design and Procedure

The initial display remained static for a random duration between 800 – 1600 ms. In the phase 1 color condition one of the central arrows then abruptly changed from grey to green, and simultaneously all the premasks changed to forwards or backwards C 's. The central green arrow stayed green for the remainder of the task. To identify the direction of the C in the target circle the participant needed to shift her attention to the circle indicated by the arrow, and respond with a keypress of k for a forward C or j for a reverse C. The response time for phase 1 was measured from the moment the central arrow changed color to the participant's keypress response. In phase 1 of the onset condition a grey arrow abruptly onset from the central circle and pointed towards the outer target circle, the arrow remained for the duration of the trial. In the phase 2 color condition one of the two grey arrows on the target circle changed to green when the participant completed phase 1 with a keypress response. This arrow signaled the participant to shift her attention to one of the outer circles on either side of the target circle, discriminate the direction of the C in this new target circle and respond with another keypress. Response time for phase 2 was measured as the time between the two keypresses in the trial. In the phase 2 onset condition a grey arrow abruptly appeared from the target circle. On trials where distractors were present an arrow either appeared, onset condition, or changed color, color condition, on one of the non-target outer circles. The distractor occurred at a random time between 0 and 50 ms after the phase 1 keypress, and remained for the duration of the trial. The type of distractor was always the same as the cue modality of phase 2. Error rates were also recorded, as the number of incorrect target identification responses, in each phase.

Trials were blocked by phase 1 and phase 2 type. At the beginning of the first block participants were given 30 practice trials, to familiarize them with the task. For each subsequent block of trials participants were presented with brief written instructions, followed by 10 practice trials. Participants were also given feedback, in the form of 1, 2 or 3 beeps, to tell them if they had responded inaccurately to the first phase, second phase, or both responses. Each participant received all 4 combinations of phase 1 and phase 2 cue types, in a randomized order. Each block consisted of 96 trials, separated with a rest screen from which the participant began each trial by pressing the space bar.

Results and Discussion

Missing Data

Of the twenty-one participants in this experiment two data sets were unusable, one due to non-completion of the experiment and one due to an accuracy rate at chance level. Each data set was examined individually, and outlying data points that were more than 3 standard deviations from the participant's individual mean were replaced with the individual mean.

Response Time Data

The response times for each phase were analyzed in a 2 x 2 x 2 x 2 x 4 ANOVA. The independent variables were the phase of the task (1 or 2), the type of cue in phase 1 (color or onset), the type of cue in phase 2 (color or onset), the presence or absence of a distractor, and the block in which the trial took place (1 - 4).

Cue Type Effects

The phase 1 cue type was found to have an effect on response times, with onset cues, M = 938 ms, being responded to faster than color cues, M = 983 ms, $F(1, 18) = 8.08$, $p = 0.011$. Although the trend was in the same direction for phase 2 cue type, onset cues M = 915 ms, color cues M = 972 ms, the difference was not significant, $F(1, 18) =$

3.39, $p = 0.08$. The direction of this effect was expected, due to many prior experiments, for example Folk, et al. (1992), which found that onset cues could be responded to faster than color cues.

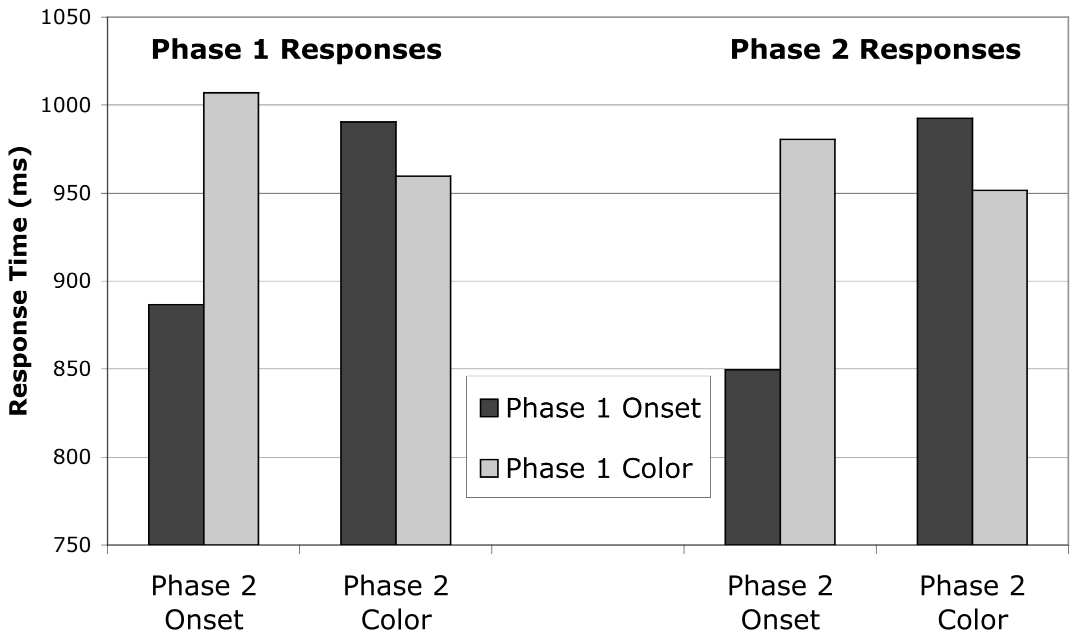

Figure 16: Response times for Experiment 4, by phase and cue type in each phase.

There was also a significant interaction between phase 1 and phase 2 cue types, shown in Figure 16 above, $F(1, 18) = 12.3$, $p < 0.001$. The quickest average response times came from blocks of trials where the cue types were the same in both phases, with the onset-onset condition yielding the fastest average responses, followed by the color-color condition. One of the main goals of experiment 4 was to examine the effects of shifting one's attentional set in order to minimize response times to different cue types. When the cue was the same type in both phases the participant could form a simpler attentional set, for only one feature, and faster response times were observed in matching cue trials. Also, it has been argued in this paper that the visual system is naturally set to detect onset, meaning the onset-onset condition required the simplest attentional set possible. It was therefore no surprise that the onset-onset condition yielded by far the fastest response times.

There was no main effect for phase, and both phases of the task, rather than just phase 2, showed faster response times for matching cue type trials, see Figure 16 above. This implies that participants were able to utilize the blocked nature of the trials to predict the upcoming cue type for each phase. However, participants only seemed to utilize the knowledge of the upcoming cue type when the cues were the same in each phase. This is clearly evidenced by the greater response times for both phases, when the cue types were different. It can be reasonably concluded that in these trials participants were unable to use the knowledge of the upcoming cue to the same degree as they did when the cues were the same. If they had been able to do so then we would expect phase 1 onset cues to produce similar response times regardless of which cue type followed in phase 2, or vice versa. In fact there were no differences between response times to onset cues or color cues when the cue types did not match in the two phases. This implies that participants were unable to create and or utilize a dynamic attentional set that shifted, in a known and reliable temporal pattern, between two singleton features. It also suggests that they did not adopt the strategy of attending more specifically for either onset or color in the mixed cue blocks, since this would have produced unequal response times in one of the two phases, which was not seen. This is strikingly similar to the results found in Folk, Remington and Johnston (1992), where participants were unable to utilize a 100% accurate color cue to reduce response times to an upcoming onset target.

Onsets have repeatedly been shown to have a unique place in visual attention, and experiment 4 provides another such example. It has been argued in Folk, Remington and Johnston (1993), that the human visual system may have an ecologically developed default for attending to onsets. As such, tuning one's attention solely to the appearance of a new figure may indeed be the simplest possible attentional setting. The addition of the need to rapidly shift from attending for onset to attending for color change mitigates the speed at which an onset cue can be responded to. This is an important fact to be taken into consideration by the designers of any system that uses cues to capture visual attention as rapidly as possible. The use of onset cues alone seems to allow for the fastest response times.

Distractor Effects

There was a main effect of distractor presence, with no distractor trials M = 918 ms, being faster than trials with a distractor, M = 986 ms, $F(1,18) = 81.4$, $p < 0.001$. However, since distractors occurred only in phase 2 there was no effect of distractor presence in phase 1 trials. This created an interaction between phase and distractor presence, $F(1, 18) = 63.6$, $p < 0.001$, which is shown in Figure 17 below. Therefore, the relevant effect is only in phase 2, where no distractor trials yielded response times of M = 880 ms, which were faster than distractor trials, M = 1006 ms. This fact, that distractors only affected phase 2 responses, also generated a complicated three-way interaction between distractor presence, phase 1 type, and phase 2 type, $F(1, 18) = 13.19$, $p = 0.002$.

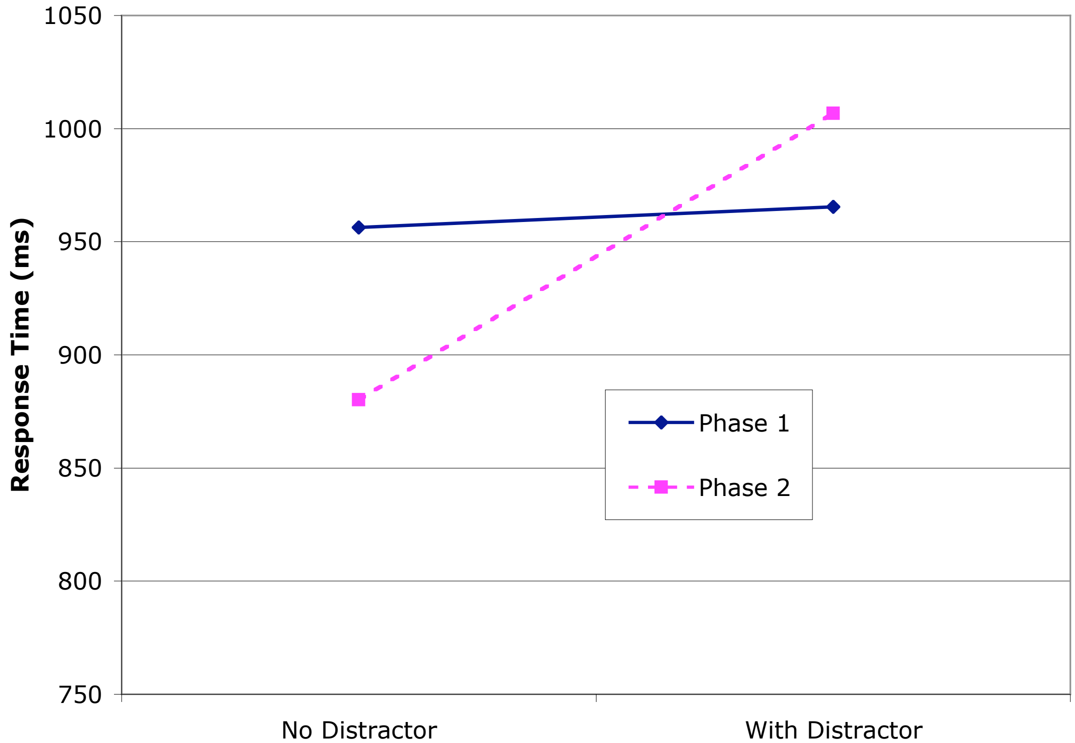

Figure 17: experiment 4, response times by phase and distractor presence.

Interestingly, there was no interaction between cue type and distractor, as seen in Figure 18 below. The presence of a distractor had a uniform effect across all cue type combinations. The distractors were always of the same type as the phase 2 cue type and therefore one might expect that the distractors would have a greater distracting power when the cue types were the same in both phases, and participants were able to form a strong attentional set for that given feature; as opposed to blocks of trials with different cue types in each phase, which called for a more dynamic, or complex, allotment of attention. Yet, for all 4 cue type combinations the distractor vs. no distractor differences were about the same, ranging from 107 ms to 152 ms.

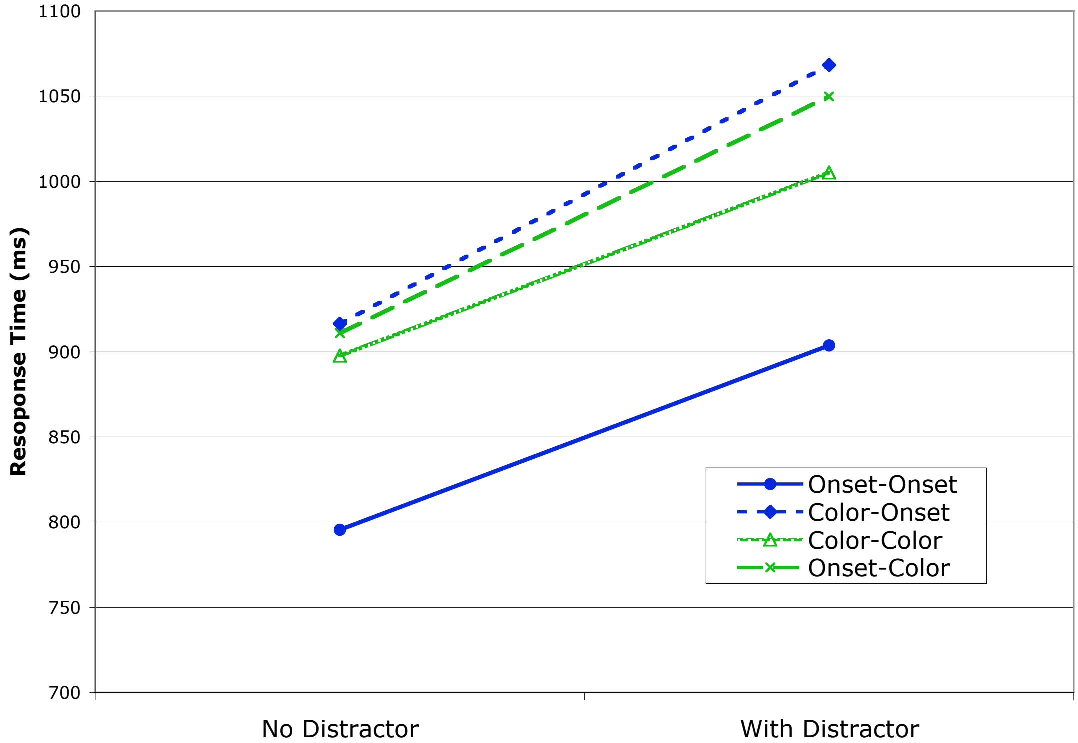

Figure 18: Experiment 4, phase 2 response times by distractor presence and cue type.

A main effect of response time by block was also found, $F(3,18) = 21.78$, $p <$ 0.001, with a linear trend of reduced response times with increased trials. This practice effect was similar to those found in the prior three experiments, and yielded no significant interactions with any of the other variables.

Accuracy

Another 2 x 2 x 2 x 4 ANOVA examining accuracy did not provide much more insight into the participant performance, and the only effect found was between distractor and no distractor trials, which translated to a difference in the relevant phase 2 trials of an accuracy rate M = 0.964 for trials without a distractor, and M = 0.929 for trials containing a distractor, $F(1,18) = 9.6$, $p = 0.0062$. The lower accuracy rate for distractor trials was in the expected direction, since any distraction from the task would be expected to yield a greater likelihood for participants to loose track of the target, and respond to the C in the circle cued by the distractor, and not the actual cue. Such a distraction was possible since both cue and distractor remained on the screen until a response was made. As with the response time data it is important to note that there was no interaction of accuracy rate effects between distractor presence and cue type. The presence of an onset distractor did not yield greater costs if it was in an onset-onset block rather than a color-onset block.

Conclusions

It is important to note that all four experiments called for the participants to shift their attention across the display, and it was during these shifts that onsets produced the greatest level of distraction. The findings are therefore potentially applicable to any task where participants have to shift attention between spatially distinct subtasks. Experiment 1 provided evidence that onsets can capture attention when participants are engaged in a typing task, and these results were in the direction expected based on the contingent orienting hypothesis. Among the most relevant findings were that the onsetting figures with goal-similar features did yield longer response times, and this effect was significant only when the figures onset while the participant was between boxes, while attention was not fixed on a specific location. This supports the notion that the attention capture was involuntary and the processing of the new perceptual figures was immediate.

Experiments 2 and 3 utilized a paradigm in which performance would be optimized with the formation of an attentional set for color change, with onset being completely irrelevant to task completion, and yet, onsetting distractors still produced time costs. The differences between the two typing strategy groups in experiments 2 and 3 show that the typing patterns adopted by the participant affected the degree to which onsets captured attention. This difference was most likely based on where in the task the participant's attention was focused when the onset occurred, and subsequently, how likely they were to be distracted from their typing pattern. Experiments 2 and 3 also showed that an onset could lead to shorter keystroke times at specific positions, while still producing time costs overall. This deferment of the costs associated with ignoring an onset raises interesting questions concerning our ability to choose a task completion strategy that would facilitate such a deferment. It also calls for a careful examination of different strategies which participants may employ in any task beyond the most basic stimulus response experiments, especially those examining the effects of onsets. The findings also suggest the need for a more complex definition of attentional set, based not only on the relationship between the features of the task and distractors, but also on the strategy of the participant, and how it affects their position within the greater task structure.

Experiment 4 successfully demonstrated some of the limitations participants have in forming dynamic attentional sets. The most striking evidence of this limitation is the difference between response times on trials with same or different cue types in each phase. Response times were over 100 ms faster for onset cues when onset was the cue in both phases, compared to trials which used onset cues in one phase and color cues in the other. Although a similar pattern was seen for color cues the effects were not large enough to be reliable. In both cases the participants had foreknowledge of the cue types that would be appearing in both phases, but when the type of the cue switched between phases they were unable to equal their performance on trials where the cue type remained the same in both phases.

One interesting lack of an effect in experiment 4 was that distractors did not yield greater costs in blocks of trials where the same cue type was used in each phase. For these trials the attentional set of the participant was more narrowly focused, on a given singleton feature, yet a distractor sharing that feature did not capture attention to a greater degree then in non-matching trials, where attentonal set was focused for two features. It therefore appears that an attentional set that is generalized for more properties does not allow for as rapid detection and redirection of spatial attention, as when only one property needs to be attended for. However, a broader set may nonetheless make the participant just as susceptible to distraction from an irrelevant object containing any of the properties for which they are attending.

Although participants in this experiment were unable to switch their attention effectively to prepare for a singleton of a given type, it remains to be seen if users can do so with further practice. Perhaps when the task has become so practiced that it is nearly automatic, it may be possible for participants to more rapidly shift from an attentional set for one property to that of another. A commercial aircraft pilot is one example of a profession that requires rapid shifts of visual attention, between controls that rely on different singleton features, color and line orientation for example. Comparing individuals in such professions may reveal if our attending capabilities can be improved with training.

Future research in this area should take these findings into consideration, especially when deciding which paradigm to use when examining the interplay between attentional set and stimulus driven attention capture. Future studies may also be able to determine the limitations in shifting between attentional sets, and the effects practice may have in overcoming these limitations. Many human-computer systems require users to monitor and make sense out of complex and dynamic visual scenes. From a human perspective we can improve such systems by determining how susceptible users are to distraction, and how we can help them to recover quickly.

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