# **RICE UNIVERSITY**

# Flying Under the Radar: Studying Inattentional Blindness in a Dynamic Task

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# ABSTRACT

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These three experiments examined noticing rates of an unexpected object (UO) that appeared during a dynamic aircraft threat evaluation task that required participants to shift their visual attention between multiple task-relevant locations. Experiment 1 manipulated the location at which the UO appeared; no effects on noticing rates were found. However, eye-tracking data revealed trends for UOs to be noticed more when participants were looking at locations closer to where the UO appeared, or when they were making more eye-movements while the UO was present. Eye-tracking data also showed a strong link between making an eye movement to the UO and noticing it. Experiment 2 manipulated the color, direction and speed of the UO to make it more or less similar to task-relevant objects. Also, to-be-ignored (TBI) aircraft were either present or absent for each participant. An interaction between the color of the UO and the presence of TBI aircraft was found with noticing rates being greater for uniquely-colored UO's only when no TBI aircraft were present. No overall effect of UO and target aircraft similarity was found. Experiment 3 manipulated the visual complexity and cognitive difficulty of the task. Noticing rates were higher only in the visually-simple, cognitivelyeasy, task pairing. These findings reveal the importance of participants' task strategies, attentional set and the interaction with task complexity unexplored by current theories of visual attention and prior findings from research on inattentional blindness. Also discussed are the implications for designers of human-machine systems.

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### **<u>1. Introduction</u>**

Whenever our eyes are open we process only a small percentage of the rich visual environment around us. The factor determining what information reaches our conscious mind is attention, "the glue that binds objects in space and time" (Treisman, 1988). When the appearance of a new object, or a change to an existing object, does reach a level of conscious awareness we say that the observer noticed the change. Noticing therefore implies that the observer can either report seeing the change, or that the change influenced the observer to alter her behavior or task strategy. Numerous studies of attention capture (Yantis & Jonides, 1990, Theeuwes, Kramer, Hahn & Irwin, 1998) have shown that new objects appearing in the visual scene are capable of eliciting shifts of attention. That is, we tend to give priority to the processing of new objects. However, many recent studies have determined that we also often fail to notice the appearance of new objects, especially if we are engaged in a task that places demands on our limited visual attention (Simons & Chabris, 1999, Newby & Rock, 1998). This phenomenon, commonly referred to as inattentional blindness, can be quite surprising to many observers, who assume that there is no way they would fail to notice the appearance of large, visually salient objects. However, the reality is that since attention is inherently limited, we fail to notice things all the time. There exists a constant balance between how we have set our attention and what objects in the environment will capture our attention. One of the most striking examples comes from an experiment involving experienced pilots simulating landing in a flight simulator with a heads-up display. Half of the pilots failed to notice another plane on the runway, and attempted to land their plane anyway, even though the obstructing plane took up as much as 45 degrees of visual angle (Haines,

1989). Given that we cannot attend to all objects all the time, it is important to know what factors determine which objects we notice and which we do not.

Because our visual environment almost always contains more information than we are aware of, we live in a constant balance between focused attention and openness to new stimuli. If we were distracted by the appearance of every new object we would be unable to read a book on the beach, or track a running animal. However, if our focused attention were undistractable we would be too absorbed in our book to notice an incoming tidal wave, or too focused on our prey to notice the presence of another predator tracking the same animal. Again, the relevant question is how we set our attention to balance these factors, and when will we fail to notice something that we would otherwise expect to see.

#### **1.1 Attention**

The term "attention" has been used in many different ways and is very difficult to define. A few useful metaphors for visual attention are those of a spotlight (Posner, 1978) or a filter (Broadbent, 1958). These metaphors describe certain properties of visual attention, namely that it can be focused on a given area in space, or set to highlight objects that posses a given feature. But, while attention can be set for both given locations and features, it requires the presence of a "thing" before it can be directed. If attention is not directed to a given "thing," then it is unlikely that "thing" will reach the level of conscious awareness. However, there is evidence that information outside of the focus of attention and below the level of conscious awareness can still be represented and processed (Simons & Levin, 1997). There is currently debate as to the degree that

unattended information present in the environment is processed subconsciously by the observer. For example, observers were capable of detecting the location of an object that changed orientation, without making an eye-movement to it (Fernandez-Duque & Thorton, 2000). However, in a Simon task, in which a cue and an unexpected object appear on the same or different sides of a screen, participants were unable to orient to the side of the screen opposite to the cue, even when they were instructed to do so. This finding supports the idea that an unattended stimuli can elicit a shift of attention but cannot engage response-selection levels of processing (Moore, Lleras, Grosjean & Marrara, 2004). It appears that a stimulus need not be noticed to act as a cue at the same location as an upcoming target, but it must be noticed to act as a cue indicating that the target will appear at a different location.

Some current models of visual attention are based on the idea that without the guiding force of attention the primary features of objects are "unbound" (Treisman, 1993, Wolfe & Bennett, 1997). This means that an observer may be aware of the general color, size, or shape of an unattended object, but they will not be able to process this object as a cohesive whole, e.g., to determine that it is an apple, without focusing attention to it. For example, Triesman's feature integration model postulates two stages of visual search. The first is called the pre-attentive stage, where attention is spread across the entire field, and detection is limited to basic visual features. The second is called the serial stage, where each object must be examined individually to detect more complex conjunctions of features. This is similar to Wolfe's guided search model, (Wolfe, 1994) which argues that the presence of the features being searched for leads to higher levels of activation on a cross-dimensional activation map. Attention is then directed to the item with the highest

level of activation. However, this item is not always the target because the transition of information between the parallel and serial stages is imperfect due to noise in the signal. This noise can help explain the variation of effects found between subjects and even laboratories, across different visual search experiments. Another similar model is Rensink's coherence theory (Rensink, 2000). This three-part model has a first stage very similar to those in Triesman's and Wolfe's models, where early processing is very lowlevel, fast, and carried out across the entire visual field. The structures resulting from this processing, which Rensink calls proto-objects, can be fairly complex, but have limited temporal and spatial coherence. In a dynamic display they are constantly in flux, and are replaced by the appearance of a new object at the same location. In the second stage, focused attention grabs several proto-objects, which while held represent a given object. Feedback at this second level provides continuity in objects across brief interruptions, and allows for the perception of change if a new object appears at the same location. In the third phase attention is removed from a given object; there is no longer any feedback and the field decays back into proto-objects. One interesting aspect of this final stage is that the decay can take up to 300 ms and may enable a detection of change without awareness. As such, it supports the idea that visual attention and visual short term memory are part of the same process (see also Wolfe, 1999).

Other models, such as those of Mack and Rock, are based on the idea that unattended objects are processed to a greater degree by unconscious processes, (Mack & Rock, 1998). Unlike those of Wolfe, Treisman and Rensink, this theory holds that features are bound together into cohesive objects at an unconscious level, yet only objects with high significance to the observer, either based on the task at hand or personal relevance, make it into conscious awareness. Therefore nothing is noticed by the observer unless it is relevant enough to have attention directed to it.

#### **1.2 Attention Capture**

Experiments examining automatic attention capture have typically taken one of two forms, either a search task or some form of attentional cuing. In the case of a search task, the observer is asked to locate a target object on the basis of one or more primary features that distinguish it from surrounding distractor items. For example, they would be asked to determine if a red T is present in a field of green T's and red L's. If the time it takes to detect the target increases with the number of distractor items then it is assumed that the search requires some level of serial processing, where each item must be individually examined before a judgment can be made whether it is the target or not. If the target is sufficiently distinct from the distractors, for example if it is the only red object in a field of green distractors, then search times are not affected by the number of distractors. In these cases the target is said to "pop out" (Triesman and Gelade, 1980). This implies that all of the items could be examined in parallel, and that the distinguishing feature or features of the target were able to "capture" attention. The limitation of such a paradigm is that observers have both prior knowledge of the features for which they were searching, and an expectation that the target object would be present on at least some of the trials. These endogenous, or top-down, factors effectively determine how the observer's attention was set, which in turn determines what captures attention. This is as opposed to observers having no prior expectations and an object capturing attention on its own, in a completely exogenous, or bottom-up, fashion. Most

theories hold that attention capture is almost always due to the combination of endogenous and exogenous cues. However, the level each type of cue plays has been widely debated. It has been argued that even basic top-down mental sets such as "I'm searching for something" can affect results as robust as pop-out (Mack & Rock, 1998).

In attentional cuing paradigms the target object is often the only object in the display, and it is preceded by a cue which either accurately or inaccurately predicts the target's location. If response times are faster when the cue accurately predicts the target's location than when it predicts a different location, it is assumed that the cue "captured" attention (Jonides, 1984; Posner, 1980). Two types of cue, either central or peripheral, have been found to produce varying effects of capture. Central cues appear at a distinct location from the target, and are symbolically representative of an upcoming location, for example a pointing arrow. Peripheral cues appear in the potential target's location, and therefore do not need to contain any additional meaning. Attention shifts to peripheral cues have been found to be faster and more difficult to inhibit. Because there is no need to interpret the symbolic meaning of a peripheral cue, shifts of attention to such cues are believed to be more automatic (Posner, 1980).

Findings from search and cuing tasks raised questions concerning the relevance that participants' expectations have in mediating the power of abrupt onsets, and targets possessing unique features, to capture attention. Folk, Remington and Johnston (1992) examined the effects that manipulating the attentional set of participants had on attention capture. They used a cueing 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

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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 as well. 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, nononset, 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 nonpredictive 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' attention was so focused for 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 an example of the uniqueness of onset above other stimulus properties in capturing attention.

This experiment raised important questions concerning 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 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

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circle turned to red. Theeuwes concluded that the onsets still captured attention, even when attentional set should be limited solely to color change. Therefore, stimulus 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.

Folk, Remington and Johnston (1993) provided a more detailed version of the contingent-orienting hypothesis. 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 search tasks used to examine attention capture 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 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 new objects plays some role in the observed effect. Even the type of response made has been found to be relevant to the debate, as shown by 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 appeared in one of four pre-set locations, and was be defined by either onset or color. As expected, distractors with the same properties 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.

To further examine the link between attention and eye movements 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 recorded using an eye tracker. The results showed that, so long as the new circle onset

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before the participant had completed their saccade to the target, the onset could disrupt 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.

#### **1.3 Processing without the focus of attention**

It has been clearly established that under many conditions the abrupt appearance of new perceptual objects will capture visual attention. However, there have been cases where the appearances of stimuli have affected judgments, behavior, and response times without participants being aware of them (Graves & Jones 1992; Kolb & Braun, 1995; Mack & Rock, 1998; Moore & Egeth, 1997; McCormick, 1997). Such cases, where stimuli can affect performance without reaching conscious awareness, can be referred to as implicit attention capture. This is different from cases where the stimuli did reach awareness, which can be called explicit attention capture. On a practical level the distinction between implicit and explicit attention capture is highly relevant. In many real world tasks it is important to know how greatly the appearance of a new object will slow down task performance, regardless of whether it is noticed. However, in other tasks the crucial question is not response time, but rather if the new object reaches a level of awareness that allows us to change our current task goal. For example, it is relevant to millions of web users if we are slower in completing a web search when animation or blinking lights are present. However, it is far less important if the brake lights of the car

in front of us slow down our response to a question asked by a passenger than if they compel us to hit the breaks.

## **1.4 Change Blindness**

Perhaps due to the balance between focused attention and stimulus-driven attention capture, people are often unaware of large visual changes until attention is drawn to them. This phenomenon, referred to as change blindness, has been shown in numerous experimental paradigms. Observers have been found to fail to notice changes in object color, location and identity (Levin & Simons, 1997; Rensink, O'Regan & Clark, 1997). These failures to detect changes have been shown when observers have been presented with: static images (Rensink, O'Regan & Clark, 2000), animation sequences (Wallis & Buelthoff, 2000) and even real world interactions (Levin & Simons 1998). One particularly interesting finding from this literature is that there is often a lag between when observers sense a change and when they are able to identify it (Rensink, 1998b).

#### **1.5 Inattentional Blindness**

As discussed in the review of the attention capture literature it has been difficult to separate the expectations of the observer and the capture of attention by new stimuli. The study of inattentional blindness attempts to remove such expectations by differentiating trials in which the observer truly had no expectation to see a new object (an incidental approach) from those where she had some suggestion a new object might appear (a divided attention approach) and those in which she was instructed to look for the new object (an intentional approach). One classic paradigm for studying inattentional blindness is that used by Mack and Rock (1998). The authors asked observers to judge which of two arms in a briefly presented cross was longer. On the fourth trial an unexpected object appeared and observers were asked if they saw anything other than the cross. In the next trial the unexpected object appeared again, but since observers had just been asked if they had seen anything on the previous trial they now had an expectation for the appearance of another object. Therefore this trial was referred to as a divided attention trial. On the following trial observers were instructed to look for the new object and ignore the cross, removing the divided attention task. The difference in self-reported rates of noticing the unexpected object in divided and undivided attention trials was calculated as the level of inattentional blindness (Mack & Rock, 1998).

Interestingly, in the unexpected object trials where the target cross was presented at fixation, and the unexpected object was presented away from fixation, 25% of observers failed to notice the unexpected object. However, when the cross was presented away from fixation and the unexpected object was presented at fixation 75% of observers failed to notice the unexpected object. This finding suggests that observers may actively inhibit processing at fixation when the target is presented elsewhere.

Mack and Rock also found that while unexpected objects possessing unique color, shape, or motion were no more likely to be noticed than a black square, observers did notice their own name or a smiley face more often than other unexpected objects, (Mack et. al., 2002). However, when their name was misspelled by even one letter, or when the face was frowning, this effect vanished. This finding is analogous to the classic cocktail party effect in the auditory domain. In this paradigm, while participants are attending to one stream of auditory information the listeners' own name, presented in an unattended stream, has a unique ability to elicit an attention shift (Moray, 1959). The fact that such an effect exists in the visual domain lends credence to models which contend a higher level of processing of unattended stimuli. For how else would a written name bearing meaning to the observer attract attention, over an almost identical misspelling, unless both were processed to the level necessary for comprehension? Only then would attention be drawn to the relevant name, while the misspelled name would fail to be noticed.

Since the uniqueness of the unexpected object has not been found to influence noticing, and personal relevance to the observer has, the most important factor determining the likelihood of an unexpected object being noticed may be the interaction between its features and the attentional set of the observer. In this sense inattentional blindness may be understood with a hypothesis similar to the contingent orienting hypothesis of Folk, et. al. This is illustrated in Most, et. al. (2001) where participants were asked to keep a mental count of how often certain moving objects "bounced" off the edges of a display. Recording self-report of noticing of the unexpected object, as well as requiring a description of it, the authors found that the more similar an unexpected object is to attended items, and dissimilar to unattended items, the more likely it is that people will notice it. When attending white objects and ignoring black objects: 99% of observers noticed a white unexpected object, 75% noticed a light grey unexpected object, 56% noticed a dark grey unexpected object, and only 6% noticed a black unexpected object. When attending black objects and ignoring white objects: 0% of observers noticed a white unexpected object, 12% noticed a light grey unexpected object, 44% noticed a dark grey unexpected object, and 94% noticed a black unexpected object. These findings clearly showed that the similarity of the unexpected object to the attended objects

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affected noticing rates. However, it was unclear how much of this effect was driven by selective ignoring of the distractor objects. In order to address this question a second study asked observers to attend grey objects, while ignoring either white or black distractors. When attending grey objects and ignoring white objects, 12% of observers noticed a white unexpected object, and 75% noticed a black unexpected object. When attending grey objects and ignoring black objects, 88% of observers noticed white unexpected object while 0% noticed a black unexpected object. Clearly the selective ignoring of objects of a given color greatly decreased noticing of unexpected objects sharing the to-be-ignored color. It seems likely that when predicting noticing rates dissimilarity to the distractor items is at least as important as similarity to the target items.

Attentional set is therefore crucial in understanding inattentional blindness. In this case the task dictated attentional set by determining the features which distinguished the to-be-attended items from the to-be-ignored items, i.e. observers set attention for luminance, ignoring other dimensions (shape, texture, color) to distinguish between attended and unattended items. These findings are therefore consistent with the contingent-orienting hypothesis of Folk et al., however, the hypothesis should also include contingent-ignoring when predicting noticing rates.

It is noteworthy that not all experiments studying inattentional blindness have been conducted using short, distinct, static trials. Other studies have demonstrated that salient objects can go unnoticed by a reliable percentage of observers watching continuous, dynamic, real-world scenes. A good example is Simons & Chabris (1999), where observers were asked to count basketball passes of one of two teams dressed in white or black. To help gauge the importance of task difficulty on the noticing of an

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unexpected event participants were assigned to either an easy task, where they kept one count for all passes, or a difficult task, where they kept two counts, one for bounce passes and one for aerial passes. While engaged in this task an unexpected object, in the form of a woman carrying an umbrella, or dressed in a gorilla suit, walked through the area where the basketball players were passing the balls. Observers focusing on the team wearing black were more likely to notice the dark colored gorilla suit; only 8% of those watching the team in white noticed the gorilla, while 46% of those watching the team in black noticed it. Also the observers with the easy task, which placed fewer demands on visual attention, were more likely to notice the unexpected object. The authors therefore concluded that "The likelihood of noticing an unexpected object depends on the similarity of that object to other objects in the display and on how difficult the primary monitoring task is" (Simons & Chabris, 1999).

In attention capture experiments, it has been shown that if a participant's attention is already focused on a specific location, as from a cue, that an onset outside of this location is unlikely to capture attention (Theeuwes, 1991b; Yantis and Jonides, 1990). An analogous finding was reported in an experiment examining inattentional blindness, where unexpected objects within an observer's area of focus were more likely to be noticed (Newby & Rock, 1998). However, when attention is distributed across the display failed attention capture cannot be attributed to spatially focused attention. One experiment that examined the special nature of location in predicting rates of inattentional blindness was Most, Simons, Scholl, & Chabris, (2000). In this experiment participants were asked to count the number of times target objects touched a line running across the screen. It was found that as the distance of an unexpected object from this task-relevant line increased rates of noticing it decreased. It should be noted that only 50% of observers noticed the unexpected object even when it was directly on the line.

As discussed, some experiments have explored aspects of inattentional blindness using distinct, segmented computerized trials. Yet others have shown continuous inattentional blindness using videos or even real-world scenes. However, there is still a need to explore the factors that influence inattentional blindness in dynamic continuous tasks, similar to those such as driving, where the failure to notice an unexpected object can become a serious safety concern. There is a need to study inattentional blindness "…. under more ecologically valid conditions, naturalistic complex scenes, as well as dynamic environments where observer or other objects are in motion" (Wallis & Buelthoff, 2000).

Many prior studies have utilized only self-report to determine if an unexpected object was noticed. However, there are grounds to believe that such reports do not tell the whole story. For example, even the phrasing of the question has been found to influence rates of noticing. In Fernandez-Duque & Thornton, (2000) observers were asked to detect a change in orientation of one object out of many non-moving objects. Participants who were given more conservative criterion for awareness, that is they were "sure" they had seen a change, reported seeing a change in only 29% of trials. Whereas participants who were given more liberal criterion for detecting a change, that is they "felt," or "thought" they had seen a change, reported seeing a change in 45% of trials. A subsequent forced-choice task, where participants were asked to select the location where they had seen a change, revealed further distinctions between the liberal and conservative criterion groups. In trials where participants said they were aware of a change 95% accurately chose the location of change in the conservative group, whereas only 85% of the liberal

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group chose the right location. Even in trials where participants reported being unaware of change they chose the correct location of the change above chance levels, 57% accuracy in the conservative group, and 55% accuracy in the liberal group, which was not a reliable difference. The measures used in the current experiments were designed to tell even more of the story, and give further insight into what level of processing the unexpected object is receiving when it is or is not consciously perceived.

### 2. General Methods

To examine inattentional blindness in a dynamic task where observers track objects in motion, I used the software suite Argus (Schoelles & Gray, 2001). The main task in Argus requires participants to monitor aircraft approaching their "ownship," and calculate the threat level of each aircraft as they cross through distinct visual areas. Aircraft that are closer to "ownship," traveling faster, and on a trajectory pointing towards "ownship" are classified with higher threat values.



Figure 1: Argus practice trial showing feedback after correctly rating a target aircraft.

The visual features of the target aircraft, as well as any distractors, can be altered to fit the desired parameters of each experimental design. Workload can also be manipulated by altering the number and speed of the target aircraft. The program also contains an optional ongoing side-task of keeping an aircraft icon within a tracking circle. The software records all mouse clicks and mouse movements for review, and can be linked to an eye tracker.

In earlier experiments on automatic attention capture (Fick, 2003) I found that it was relatively easy to generate a bias for detection of objects possessing task-relevant features, i.e., color change. However, it was also difficult to focus participants' attention to the degree that they were completely immune to distraction from objects sharing no task-relevant features. The Argus tasks were therefore of special interest because they could require participants to split their attention between two locations, and focus the participants' attention to features relevant to the task. In this way the Argus task is very similar to real-world situations such as driving, where drivers are simultaneously engaged in multiple tasks that require part of their attention, such as navigating and carrying on a conversation. As more attention is given to cognitively demanding tasks the drivers visual attention is likely to become even more narrowly focused on driving-related elements, meaning that drivers will be less aware of changes in the visual scene, especially those unrelated to driving. Such an effect was found in Richard, et. al. (2002) where a concurrent auditory task slowed participants' response times to detecting changes in a driving scene, especially changes to elements unrelated to driving elements, e.g. mailboxes.

### 2.1 Stimuli

The Argus screen is divided vertically into two sections. The left two-thirds of screen make up the radar-like target area with "ownship" at the bottom and target aircraft in the area above, which was segmented by four concentric ring segments. The right third of the screen contained the tracking task and a classification box that appeared when an aircraft was selected and contained information about the selected aircraft and the threat level choices. Only in the first practice trial an additional feedback box appeared after each classification, informing the participant if the classification was correct or incorrect. This same screen layout was used in all three experiments.

#### 2.2 Equipment

The experiment was displayed on Apple eMac computers running OS X, with responses being made with a standard single button mouse, and standard OWERTY keyboard. The software used was an adaptation of Schoelles & Gray's Argus software suite, programmed and run using Macintosch Common Lisp (MCL). The monitors used were 17 inches across diagonally, and were run at a display resolution of 800 x 600. Approximately 10% of the participants performed the same task while their eye movements were tracked using an ISCAN RK726/RK520 HighRes Pupil/CR tracker with a Polhemus FASTRACK head tracker. This system included a head-mounted video camera, and determined the point of gaze (POG), also known as point of regard, by shining an infrared light onto the eve and calculating a vector between the location of the pupil and the reflection of the part of the eye closest to the camera. This system produced POG reports that are accurate to within one-half degree of visual angle. While the participant was engaged in the task their POG was overlaid in real time on a separate monitor, showing the same screen that the participant saw. This overlay was recorded and transferred to digital video then analyzed. This equipment was used for each of the three experiments presented here.

### **<u>3. General Procedure</u>**

In each experiment the general procedure remained the same. Participants were given basic instructions for the Argus task and then run through a five-minute practice trial of the classification task only, during which they received feedback in the form of a thumbs up or thumbs down when they correctly or incorrectly rated the threat level of a target aircraft. They also were shown their classification score at the end of the trial.

Participants were then instructed that they would be practicing both the tracking and classification task, during which they no longer received direct feedback on the classification task. Following this second five-minute practice trial they were shown their scores for both the classification and the tracking task. Participants were then instructed to try their best on the next trial where their scores would be recorded. Near the end of the third trial an unexpected object appeared within the Argus task space and remained on the screen for 5 seconds, which usually allowed the unexpected object to be present while participants engaged in one or more shifts of attention. The trial then came to an end and participants were immediately questioned concerning the unexpected object. In a written questionnaire they were asked if they noticed anything different on the last trial: yes or no. They were then asked to briefly describe what they saw, and finally they were asked to make three forced-choice decisions concerning the object that appeared near the end of the trial. Because the appearance of a new object would no longer be unexpected after it occurred once and participants were questioned about it, there was only one critical trial for each participant.

### 4. Dependent Variables

#### 4.1 Questionnaire data

One dependent measure in these experiments was a self-report noticing measure; the participants were simply asked whether they had noticed a new object appear near the end of the last trial. Participants were then asked to describe the object and then asked to make three forced-choice selections. The first was to choose one of eight locations at which they believed they saw the object, the second was to select which of eight objects they believed they saw, and the third was to chose which of eight colors they believed the object to have been. From these questions the two other dependent measures were calculated. The first was a noticing "hit" rate, where a "hit" was scored as 1 and a miss was scored as 0. A participant was determined to have noticed the object, "hit," if they could correctly describe the object, or if they correctly answered two of the three forcedchoice questions. The other dependent measure was a forced-choice metric calculated by taking how many of the 3 forced-choice questions each participant answered correctly and dividing by 3. This measure was therefore the only measure that was not scored as only a 1 or a 0.

Data from the three forced-choice questions was also examined individually to provide a comparison to the basic self-report of noticing the object. Prior experiments have shown that the majority of participants who report seeing the unexpected object also successfully describe it; however, for those who reported not seeing the unexpected object the forced-choice questions allowed further insight into the level at which the unexpected object was processed without reaching awareness. The following figures show the three forced choice questions.



Figure 2: Forced choice, location of the unexpected object. "Please mark the area in which you believe the unexpected object appeared; if you are not certain please take your best guess."



Figure 3: Forced choice, shape of the unexpected object. "Please circle the shape of the object that appeared, if you are not certain please take your best guess."



Figure 4: Forced choice, color of the unexpected object. "Please circle the color of the object that appeared, if you are not certain please take your best guess." (The colors from left to right top to bottom are: red, purple, yellow, brown, aqua-blue, green, pink, blue.)

# 4.2 Response time data

In addition to the questions regarding the unexpected object, response time data was collected throughout the experimental trials. I initially intended to compare the amount of time taken to make an aircraft classification when the unexpected object was present with response times of classifications made when the unexpected object was not present. However, since participants were free to use any task completion strategy there was a great degree of variability between, and even within, classifications. For example participants often shifted to the tracking task in the middle of classifying an aircraft, or decided to select a different aircraft to compare the threat level. When the unexpected object appeared participants could be engaged in any stage of classification, tracking or somewhere in between. This variability made response time measures impractical.

#### 4.3 Performance score data

Classification and tracking task scores were recorded for each participant. Higher scores indicated more successful classifications and better tracking performance.

### 4.4 Eye-tracking data

To gain further insight into the relationship between noticing, attention capture and self report I collected eye-tracking data from approximately 10% of the participants. These participants completed the experimental trials while wearing a head mounted eyetracking camera. The only procedural difference for these participants was that they were asked to complete a brief calibration task before each of the three trials. I recorded point of gaze information in the form of a digital video movie for these participants. This video showed a small white cross over the real-time images seen by the participant. By playing back the experimental trial video I was able to see where the participant's point of gaze was when the unexpected object appeared.

The first dependent measure from the eye-tracking data was point of gaze location. This measure was determined by which task area the participants' point of gaze was located in when the unexpected object appeared. The four possible locations were: the radar screen, the information box, the tracking task or transitioning between two of these locations. The second measure was point of gaze distance. This was measured as the distance between the location of the unexpected object and the point of gaze of the participant at the moment the unexpected object appeared, measured in centimeters of screen distance. The third measure was the number of saccades a participant made while the unexpected object was present; a saccade was counted if an eye movement was made between two locations greater than one centimeter of screen distance apart and was not counted for small eye movements such as occurred when participants were engaged in the tracking task or reading in the information box. The final measure was whether or not a participant made a saccade to the location of the unexpected object, basically if they looked at the object, while it was present on the screen. A participant was determined to have looked at the object if their point of gaze fixated within one centimeter of the unexpected object for more than 200ms while the object was present.

#### 4.5 Initial piloting

I piloted this experiment with 14 participants. Initially the unexpected object was green, equaluminant to the blue of the targets and remained on the screen for 10 seconds. Also initially I did not use the concurrent tracking task. I observed noticing rates around 79% (11 of the 14 participants noticed the unexpected object). I judged this rate too high to allow a good range of noticing rates. I changed the unexpected object color to the blue of the target aircraft, reduced the time it remained on the screen to 5 seconds, and included the concurrent tracking task. I then piloted with 6 more participants and half of these individuals noticed the unexpected object. I therefore concluded that the unexpected object would yield an acceptable variance in noticing rates.

#### 5. Experiment 1

In Experiment 1 I assessed the effect of the location at which an unexpected object appeared by systematically manipulating that location within the Argus radar screen. Since objects in the areas closest to the arcs, and closest to "ownship," are the most important in the task, I compared noticing rates of the unexpected objects at different positions relative to these arcs and at different distances from "ownship." Task relevance has been found to be a crucial element in determining noticing rates and I expected to find a relationship between the location of the unexpected object and the rates of noticing the object. The finding of such a relationship would lend support to theories of attention such as those of Mack and Rock, since the object would be noticed more if its position made it relevant enough to the task to be deemed worthy of attentional resources. This is somewhat distinct from local activation levels in theories similar to Wolfe's, where the object would be noticed because its appearance led to a higher level of activation at its location.

The visual salience of an object has been shown to be a crucial factor in whether it will be noticed. Therefore one step necessary in this experiment was to equalize the visual salience of the target aircraft and the unexpected object. To do this I maintained as much similarity as possible between the singleton features of the unexpected object and the target aircraft across multiple dimensions. The unexpected object needed to be visually distinct from the target aircraft in order for it to be noticed as different and later described. However, the size, luminance and basic visual properties, such as number of crossing line segments, were the same as the target aircraft.

One of the most important purposes of Experiment 1 was to provide a range of noticing rates for the same unexpected object across different locations in the target area. If, for example, noticing rates were low across all locations it would suggest that the task might need to be altered, such as made less visually demanding, in order to find finegrained differences. On the other hand, if noticing rates were high across all locations it would suggest that the task might not be demanding enough of the participants attentional resources to generate inattentional blindness for the new objects.

There were two general predictions concerning noticing rates based on the location of the unexpected object. The first was that unexpected objects within an area of focus would be noticed more (Mack & Rock, 1998; Newby & Rock, 1998.) The second was that in this dynamic task unexpected objects would be no more likely to be noticed within the focus of attention (Simons & Chabris, 1999.) In the Argus task it is most important to classify aircraft before they reach "ownship." Therefore the area closest to "ownship" should receive the most focused attention. Also, every time an aircraft crosses an arc it needs to be reclassified, and likewise participants receive higher scores the more aircraft they classify. This makes it more important to classify aircraft that are about to cross an arc. However, after watching numerous participants complete the task it was determined that a different strategy was being employed near the end of the trial. Once participants had already classified all the aircraft they were waiting to reclassify aircraft that had just crossed an arc. At the end of the trial, when the unexpected object appeared, it was the area just below an arc that was likely to receive the most focused attention. Therefore if unexpected objects appearing just below an arc and closer to "ownship" were noticed more often it would support theories such as those proposed by Mack and Rock.

#### 5.1 Methods

#### 5.1.1 Participants

64 Rice University students took part in this experiment for partial course credit. All participants reported normal, or corrected, vision and were naïve as to the purpose of the study. 37 of the participants were female and 27 were male, they ranged in age from 18 to 22. Of these 64 participants16 were run with the eye-tracking equipment.

# 5.1.2 Design

Both independent variables in Experiment 1 were based on the location of the unexpected object. The first was the distance of the unexpected object from "ownship," close, midrange and far. The second was the position of the unexpected object relative to the arcs in the target area, either just above an arc or just below it. To examine possible position effects the unexpected object appeared in the right half of the radar screen on half of the trials, and in the left half of the radar screen on half of the trials. As such the unexpected object always appeared at one of twelve different locations. The design was therefore a 3 x 2 x 2, three general distances from "ownship," two positions relative to the closest arc, and two sides of the screen.

#### 5.1.3 Procedure

Participants were first presented with a brief oral description of what they would be asked to do during the experiment, omitting any reference to unexpected objects appearing. They then received written instructions describing the Argus task, see "Instructions for Experiment 1" in appendix A. Following reading these instructions participants completed two five-minute training trials, during the first of which they received positive or negative (thumbs up or thumbs down) feedback after they completed each aircraft classification. They were also permitted to ask questions after reading the instructions and after each practice trial. Finally, they completed the experimental trial, where they were informed that their classification and tracking scores would be recorded. Just before the end of the critical trial an unexpected object, similar to but distinct from the target aircraft, appeared at one of twelve different locations on the screen. Five seconds after the offset of the unexpected object the critical trial ended and participants were asked the series of questions described in the Dependent Variables section above. For participants in the eye-tracking condition the only procedural difference was a brief calibration of the eye tracker before each of the three trials.

#### 5.2 Results

#### 5.2.1 Excluded data

Data from three participants was unusable due to computer error, yielding a total of 61 data sets on which I conducted analysis.

#### 5.2.2 Unexpected object location

There was a large degree of variability on the questionnaire measures between the different locations. The overall mean rates for the noticing measures were around .35, self-report noticing rate (M = .33, SD = .47), noticing "hit" rate (M = .36, SD = .48), forced-choice metric (M = .40, SD = .39). Certain locations seemed to have lower or higher than average noticing rates but these locations did not seem to group by distance


Figure 5: Location of each numbered position where the unexpected object appeared. The lines represent the arcs on the radar screen, numbers 1-4 are in the closest distance from "ownship" with numbers 1 and 3 being below the arc.



Figure 6: Average rates of dependent measures by position of unexpected object.

		Noticing	Noticing "hit" rate		rt noticing	Forced ch	oice metric
Position	<u>n</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
1	7	.29	.41	.43	.52	.52	.34
2	5	.40	.55	.40	.55	.47	.51
3	5	.40	.55	.40	.55	.40	.28
4	5	.20	.45	.20	.45	.33	.41
5	5	.20	.45	.20	.45	.27	.44
6	7	.29	.49	.43	.45	.33	.33
7	5	.40	.55	.40	.53	.40	.43
8	5	.20	.44	.40	.55	.47	.38
9	5	.60	.55	.40	.55	.40	.55
10	6	.17	.41	.33	.55	.39	.39
11	5	.60	.55	.60	.52	.60	.55
12	5	.20	.44	.20	.48	.20	.30

Table 1: Average rates of dependent measures by position of unexpected object.

I initially conducted a between-subjects ANOVA to determine if objects which onset at any one of the twelve different locations were noticed to a greater degree; none of the measures approached a 0.05 alpha level of significance. Also, none of the dependent measures showed a difference between unexpected objects that appeared on the right or left side of the radar screen.

I then conducted a 2 X 3 between-subjects ANOVA for each of the dependent measures for the two positions that the object appeared relative to the closest arc (above or below) and the three distances that the unexpected object onset from ownship (near, mid, or far). Self-report noticing rates by position around arc, F(1, 63) = 1.82, p < .18, by distance, F(2, 63) = 0.37, p < .69 and the interaction between position and distance, F(2, 63) = 0.98, p < .38. None of the measures showed differences reliable at a 0.05 alpha

level based on the position of the object relative to the closest arc or the distance of the object from "ownship." However, a trend did appear for greater noticing rates for objects below the arc farthest from "ownship," shown below in Figure 7 are the average self-report noticing rate by distance and position around arc of the unexpected object.



Figure 7: Average self-report noticing rates by position of the unexpected object.

<u>Performance score data:</u> No reliable differences were found in either the classification or tracking scores based on the location at which the unexpected object appeared. This was as expected since the UO appeared so late in the experimental trial. Even if performance on either measure was influenced by the UO the overall score would not be greatly affected.

Self-report noticing	$\underline{No(n=43)}$	$\underline{\text{Yes}(n=21)}$	
Correct description	0	18	
Correct color	14	15	
Correct location	7	19	
Correct shape	3	19	

Table 2: Distribution of questionnaire measures by self-report noticing.

# 5.2.3 Eye-tracking results

Saccade to the unexpected object: Each noticing measure was examined in regard to whether the participant made a saccade to the location of the unexpected object. Simply put, if participants did not look at the object they were highly unlikely to "see" or notice it. Of the 6 participants who looked at the unexpected object 5 reported noticing it. This effect is shown below in Figure 8.



Figure 8: Noticing rates by if a saccade was made to unexpected object.

As can be seen in figure 8 noticing rates for participants who looked at the unexpected object were around 80% while noticing rates for participants who did not shift their point of gaze to the object were around 10%, though slightly higher for the forced choice metric. A chi-square revealed that this effect was reliable at a .05 alpha level for self-report noticing rate,  $x^2(1, N = 15) p = .011$ , and noticing "hit" rate,  $x^2(1, N = 15) p = .011$ . A one tailed t-test of the forced-choice metric by whether a saccade was made to unexpected object was also reliable, t(16) = 2.35, p = .016.

I also examined the data from participants who did not look at the unexpected object. Of these 10 participants one reported noticing the object but did not answer any questions about it correctly, five correctly selected the color of the object, one correctly selected just the object's shape, and one just the object's color. However one participant correctly selected the object's location and color and reported seeing a flash, but not thinking it was a new object.

Point of gaze location: I examined each dependent noticing measure based on the location in the Argus task space where the participant was looking when the unexpected object appeared. Of the four possible point of gaze locations in this analysis one participant was looking at the information box, seven were looking at the radar screen, five were looking at the tracking task, and three were making a saccade between two of these task spaces when the object appeared. Noticing rates were highest, nearly twice those of other locations, when participants were looking at the radar screen.



Figure 9: Noticing rates by point of gaze location at the onset of the unexpected object.

I examined noticing rates by where the participant was looking when the unexpected object appeared as the independent variable. Although neither the ANOVA results for the forced-choice measure, nor the chi-square results for the noticing "hit" rate, reached an alpha level of 0.05, the self-reported noticing measure approached significance,  $x^2(1, N = 15) p = .07$ . If participants were in fact more likely to notice the unexpected object when it appeared while they were looking at the radar screen it is likely due to three factors. First, the object appeared in the same region of the screen in which they were engaged. Second, their point of gaze was likely to have been closer to the location at which the unexpected object appeared. Third, they were more likely to be making a saccade within the radar screen, rather than a smooth pursuit focused eyemovement as in the tracking task.

<u>Point of gaze distance from unexpected object:</u> I examined the relationship between noticing rates and the distance between the unexpected object's location and the location of each participants' point of gaze when the object appeared. For all three measures the trend was for greater noticing rates when participants were looking at a location closer to the object when it appeared.



Figure 10: Forced choice metric rates and distance (cm) of Point of Gaze from Unexpected Object location at time of onset.

I conducted a logistic regression for both the self-report noticing measure, p = .11and the noticing "hit" rate, p = .36, neither revealed a relationship reliable at the .05 alpha level. Nor did a linear regression of the forced-choice metric with the distance of point of gaze from the objects location as the dependent measure,  $r^2 = 0.058$ , F(1,15) = .86, p =0.37. Though not reliable, the trend in this data is for the unexpected object to be noticed more when the participant was looking somewhere closer to where it appeared.

<u>Number of saccades:</u> I examined the relationship between noticing rates and the number of saccades a participant made while the unexpected object was present. Of the 16-eye tracked participants 4 made no saccades while the unexpected object was present, none of whom noticed the UO. All 4 of these participants were looking at the tracking

task when the unexpected object appeared and they remained engaged in smooth pursuit eye movements at that location until after the unexpected object disappeared. Participants who made more saccades while the unexpected object was present were more likely to notice the object as shown below in Figure 11.



Figure 11: Number of saccades made while unexpected object is present and forced choice metric rate.

I conducted a linear regression, examining the relationship between the number of saccades made and the forced-choice metric. The trend was an increased noticing rate with an increased number of saccades,  $r^2 = 0.23$ , F(1,15) = 4.27, p = 0.058. Logistic regressions for the self-report noticing measure, p = .096, and the noticing "hit" rate, p = .096, revealed weaker relationships.

#### 5.3 Discussion

The eye-tracking data from Experiment 1 showed higher noticing rates of the unexpected object (UO) when participants made a saccade to the UO. This finding in itself was not particularly surprising, since all major theories of visual attention posit that objects to which focused visual attention is shifted are more likely to be encoded into memory. However, this data supports the strong link between visual attention capture and eye movements. If the onset of the unexpected object captured visual attention it was likely to be followed by an eye movement to that location. Theories such as those of Most, et al. claim that people will not necessarily become aware of an object just because they looked directly at it, however I found a strong link between noticing of and looking at the object. This finding is relevant to the entire concept of inattentional blindness as a failure to notice objects which have been looked at. Rather it suggests inattentional blindness is primarily driven by the failure of an object to capture attention and elicit an eye movement to its location.

Most participants who did not make a saccade to the unexpected object did not recall seeing it. However, the fact that even a few participants could recall features of the UO without shifting their point of gaze to it may be evidence for implicit attention capture where attention is not explicitly drawn to the location of the new object but certain features of the object are still encoded. This supports models of visual attention such as those of Wolfe, Treisman and Rensink where low level pre-attentive processes encode features such as color and location of objects across the entire visual field and higher-level processes make determinations as to which features are relevant enough to elicit shifts in visual attention, and subsequent eye movements. The eye-tracking data also hinted that participants were less likely to notice the UO when they were looking at a location farther away from the location where the new object onset. This is consistent with prior studies of inattentional blindness (Most, et al., 2000), where participants were less likely to notice a new object if it appeared further away from the focus of their visual attention. However, point of gaze distance is not likely to be the only factor influencing the noticing rates of the unexpected object. Since the UO always appeared in the radar screen the furthest points from this location often fell in the information box. When participants were looking in this box they were likely reading or making a threat level classification, and were therefore engaged in a specific task which in itself may have made them less likely to notice the UO. The data therefore also support theories such as those of Mack and Rock (1998), where unexpected objects appearing outside of the area of focus are less likely to be noticed.

Prior studies (Theeuwes, Kramer, Hahn & Irving, 1998) have suggested that our visual attention, and eye movements, are more likely to be drawn to a new object if it onsets during a saccade. This increased susceptibility to onsets eliciting explicit attention capture during saccades may be the factor driving the effect of increased noticing rates with increased saccades. It is possible that in a state of scanning around the Argus task space participants were more likely to detect and encode features of the unexpected object then if they were focused on one or only a few locations while the object was on screen. When visual attention was focused on a given location it not only made the UO less likely to explicitly capture attention, it also limited scanning of the visual field at large, reducing the ability of the pre-attentive visual system to encode information about both the UO and all other objects on the screen.

At the beginning of each trial participants seemed to be following the originally expected pattern, classifying aircraft closest to "ownship" first. However as each trial progressed this pattern shifted because all or most of the aircraft had been classified. Therefore participants were waiting for aircraft to pass over and arc in order to reclassify it. This made aircraft directly below an arc the most likely to draw attention and elicit an eye movement and subsequent mouse click allowing it to be classified. The higher noticing rates for UOs just below the farthest arc may have been due to this pattern of allocation of visual attention. However, upon closer examination, 2 of the 21 participants who reported seeing a new object did not correctly answer any of the three forced choice questions about it making their forced choice metric and noticing "hit" score zero. Both of these two participants were in the condition in which the unexpected object onset just below the farthest arc. This finding showed a possible limitation to the self-reported noticing measure and supported the continued use of the other measures.

Since UOs were noticed to the same degree across all locations it seems most likely that participants were allocating their attentional resources in a distributed manner, at least across the radar screen segment of the Argus task space. This finding gave me adequate cause to believe that I could keep the location of the object constant when examining other effects in future experiments. Experiment 1 also showed that the particular set-up of the Argus task, including the specific UO, was providing a good range of noticing rates for other effects to be found.

# 6. Experiment 2

The degree to which the early stages of visual processing encode the features of a visual scene is of prime concern to different theories of visual attention. When engaged in any task, certain features will be relevant to the task, while other features will be irrelevant. Our attentional system is able to give priority to items possessing the relevant features, yet objects possessing no relevant features sometimes still elicit focused attention and are often still perceived or encoded into memory to some degree. Within the Argus task the target aircraft all share the same color and shape, yet they vary in the direction and rate of their movement. To examine which features of the unexpected object affect noticing, feature encoding, and eye movements I manipulated the similarity between the target aircraft and the unexpected object on multiple dimensions. These dimensions included speed, direction and color, but size and luminance, which determine basic visual salience, were kept constant. This control is important since both visual salience and the similarity between the unexpected object and the targets have been found to influence noticing rates. I also included the presence of to-be-ignored "friendly" aircraft for half of the participants. These aircraft were a distinct color and shape from both the target aircraft and the unexpected object. This manipulation was designed to examine how noticing rates were influenced by the complexity of the attentional set needed to complete the task.

Of the unexpected object conditions in this experiment, the UO was maximally similar with the target aircraft when the object was moving at an average speed in a direction directly towards "ownship," and was the same color as the target aircraft. One condition was maximally dissimilar to the target aircraft. That is, when the UO was moving at a fast speed, in a direction directly away from "ownship" and was a different color than the target aircraft. In all the other conditions the unexpected object had a mix of similar and dissimilar features to the target aircraft.

There were two possible predictions concerning noticing rates of the unexpected objects in this experiment. The first was that maximally similar UOs would be noticed to a greater degree, since they share so many task-relevant features for which the participant's attention should be set. This prediction is therefore supported by both the contingent-orienting hypothesis, and by theories such as those proposed by Mack and Rock, in which only objects with task-relevant features would be deemed worthy of eliciting an attentional shift.

The other possibility is that the maximally dissimilar UO's would be noticed to a greater degree, since they are visually distinct from the target aircraft, and therefore more visually salient in the local environment. This finding would yield support to bottom-up or stimulus-driven models of attention capture, such as those proposed by Theeuwes (1994). This finding would differ from the findings reported in Most, et. al. (2001) and Mack and Rock (1998) where unexpected objects with distinct color and motion were no more likely to be noticed then simple black shapes.

The presence or absence of to-be-ignored aircraft dictated the complexity of the attentional set participants adopted to perform the classification task. When no to-be-ignored aircraft were present participants needed to attend to all objects in the display, regardless of the objects' shape or color, since all the target aircraft shared the same shape and color. This relatively simplistic display may have allowed participants to devote less attentional resources to the classification task and the radar half of the

display. On the other hand when to-be-ignored aircraft were present participants had to adopt a more complex set of criterion to perform the classification task. They needed to focus their attention on the blue target aircraft and not concern themselves with the orange TBI aircraft. This more complex attentional set may have demanded more attentional resources to be focused on the classification task and the related half of the display. I therefore predicted that unexpected objects would be noticed more often when TBI aircraft were present. However, when the UO was of a distinct color it might be noticed more when TBI aircraft were absent, since it would be the only object of a distinct color in the classification half of the display, and would therefore be more likely to generate pop-out attention capture due to its local distinctness. Current theories have not addressed such an interaction between display complexity and UO/target similarity. One of the goals of this experiment was therefore to examine how the interaction between these variables influenced noticing rates of the UO.

### 6.1 Methods

The equipment and stimuli of Experiment 2 were the same as Experiment 1, as was most of the general procedure. Unlike Experiment 1, the unexpected object always appeared at the same distance from "ownship" and was equidistant from the arcs above and below it. The other differences were the manipulation of similarity between the target aircraft and the unexpected object and the presence or absence of aircraft of a distinct color which participants were instructed to ignore. Participants in conditions where the to-be-ignored aircraft were present received modified instructions explaining that the blue aircraft were unknown targets but the orange aircraft were friendly and should be ignored. The forced-choice questions concerning the shape, color and location of the unexpected object were also kept constant, with correct answers tailored to fit each condition in Experiment 2.

#### 6.1.1 Design

The independent variables in Experiment 2 were the speed, direction, and color of the unexpected object, as well as the presence or absence of to-be-ignored aircraft of a distinct color. The three speeds of movement were: not moving, moving at the average speed of the target aircraft, or moving about four times the average speed of the target aircraft. The three directions of the unexpected object's movement were either directly towards "ownship," not moving, or moving directly away from "ownship." The two colors of the unexpected object were either matching, the same blue color as the target aircraft, or unique, a distinct green color of the same luminance. The last variable was the presence or absence of to-be-ignored (TBI) aircraft that were an orange color not used anywhere else in the Argus task. Whether or not TBI aircraft were present the total number of aircraft on the radar screen remained constant. This 3 x 3 x 2 x 2 design yielded 24 different unexpected object conditions.

#### 6.1.2 Participants

For Experiment 2, participants were 138 Rice undergraduates, 21 of whom completed the experiment with the eye-tracking equipment. All participants received credit in current courses for their participation. 63 participants were male, 75 were female, and they ranged in age from 18 to 22.

# 6.1.3 Measures

The dependent variables in Experiment 2 were the same as in Experiment 1.

### 6.2 Results

### 6.2.1 Excluded data

10 data sets were removed due to computer error and two were removed after participants reported prior knowledge of the experiment leaving 126 data sets for analysis.

# 6.2.2 Unexpected object and target similarity

The most striking finding from this experiment was the interaction between UO color and TBI (presence or absence of to-be-ignored aircraft). With TBI the noticing rate differences between matching and unique UO's were very small, however when there was no TBI unique UO's were noticed much more often than matching UO's. This interaction is shown below in Figure 12.



Figure 12: Noticing "hit" rate for unexpected objects by color and TBI (presence or absence of to-be-ignored aircraft.)

A 3 x 3 x 2 x 2 between-subjects ANOVA for noticing "hit" rate by speed,

direction, color and TBI showed that the interaction between UO color and TBI was reliable F(1, 92) = 11.13, p < 0.001. This pattern also held true for self-reported noticing and forced-choice metric rates, shown below in Table 3.

	<u>n</u>	Noticing <u>M</u>	<u>"hit" r</u> <u>SD</u>	rate <u>Self-repo</u> <u>M</u>	ort noticir <u>SD</u>	ng Forced cho <u>M</u>	<u>bice metric</u> <u>SD</u>
TBI / Matching	34	.53	.51	.50	.51	.50	.41
TBI / Unique	31	.52	.51	.55	.51	.46	.43
No TBI / Matching	33	.24	.43	.33	.48	.33	.37
No TBI / Unique	29	.76	.44	.76	.44	.65	.40

Table 3: Noticing rates by color of unexpected object and TBI.

Data for the other independent variables, speed and direction, did not show such clear effects or interactions. Unexpected objects moving at a speed average to the aircraft were noticed more, noticing "hit" rate (M = .62, SD = .49), than objects which were not moving, noticing "hit" rate (M = .49, SD = .51), or objects moving four times as fast as the aircraft, noticing "hit" rate (M = .4, SD = .50). Noticing rates showed only very slight differences based on whether the unexpected object was moving towards or away from "ownship;" for example noticing "hit" rates for objects not moving (M = .49, SD = .51), for objects moving towards "ownship" (M = .55, SD = .50), for objects moving away from "ownship" (M = .48, SD = .50). When the interactions between all independent variables were examined a few patterns did emerge, however noticing rates did not seem to be greater or lower for objects based on their overall similarity or dissimilarity to the target aircraft. No other main effects or interactions reached a 0.05 alpha level. Shown below are noticing "hit" rates for unique (Figure 13) and matching (Figure 14) unexpected objects by movement patterns and TBI.



Figure 13: Noticing "hit" rates for unique "green" UO's by movement and TBI.



Figure 14: Noticing "hit" rates for matching "blue" UOs by movement and TBI.

Self-report noticing	<u>No (n = 60)</u>	$\underline{\text{Yes } (n = 67)}$	
Correct description	1	63	
Correct color	10	47	
Correct location	7	59	
Correct shape	3	56	

Table 5: Distribution of questionnaire measures by self-report noticing.

<u>Performance score data:</u> No reliable differences were found in either classification or tracking scores in this experiment. This finding was somewhat surprising since the presence of TBI aircraft made the classification task slightly more demanding. However, participants seemed able to perform well on both the tracking and classification.

# 6.3 Eye tracking data

# 6.3.1 Saccade to the unexpected object

As in Experiment 1, if a participant made a saccade to the unexpected object they were far more likely to notice it and correctly answer questions about it, as shown in Figure 15 below. In this experiment 3 participants made a saccade to the unexpected object but did not report noticing it and did not answer any of the forced choice questions about it correctly. Of the 8 participants who did not make a saccade to the unexpected object none reported noticing it. One answered the shape question correctly and one answered the location question correctly.



Figure 15: Noticing rates by saccade made to unexpected object.

I conducted a chi-square for the self-report noticing rate and noticing "hit" rate, with whether or not the participant made a saccade to the unexpected object as the independent variable. Both measures showed an effect reliable at the 0.05 alpha level; self-report noticing rate,  $x^2(1, N = 17) p < 0.01$ , noticing "hit" rate,  $x^2(1, N = 17) p < 0.01$ . A t-test revealed that the effect was also reliable for the forced-choice metric, t(18) =3.84, p = .0006.

### 6.3.2 Point of gaze location

In this experiment, three of the 18 participants were looking at the information box, eight were looking at the tracking task, one was looking at the radar screen and six were making a saccade between two task locations when the object appeared. Figure 16 below shows noticing rates by point of gaze location.



Figure 16: Noticing rates by point of gaze location at the onset of the unexpected object.

A chi-square showed no differences reliable at a 0.05 alpha level for any of the noticing measures by point of gaze location. The lack of reliable effects may be due to the greater number of participants who were making a saccade when the unexpected object appeared and also the limited number of participants who were looking at each area when the UO appeared. The trend, if any, appears to be for higher noticing rates among participants who were making a saccade when the object appeared.

# 6.3.3 Point of gaze distance from unexpected object

I compared each of the dependent measures with the distance between each participants' point of gaze and the location of the unexpected object. Unlike in Experiment 1 the trend was for higher noticing rates when the participant was looking at a location farther from where the unexpected object onset. However, a logistic regression of the self-report noticing rate, p = .24, and noticing "hit" rate, p = .24, as well as a linear regression with the forced-choice metric,  $r^2 = 0.03$ , F(1,16) = 0.53, p = 0.48, revealed that this relationship was not reliable at a 0.05 alpha level.



Figure 17: Forced-choice metric rate and distance (cm) of point of gaze from location of unexpected object at onset.

# 6.3.4 Number of saccades

I compared the number of saccades made while the unexpected object was present with each of the dependent measures. The trend again was for participants who were looking around more to be more likely to notice the unexpected object.



Figure 18: Forced-choice metric rates and number of saccades made while unexpected object was present.

I conducted a linear regression of the number of saccades made while the unexpected object was present on the forced choice metric rate. A strong positive relationship was found,  $r^2 = 0.35$ , F(1,16) = 8.73, p < 0.01. The logistic regressions for the self-report noticing rate, p = .078, and the noticing "hit" rate, p = .078, showed less convincing evidence of a relationship.

#### 6.4 Discussion

In the No-TBI condition, when all of the aircraft on the radar screen were blue, green unexpected objects were nearly three times more likely to be noticed than blue unexpected objects. However, when the radar screen contained both blue target aircraft and orange, friendly, to-be-ignored (TBI) aircraft there was no difference in noticing rates between matching and unique unexpected objects. These results therefore show a strong attention capturing "pop-out" effect of uniquely colored (green) unexpected objects when they appear in a field of blue aircraft. However, this effect is not present when participants are required to ignore some of the aircraft based on color. When these findings are viewed together it is difficult for any single current theory to explain them.

Wolfe's multi-stage visual processing model is based mainly on data from visual search tasks where participants are looking for a target with a given set of features. In his model, the object with the highest level of local activation will capture attention, which is determined by the visual salience of the object and the number of features it possesses that participants are looking for. In Experiment 2 a unique, green, object in a field of blue objects was highly distinct and as such had a high level of local activation, drawing attention and likely a subsequent eye movement to the new object's location. A green object appearing in a field of blue and orange objects did not have as high a level of local activation, and might not have been distinct enough to elicit a shift of attention. In the TBI condition Wolfe's guided search model would thus predict that a new unique green object would be more salient then a new blue object, yet they were noticed to the same degree. However, in both cases the green object did not posses features for which a participant was searching. Wolfe's model does not provide predictions on how the

activation levels of a locally distinct object will compare with activation levels of objects possessing features participants are searching for. In this experiment participants were not searching for any particular feature, however they were using the location of objects to make decisions about how best to complete the task. Also, in the TBI condition they were using color to distinguish between which objects were relevant and which were task irrelevant. Wolfe's model simply does not speak to the interaction between unique vs. matching UOs and the attentional set of participants in the TBI vs. no TBI conditions.

The contingent-orienting hypothesis of Folk, et. al. suggests that new objects possessing features similar to task relevant objects are more likely to attract visual attention, but it also does leave room for task-irrelevant objects to capture attention if they are highly salient. In this case unique green objects were completely irrelevant to the task, while matching blue objects were highly relevant. The contingent-orienting hypothesis would therefore predict that a unique UO would be noticed less than a matching UO, since participants' attention should already be set to attend blue objects and to ignore orange objects. Yet when only blue aircraft were present a matching UO was noticed far less than a unique UO. It appears clear that in this case the strong bottomup "pop-out" effect of the uniquely colored UO overrode the top-down attentional set for matching, blue, objects. Also, when blue and orange aircraft were present (in the TBI condition) matching UO's with the task relevant blue color were equally likely to be noticed as task irrelevant green UO's.

As discussed by Most, et al. (2005) there is an important link between attentional set and implicit attention capture. My findings suggest that the complexity of the attentional set, not solely the features important to the task, also plays a role in

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determining which objects get noticed. Most, et al. (2005) posits that implicit attention capture leads to a "transient shift" of attention which is followed by sustained attentional processing, and conscious awareness, only if the new object possesses features important to the task. However, my results show that irrelevant objects are often still noticed. This means that they received sustained processing even though their features were task irrelevant. Eye-tracking data showed a strong link between noticing a UO and making a saccade to its location, for both matching and unique UOs. This eye-movement might be interpreted as the "transient shift" described by Most and colleagues however, they would predict that only task relevant "matching" UOs would receive the further processing required in order to be noticed. This was simply not the case and the eye-tracking data showed that both matching and unique UO's were highly likely to be noticed if the participant looked at them.

I find it interesting that Most, et al. did not delve deeper into how the interaction between attentional set and pop-out influences noticing rates. In Experiment 3 of Most, et al., (2001), a red cross was noticed by 72% of participants attending to either white or black objects while ignoring the other. In Experiment 2 of Most, et al., (2001), a black cross was noticed by 75% of participants attending to grey shapes and ignoring white shapes. However, the authors still claim that attentional set, more than distinctness, determines what gets noticed. I believe these results, when combined with my current findings, clearly show that both distinctness and attentional set are important factors in determining which objects are likely to be noticed. As mentioned before, objects with unique but task-irrelevant features were noticed more in the no-TBI condition where participants were able to utilize a more simplistic attentional set. The experiments

described in both Most, et al., (2001) and Most, et al., (2005) all required participants to ignore one subset of objects while attending another. More complex tasks consume a greater degree of attentional resources and new objects which have no task-relevant features are likely to receive less processing in these cases. My findings show that the complexity of the attentional set, namely the presence or absence of TBI objects, interacts with how distinctness vs. attentional set similarity determine noticing rates. Most and colleauges do discuss the difficulty of ruling out top-down guidance of so-called automatic attention capture. They claim that pop-out occurs in part because observers in search tasks have readied their attentional system to detect a target. However, participants in my experiments had no prior expectation that any new object would appear, and they were in not operating in a "signal detection mode." Folk, et al., (2003), further discuss the impossibility of ruling out the observer having some sort of expectation even when they are not engaged in a search task. I agree that attention never exists in a setless state but instead of trying to rule it out, I believe top-down guidance needs to be factored into future models of attention capture. The interaction found between noticing rates of irrelevant objects and the complexity of features required to distinguish "targets" is therefore relevant to theories of attention capture and should be included in predictive models.

Mack and Rock's model predicts that only objects deemed relevant to the task at hand, or personally relevant to the viewer, will be noticed. Only in the no-TBI condition was the new object noticed more often when it was a distinct, task-irrelevant color. In this condition requiring only a simplistic attentional set it is clear that the attentional system was not using task relevance to determine whether the object was worthy of focused attention. As such this finding challenges the generality of prior research where unexpected objects were more likely to be noticed if they were similar to target objects, and therefore shared a degree of task relevance. In these prior studies, participants needed to attend to certain objects and ignore other objects based on differences in color, similar to the TBI condition. However, my data suggests that without the presence of to-beignored objects it is not similarity between the targets and unexpected object, but rather the contrast between the unexpected object and the local environment that makes attention capture more likely. This helps to shed light on the differing results of experiments showing contingent capture (Folk et al., 1992, Mack & Rock, 1998 etc.), and experiments where salience was more relevant then target similarity in capturing attention (Theeuwes, 1991 etc).

Theories such as Triesman's with a low-level pre-attentive visual stage would expect dissimilar unexpected objects to be noticed more often, due to bottom-up attention capture. They would also predict a uniquely-colored object to be noticed more in field of all blue objects, (i.e., no TBI), than in field of blue and orange objects ( i.e., TBI), which was found to be true. However, UO's with a unique direction and speed did not capture attention to a greater degree, as would be expected. On the other hand, the contingent orienting hypothesis would predict that the most target-similar unexpected objects would be noticed more often. This pattern may be closer to findings based on speed and direction but UO similarity to the task relevant targets did not dramatically effect noticing rates. Also the difference based on color only in the no TBI condition calls into question if any single theory can explain the noticing rates found in this experiment.

# 7. Experiment 3

Theories based on multiple stages of visual processing, such as Triesman's, posit that early, or parallel, search has basically unlimited resources; that is, basic features can be detected in parallel across the entire visual field. However, later stages of search require directed attention while each object is examined in a serial fashion. Since attention is a finite resource the more objects that require this level of processing the greater the demands put on the visual system. The primary question I address in Experiment 3 is how the demands put on the visual system from serial processing affect the ability of parallel processing to detect change in the form of a new unexpected object. This was examined by manipulating the number of target aircraft within the Argus task, and therefore varying the level of visual engagement required in each task. Visual engagement is directly related to, but not the same as, task difficulty, which can be manipulated in Argus by making the classification of the target aircraft more difficult. Wolfe's guided search model would suggest that as the task becomes more visually demanding there are more task-relevant objects with high levels of activation making it less likely that attention will be directed to a new object with a lower level of activation.

Prior experiments such as Simons and Chabris (1999) have showed decreased noticing rates when participants are engaged in "harder" tasks, but have not systematically examined how visually demanding the tasks were. Using Argus I manipulated the number of target aircraft to make the task more or less visually demanding. I also made classification of the aircraft more difficult by adjusting their speed and altitude, making the task more cognitively demanding. For example, if all the aircraft have the same speed and altitude then threat level calculations are based only on distance from and trajectory towards "ownship." In this case, once one aircraft is correctly classified then the others at similar distances should be easier to classify. On the other hand, if the aircraft have varying speeds, altitudes, trajectories and distances from "ownship" they will each be more difficult to classify. This distinction was designed to provide insight into how important visual and cognitive resources are on influence the noticing of a new object. I therefore hoped that this experiment could fill the need for an experiment assessing the effects of varying degrees of attentional engagement on capture.

As both the visual and cognitive demand increase there should be less available attentional resources to detect the presence of the unexpected object. Therefore I expected noticing rates would be highest in the low-demand visual, low-demand cognitive condition, and lowest in the high-demand visual, high-demand cognitive condition. However, I was very interested to see how noticing rates compared in the conditions of high-demand visual, low-demand cognitive, and low-demand visual, highdemand cognitive. Due to the nature of the Argus task, and the fact that visual attention resources are necessary for noticing unexpected stimuli, it was my prediction that noticing rates would be influenced to a greater degree by the visual demand then the cognitive demand. This means noticing rates would be lower in the high-demand visual, low demand cognitive then in the low-demand visual, high-demand cognitive condition.

I also planned to examine if the high-demand visual and high-demand cognitive tasks influence certain dependent variables differently. For example, participants in the high-demand visual task might be able to correctly identify the location of the unexpected object, or make eye movements towards it, without being able to correctly identify it. Such a finding would lend more credence to theories such as Wolfe, Treismann and

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Rensink, where primary features of objects are unbound until attention is focused on them. In such a case the unexpected object might reach a mid-level of processing, such as a proto-object in Rensink's coherence theory (Rensink, 2000). However, without enough attentional resources to maintain a representation of the object it would decay without being encoded into short-term memory. As such a participant might be able to detect that a change occurred in a given location without being aware of the features of the unexpected object.

#### 7.1 Method

The equipment and general stimuli in Experiment 3 were the same as in Experiments 1 and 2. Participants however were both Rice undergraduates participating for course credit and members of the Rice undergraduate and graduate student community who received pay for their participation.

#### 7.1.1 Design

In Experiment 3 the unexpected object was not manipulated, rather it stayed constant and the task in which it appeared acted as the independent variable. In this 2 x 2 design there were two levels of visual demand and two levels of cognitive demand that were determined by the number of target aircraft and the number of variables which determined their threat level classification. For the low visually demanding task there were only 11 target aircraft present in the target area at any time. For the high-level visual demand task there were 22 target aircraft present at all times. In the low-demand cognitive task the aircraft were all moving at the same speed and flying at the same

altitude which made classification relatively easy. In the high-level cognitive task each aircraft was flying at a different speed and altitude, as well as beginning at different distances and flying at different vectors towards "ownship" making classification difficult. Participants received specific written instructions describing the classification task based on which cognitive condition they were in.

#### 7.1.2 Participants

For Experiment 3 participants were 64 Rice undergraduate and graduate students who received course credit or payment for their participation, \$8 for non-eye tracked participants and \$15 for eye-tracked participants. 16 of the participants completed the experiment with their point of gaze being recorded with the eye-tracking equipment. 36 participants were male and 36 were female, they ranged in age from 18 to 29.

#### 7.1.3 Measures

The dependent measures in Experiment 3 were the same as Experiments 1 and 2.

### 7.2 Results

#### 7.2.1 Excluded data

One data set was removed due to computer error and one was removed when the participant reported prior knowledge of the experiment, leaving 62 usable data sets for analysis.

#### 7.2.2 Cognitive and visual task demand

As expected noticing rates were greater for participants engaged in visually simple tasks than for those in visually complex tasks. This trend was true for both noticing "hit" rates, and for the forced choice metric, However there was no difference between visually complex and visually simple trials for the self-reported noticing measure. Among the individual forced-choice questions the rates of correct answers for the location question differed to the greatest degree.

		Noticing Self "hit" repo rate notic		lf- ort cing	Force cho met	ed- bice tric	Cor loca reca	rect tion lled		
	<u>n</u>	М	SD	М	SD	М	SD	М	SD	
Visual simple	32	.44	.50	.41	.50	.49	.41	.50	.51	
Visual complex	32	.34	.48	.41	.50	.41	.42	.34	.48	
Cognitive easy	32	.41	.50	.47	.51	.48	.42	.53	.51	
Cognitive hard	32	.38	.49	.34	.48	.42	.41	.31	.47	

Table 6: Dependent measure rates, including location question, for main effects of visual complexity and cognitive difficulty.

The overall trend for the cognitive difficulty of the task was also in the expected direction for all measures, with greater rates for participants who were given the easier classification task. Also, as with visual complexity, the rates of correct answers for the location question were also accordant with the trend. The main effects, however, do not show the whole picture. Noticing rates were reliably highest in the visually simple / cognitive easy task pairing, shown below in Figures 19-22 and Table 7.



Figure 19: Noticing "Hit" rate by visual complexity and cognitive difficulty.

		Noticing "hit" rate		Self- report noticing		Forced- choice metric		Correct location recalled	
	<u>n</u>	М	SD	М	SD	М	SD	М	SD
V simple / C easy	16	.50	.52	.50	.52	.60	.39	.75	.45
V simple / C hard	16	.38	.50	.31	.48	.38	.41	.25	.40
V complex / C easy	16	.31	.48	.44	.51	.35	.43	.31	.48
V complex / C hard	16	.38	.50	.38	.50	.46	.42	.38	.50

Table 7: Dependent measure rates, including location question, by visual (V) and cognitive (C) tasks pairings.


Figure 20: Forced-choice metric rate by visual complexity and cognitive difficulty.



Figure 21: Self-report noticing rate by visual complexity and cognitive difficulty.



Figure 22: Correct location rate by visual complexity and cognitive difficulty.

As can be seen in the above figures the highest rates were found in all measures when the task was both visually simple and cognitively easy. As for the other three conditions, although there is some variability between measures, there appears to be no overall difference in noticing rates. However, 5 out of the 16 participants in the visually simple / cognitive easy task pairing did not report noticing the unexpected object yet correctly identified the location at which it appeared. Whereas only 2 of the 48 participants in the other three conditions correctly identified the object's location without reporting noticing it, and both of these were in the visually simple / cognitive difficult task pairing. When asked to describe the object a few participants who did not report noticing a new object reported noticing something, or seeing a flash, at the location of the unexpected object, but believed that it was nothing important or that one of the aircraft

	Noticing "hit"		Self- report		Forced choice		Correct location	
	ra	nte	noti	cing	me	tric	reca	lled
Df(1,63)	F	<i>p</i> =	F	<i>p</i> =	F	<i>p</i> =	F	<i>p</i> =
Visual	.56	.45	.00	1.0	.66	.42	1.78	.19
Cognitive	.06	.80	.99	.32	.37	.54	3.48	.067
Interaction (V x C)	.57	.46	.25	.62	2.64	.11	5.76	.02**

had disappeared. I conducted a 2 x 2 ANOVA for each of the dependent measures as well as for the location question, shown below in Table 8.

Table 8: ANOVA results for each dependent measure, and the location question for visual complexity, cognitive difficulty and the interaction between the two. (\*\* indicates reliable effect below the .05 alpha level.

The location question was not regularly used as a dependent measure, however at no point in any of the other experiments did the correct answer rates to a single forcedchoice question show a larger effect than any of the three dependent measures. I feel confident that the location question is tapping into a legitimate effect especially since the effect was highly consistent with the other measures. In fact, only the location question showed a result that reached an alpha level below 0.05 for the interaction between visual complexity and cognitive difficulty, F(1, 63) = 5.76, p = 0.02.

Self-report noticing	<u>No (n = 38)</u>	$\underline{\text{Yes } (n = 26)}$	
Correct description	0	22	
Correct color	9	24	
Correct location	7	20	
Correct shape	2	24	

Table 9: Distribution of questionnaire measures.

<u>Performance score data:</u> Somewhat surprisingly, no reliable differences were found in either the classification or tracking scores based on the visual or cognitive difficulty of the task. This was unexpected since better classification scores were predicted when the task was both cognitively and visually easier. The lack of a difference supports the idea that participants were highly focused on the main tasks and highly motivated to score well. However, the lack of a performance score difference does call into question how different the easy and difficult task truly were. More extreme differences in difficulty may have produced stronger noticing effects.

## 7.3 Eye tracking data

### 7.3.1 Saccade made to unexpected object

I examined each noticing measure based on whether or not the participant made a saccade to the location of the unexpected object. As in Experiment 1 and Experiment 2, if participants did not look at the object they were highly unlikely to notice it. Of the 6 participants who did not make a saccade to the unexpected object none of them reported noticing it. On the other hand 10 of the 12 participants who did make a saccade to the object reported noticing it. This data is shown below in Figure 23.



Figure 23: Noticing rates by whether or not a saccade was made to the unexpected object.

As in Experiments 1 and 2, participants were more likely to notice the object if they had made a saccade to its location. Chi-square tests for the self-report noticing rate,  $x^2(1, N = 17) p < 0.001$ , and noticing "hit" rate  $x^2(1, N = 17) p < 0.001$ , and a t-test for the forced-choice metric, t(18) = 4.33, p = .00019, revealed that this effect was reliable at the 0.05 alpha level for all three measures.

## 7.3.2 Point of gaze location

In this experiment the point of gaze location was fairly well distributed with five of the 17 participants looking at the information box, four looking at the radar screen, five looking at the tracking task and three transitioning when the unexpected object appeared. Noticing rates for each point of gaze location are shown below in Figure 24.



Figure 24: Noticing rates by point of gaze position at onset of unexpected object.

I conducted an ANOVA for the forced-choice metric rate, and a chi-square for self-report noticing and noticing "hit" rate, by point of gaze location. Although none of the measures reached the 0.05 alpha level for significance the self-report noticing measure was the strongest effect,  $x^2$  (1, N = 17) p = 0.20. As in Experiment 2, the greatest noticing rates occurred for participants who were transitioning between locations when the unexpected object appeared. They were lowest when participants were looking at the information box. However, the visual and cognitive complexity of the task may have interacted with noticing rates based on point of gaze location. Of the 6 participants who were in the visually simple condition noticed the object, the 2 who were in the cognitively easy / visual complex condition noticed the object and the 1 who was in the visually complex / cognitively difficult condition did not notice the object.

## 7.3.3 Point of gaze distance from location of unexpected object

I compared each of the dependent measures with how far each participants' point of gaze was from the location where the unexpected object appeared. As in Experiment 1, the trend was participants who were looking at a location closer to the unexpected object were more likely to notice it. All of the dependent measures showed the trend in the same direction; the self-report noticing measure is shown below in Figure 25.



Figure 25: Forced-choice metric rate and point of gaze distance (cm) from the unexpected object.

I conducted a linear regression of point of gaze distance from the unexpected object with the forced choice metric rate  $r^2 = 0.01$ , F(1,17) = 0.19, p = 0.67, and logistic regressions for self-report noticing, p = .31, and noticing "hit" rate, p = .45. The

relationships were small, and not reliable at a 0.05 alpha level, though the trend was for a very slight decrease in the forced choice metric rate as point of gaze distance from the unexpected object increased.

## 7.3.4 Number of saccades

I examined each dependent measure based on the number of saccades each participant made while the unexpected object was present. As in Experiments 1 and 2 all three measures showed a trend in a positive direction with participants who looked around more being more likely to notice the unexpected object. This relationship is shown for the noticing "hit" rate measure below in Figure 26.



Figure 26: Forced choice metric rate and number of saccades made while the unexpected object was present.

The number of saccades made while the unexpected object was present did not correlate strongly with the forced choice metric rate,  $r^2 = 0.035$ , F(1,17) = 0.58, p = 0.46, nor with the self-report noticing rate, p = .30, nor noticing "hit" rate, p = .20. Though the trend for all three measures was an increased rate with an increased number of saccades, the relationships were not reliable at a 0.05 alpha level.

### 7.4 Discussion

In the least-demanding condition participants had the greatest amount of attentional resources free, and it was only in this condition that some participants correctly identified the unexpected object's location, though failing to report noticing it. If unattended objects were processed at a high level it seems unlikely that only a limited subset of the objects features would be encoded into memory. It is more likely that the unexpected object was processed at an early, low level, but due to the demanding task and the limited resources of the visual attention system its features were not encoded and remembered. Thus findings from Experiment 3 support theories such as Wolfe's and Triesman's where low-level features of a new object are encoded without the object being processed as a cohesive whole. In such a case, the participant would be aware of the location where something had occurred but might not have encoded any more features of the object. This finding strongly supports the special nature of "where" information within the visual system. In order for any object to be attended the visual system must first process the location of the object so that attention can be shifted to that location. This location information was retained more in the visually simple conditions

which suggests a connection between short-term-memory and the limited resources of the attentional system.

Rates for all noticing measures were highest in the visually simple / cognitive easy condition. This effect is in the expected direction since participants in this condition had the fewest limitations put on their visual attention and cognitive systems. Near the end of the trial, when the unexpected object appeared, most participants in the visually simple / cognitive easy condition had classified all the aircraft and the classification task became more of a monitoring task than an interactive one. In such a setting, participants were engaged in the tracking task and merely watching, not interacting with, the radar screen. The unexpected object exerted a strong attention capturing influence in this situation. However this was not simply due to the visual simplicity of the task, but also on the strategies of participants in the different conditions, since participants in the visually simple / cognitively difficult condition did not notice the UO as often. Participants in the visually simple / cognitive difficult condition often continued to click on aircraft in the classification task even after they had already classified them all, sometimes changing the threat level before the aircraft crossed an arc. This behavior showed that the participants were second-guessing or changing their minds on the threat level classifications. This strategy effectively kept the classification task interactive not just at the cognitive but also at the visual level. Clicking on an aircraft required directed visual attention, whereas merely monitoring the whole radar screen could be accomplished with more widely distributed attention.

Unlike the visually simple tasks, the visually complex tasks showed no difference in noticing rates when paired with cognitively easy or cognitively difficult tasks. Because

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of the greater number of aircraft in the visually complex task, the classification task continued to require involvement from the participants even until the end of the trial. There were always some aircraft that were about to cross or had just crossed an arc, requiring a new threat level classification. The level of cognitive difficulty therefore did not alter the task strategy in the visually complex tasks as much as it did in the visually simple tasks. In effect the visually complex task may have made the cognitive difficulty of the classification task irrelevant. Many participants in the visually complex classification task seemed to be making threat level classifications very rapidly, taking a rough guess and moving on to the next aircraft rather than taking time to think deeply about each decision. Since their score was based on how many of the aircraft they could classify correctly it was not a bad strategy to take a rough guess on a larger number of aircraft, rather than spend time determining a more refined guess on a smaller number of aircraft.

### 8. General Discussion

These experiments were intended both to address current theoretical debate in the areas of inattentional blindness and general theories of visual attention, as well as to provide a test of how well current theories in these fields could predict and explain findings from a dynamic task where participants have a large degree of volitional control over their task strategies and local behaviors. In the complex dynamic task used in these experiments no current theory was fully able to predict the likelihood that an unexpected object would be noticed. Past research of inattentional blindness has examined the noticing of new objects based on the attentional set of the participant, the task relevance

of the new object and the distinctness of the new object. While these factors do affect the likelihood of an object to be noticed, they do not explain the whole picture. The more freedom participants are given to perform a task the more varied their task strategies may be. For this very reason, experimenters tend to use extremely limited, repetitive tasks; however, in order for findings concerning inattentional blindness to help reduce accidents in the real word the effects must be shown in more realistic, dynamic tasks.

Findings from experiments where a participants' attention was constrained to a simple task, or a set location, may not transfer to a situation where a participant has more volitional control. For example, Mack and Rock (1998) found that unexpected objects appearing at fixation were less likely to be noticed than objects appearing at 2 degrees of visual angle away from fixation. They were quite surprised by this finding and used it to illustrate the counterintuitive nature of inattentional blindness, that participants failed to "see" an object they were "looking" directly at. However, their task required participants to focus their attention on, and make judgments about, a cross which appeared either at or slightly away from fixation. When the cross appeared away from fixation the unexpected object appeared at fixation and participants' entire task strategy was to shift their attention to the cross, and therefore away from the unexpected object. It does not seem counterintuitive that the unexpected object was noticed less in this condition considering that in order to complete the task, participants were required to shift their attention away from the unexpected object. The more complicated tasks in my experiments allowed participants to shift their attention between multiple locations which were all relevant to the tasks and the data showed a strong link between looking at the unexpected object and noticing it. Eye-tracking data showed that more than 75% of participants who made a

saccade to the location of the unexpected object reported noticing it. In many prior experiments examining inattentional blindness the unexpected object was close to the task-relevant location, sometimes even between objects on which the participant was supposed to be focused, however this does not mean that the participant made a saccade to the unexpected object's exact location. My data shows that without looking at an object it is highly unlikely that the object will be noticed. Also, participants who looked around more while the unexpected object was present were more likely to look at it. Therefore inattentional blindness may not be as counterintuitive as some have suggested. It seems less an issue of how a participant failed to see an object they looked at and more an issue of the likelihood that a participant will look at the object in question. The data from these experiments suggest that when a participant has a high degree of volitional control the likelihood that a new object will be looked at is determined by the interaction between the complexity of the participants' attentional set, the uniqueness of the new object within the local environment, and the visual and cognitive complexity of the task. For example, when the task and related attentional set are complex the distinctness of a new object is less important to it capturing attention then when the task and attentional set is simple, as shown in Experiment 2.

Unlike most prior studies of inattentional blindness, participants in these experiments were not merely engaged in a monitoring or counting task, rather they had free reign to decide how they would allocate their attentional resources. The eye-tracking data from these experiments showed that participants' strategies controlled where they were looking and how many shifts of attention they were making within a given time period. These strategies were somewhat driven by the different experimental conditions and relative requirements and constraints they imposed. However, there was also a large degree of variation between individuals. These factors, in conjunction with the basic properties of the task and features of the unexpected object, influenced the likelihood that the UO would be noticed. For example, in Experiment 1 and Experiment 3 the trend was for UO's appearing further away from the focus of attention to be noticed less often. However, in Experiment 2 uniquely-colored objects in the no-TBI condition still captured attention even when participants' point of gaze was focused quite far away. Theories of inattentional blindness need to take into account how greatly noticing rates can be determined by the complexity of the task as well as the individual strategies of participants. As inattentional blindness is studied in more complex settings it is apparent that point of gaze data needs to be included in the analysis along with standard self-report noticing measures. Also, forced-choice questions concerning features of the unexpected object can provide insight about the degree to which the object was processed and encoded.

My findings are best explained by blending concepts from more than one theory of visual attention. First, attentional set should be viewed not just as an attentional filter to give preferential processing to objects possessing a given feature, but also as being determined by the complexity of the task at hand. When only blue aircraft were present the participants' attentional set was fairly simple, so much so that their attention was most likely set only for the presence of objects on the radar screen, not specifically for blue objects. When a matching UO appeared in this condition it did not exert a high level of local activation, since it was just another blue object in a field of blue objects. However, when a unique UO appeared the presence of a uniquely colored object overrode the simple "focus on objects" attentional set and captured attention due to its high level of distinctness and accompanying surprise factor or "pop-out." When participants had to focus on blue aircraft and ignore orange aircraft they had to form a more complex attentional set, perhaps ignore orange objects and focus on the rest. When either a matching or unique, green or blue, UO appeared the "ignore orange" attentional set was not activated and these objects were equally likely to be noticed. Furthermore, since there was more than one color of objects present in the TBI condition the new object being green did not produce as high a level of local activation as it did in the no-TBI, all blue objects, condition. Mack and Rock have suggested a flexible selection theory where attention is shifted to an object after a variable degree of processing has occurred. This theory therefore allows for the discrepancies between experiments where attention seems to be shifted only based on low-level processing, and experiments where a higher level of processing appears to occur before attention is shifted. However, the theory does not adequately explain why a higher or lower level of processing occurs in a given experiment before attention is re-directed. My data suggests that the complexity of the task, and the resulting attentional set of the participant may determine the level of processing that unattended objects receive. The more simple task and attentional set may have lead to an overall lower level of processing for unattended items where a low-level effect like pop-out of a uniquely colored object captured attention.

Overall the findings from these experiments show that the crucial factor determining the likelihood of the UO being noticed was whether or not the participant looked at it, rather than whether or not they encoded information about the object after looking at it. Eye-tracking data showed that making a greater number of saccades while the object was present increased the chances of noticing the object. An application of this finding is currently taught in drivers' education courses, that is, in order to notice new objects a driver should keep his eyes moving, and not just stare at the car in front of him. This finding should also instruct the designers of displays, where noticing a new object is important, not to require their users to focus for too long on any one location. For experimenters studying inattentional blindness it shows the importance of taking into consideration the number of eye movements a participant is likely to be making when designing an experiment, or better yet including a count of eye movements when analyzing the data. These experiments also show the overwhelming link between noticing an unexpected object and making a shift of foveal attention to the location of that object. Shifts of visual attention and eye movements have been shown to be highly related, but this finding also strengthens the notion that without looking at an object the viewer is not likely to notice it. This does not, however, mean that it is impossible to notice a new object without making an eye movement to it, only that it is highly unlikely. Of all the eye-tracked participants, only one participant reported noticing an object and was able to correctly answer two out of three questions about it without making a saccade to it. On the other hand, it is also possible, though unlikely, to look at a new object without noticing it. The link between eye movements to, and noticing rates of, objects shows the natural progression of eye movements following attentional shifts, and the subsequent encoding of information about the object at the focus of visual attention.

The findings from Experiment 2 are also relevant to designers of computer and other machine systems designed to attract visual attention. In a display, or specific area within a display, where all objects are the same color, an object with a unique and unexpected color is much more likely to be noticed than one sharing the color already present. However, in a display where objects of one color are relevant and objects of another color are not a new object will likely be noticed equally regardless of whether it possesses a unique color. Since the Argus task is a simplified air traffic control task this seems a field for which these findings would be particularly useful. If, for example, the air traffic controller's display showed all aircraft in the same color the appearance of a uniquely colored aircraft, to indicate an emergency situation, would have a greater chance of explicitly capturing attention, and therefore being noticed automatically by the air traffic controller. The finding is also important to designers of in-car navigation systems. If a display is usually monochromatic a new object or warning of a unique color would have a high likelihood of being noticed. Whereas a uniquely-colored object would be noticed less often in a display where roads were shown in one color and vehicles in another.

Participant strategies played a large role in influencing noticing rates, as was seen in findings from Experiment 3. Unexpected objects were most likely to be noticed when the task was visually simple and cognitively easy, however, objects were equally likely to be noticed among the other three task pairings. Since attentional resources are limited, current theories would predict the lowest noticing rates in the visually complex / cognitively difficult trials. The absence of this effect was likely due to the adaptive strategies of participants, which were formed to maximize their performance in a difficult task. Because the task was so demanding, participants used shortcuts to free up attentional resources. So, while a simple design and easy task allowed the greatest chance of noticing a new object, a complicated design and difficult task lead users to adopt timesaving strategies, making them more likely to notice a new object than would have otherwise been predicted. The finding of this interaction is important for designers of systems where users should notice new unexpected objects, such as navigation screens in automobiles.

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## <u>Appendix A: Instructions for Experiment 1</u>

Welcome to the aircraft tracking and threat evaluation task.

Your two-fold mission will be to classify the aircraft on your radar screen based on their speed, altitude, course and distance from your ship, and also to track a separate fighter jet by keeping a circle around it.

On every trial your ship is represented by a small cross at the bottom of the screen. Above your ship are four arcs with 50 miles of space represented between each arc. Your job is to classify the threat levels of each aircraft before they cross the next arc closer to your ship. In other words **you will need to reclassify each aircraft once it crosses an arc**.

#### How to classify an aircraft.

First click on a blue aircraft icon in the target screen, a threat level classification box will appear in the right half of the screen. At the top of this box all of the information concerning the selected aircraft will be displayed. Based on this information you will click on one of the buttons in this box that you feel best represents the threat level of the selected aircraft, the higher the number the greater the threat level. During your first training trial a grey feedback box will appear after you classify an aircraft, **click** in this box and it will reveal a blue thumbs up if you correctly classified the threat level of the aircraft, or a red thumbs down if the classification was incorrect. If you got it right move on by clicking a different aircraft icon, if you got it wrong reclassify it and click the feedback box again, repeat this until you get the blue thumbs up.

How to calculate the threat level of a given aircraft.

Aircraft are classified with higher threat levels the faster they are moving, the lower they are flying, the closer they are to your ship, and the more directly they are coming towards your ship. Of these four factors the most important is **how close the aircraft is to your ship**. For example, an aircraft about 90 miles away flying directly towards your ship may be classified with a threat level of 8-9, while the same aircraft only 40 miles away may need to be classified as a threat level of 10-11. An aircraft 200 miles away flying a course that does not take it towards your ship will need to be classified with a low threat level, maybe 2-3 for example. You will have a chance to practice and get a feel for how to classify aircraft with different characteristics.

#### How to track the fighter jet.

While you are engaged in the classification task you will also need to track a fighter jet on the right half of the screen. To shift to the tracking task you need to hold down the "**shift**" button on your keypad. While holding the shift button your mouse will control the tracking circle, and moving the mouse will move the circle. Try to keep the fighter jet within the circle as often as possible, but realize that it is difficult to keep it in the circle 100% of the time, given that you have to switch back and forth between the classification and tracking tasks. If the fighter has been away from the blue circle for too long it will change to yellow then red. When you release the shift button the mouse will go back to controlling the classification task.

### Practice trials.

You will now begin the first of two practice trials. In the first trial you will be practicing just the classification task, the fighter jet will not be present. The purpose of this practice trial is to learn how to classify the threat levels of the aircraft on the radar screen. In other words don't worry about your score during practice, just try to get a feel for the task. On the second practice trial you will train on the tracking task, so you will not be receiving feedback on the classification task.

Once you are finished with each trial please alert the experimenter.

### Real trials.

After you have completed your two training trials you will complete two trials where your score will be recorded. Please try to do your best on these trials, but don't get upset if there are more aircraft than you can classify before they cross over the next arc, or if you can't keep the fighter jet in the circle the whole time. After each trial you will see a percentage score for both the classification and the tracking task, the participant who has the highest combined score will win prize of \$20, the participant with the second highest combined score will win a prize of \$10. These prizes will be awarded after all 60 participants have completed the task. Winners will be contacted through the email address they listed on Experimetrix.

In Brief.

- Click on a blue aircraft icon.
- Take your best guess at the threat level by clicking one button in the scale, click enter. (The closer the aircraft is to you the higher the threat level.)
  - If this is the training trial click on the grey box that appears to see if you were right.
- Reclassify aircraft once they cross a black arc.
- For all but the first trial switch to the tracking task by holding shift.

Once you are ready please begin your first practice trial by clicking the "Go" button in the center of your screen, and remember it is ok to ask questions during the practice trials.

# <u>Appendix B: Instructions for Experiment 2 (changes from Experiment 1</u>

## instructions only).

How to classify an unknown aircraft.

There will be blue "unknown" and yellow "friendly" aircraft on your screen. You should ignore the yellow aircraft and focus only on the blue aircraft. First click on a blue aircraft icon in the target screen, a threat level classification box will appear in the right half of the screen. At the top of this box all of the information concerning the selected aircraft will be displayed. Based on this information you will click on one of the buttons in this box that you feel best represents the threat level of the selected aircraft, the higher the number the greater the threat level. During your first training trial a grey feedback box will appear after you classify an aircraft, **click** in this box and it will reveal a blue thumbs up if you correctly classified the threat level of the aircraft, or a red thumbs down if the classification was incorrect. If you got it right move on by clicking a different aircraft icon, if you got it wrong reclassify it and click the feedback box again, repeat this until you get the blue thumbs up.

### In Brief.

- Click on a blue "unknown" aircraft icon. Remember, don't click the yellow "friendly" aircraft.
- Take your best guess at the threat level by clicking one button in the scale, click enter. (The closer the aircraft is to you the higher the threat level.)
  - If this is the training trial click on the grey box that appears to see if you were right.
- Reclassify aircraft once they cross a black arc.
- For all but the first trial switch to the tracking task by holding shift.

## <u>Appendix C: Instructions for Experiment 3 (changes only)</u>

### Cognitive Easy task

How to calculate the threat level of a given aircraft.

Aircraft are classified with higher threat levels the closer they are to your ship, and the more directly they are coming towards your ship. Of these two factors the most important is **how close the aircraft is to your ship**. For example, an aircraft about 90 miles away flying directly towards your ship may be classified with a threat level of 8-9, while the same aircraft only 40 miles away may need to be classified as a threat level of 10-11. An aircraft 200 miles away flying a course that does not take it towards your ship will need to be classified with a low threat level, maybe 2-3 for example. You will have a chance to practice and get a feel for how to classify aircraft with different characteristics.

### Cognitive difficult task

How to calculate the threat level of a given aircraft.

Aircraft are classified with higher threat levels the faster they are moving, the lower they are flying, the closer they are to your ship, and the more directly they are coming towards your ship. Of these four factors the most important is **how close the aircraft is to your ship**. For example, an aircraft about 90 miles away flying directly towards your ship may be classified with a threat level of 8-9, while the same aircraft only 40 miles away may need to be classified as a threat level of 10-11. An aircraft 200 miles away flying a course that does not take it towards your ship will need to be classified with a low threat level, maybe 2-3 for example. You will have a chance to practice and get a feel for how to classify aircraft with different characteristics.