USING PREVIEW INFORMATION TO FACILITATE COMPLEX VISUAL SEARCH

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USING PREVIEW INFORMATION TO FACILITATE COMPLEX VISUAL SEARCH

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SUMMARY

The complex visual search involved in baggage screening requires operators to determine quickly whether a bag contains threatening objects that are embedded in a high degree of visual clutter. Methods for calculating visual clutter have been developed, and research has demonstrated the negative impact of clutter on search performance. The current study examined whether leveraging visual clutter information on the display during search could improve baggage screening performance above and beyond the conventional screening process. Ninety undergraduates searched x-ray images of bags for weapon items in a low fidelity baggage screening simulation; two clutter-based preview conditions displayed a limited portion of the bag to the participant before the entire bag was displayed. Eye movement data confirmed that the preview process guided the participant's attention to the corresponding previewed region. However, analysis of the baggage screening performance data showed there were no significant benefits associated with either clutter-based preview conditions compared with a control condition in which the entire bag was displayed for the duration of the trial. Thus, the results suggest that using clutter-based preview to guide visual attention does not substantially improve weapon detection performance. Despite this null effect, the current study provides additional evidence regarding the impact of visual clutter on complex search performance by demonstrating significant reductions in weapon detection accuracy and search efficiency due to increasing levels of visual clutter. Further research should explore methods for improving complex visual search by considering the negative impacts of visual clutter and ensuring that both attention guidance and object recognition processes are facilitated during search.

CHAPTER 1

INTRODUCTION

Humans routinely search their environment with the goal of identifying and extracting precise information in order to complete tasks. Our extraordinary capacity for scanning the environment, quickly recognizing objects, and making sense of visual information is unmatched by existing technology (Eckstein, 2011). Visual search tasks are ubiquitous, ranging from the everyday instance of identifying the location of one's house keys on a desktop, to the more extreme case of an airport luggage screener scanning x-ray images of bags for threatening objects. Modern operators (e.g., luggage screeners or air traffic controllers) are often tasked with quickly scanning complex displays for particular information that is surrounded by competing information sources. The potentially stressful work environment further compounds difficulties associated with the complex visual tasks routinely carried out by modern operators (Harris, 2002). Therefore, understanding the demands placed on the visual system during complex search tasks is crucial for improving the way this information is displayed and accessed by operators.

The current study will seek to leverage knowledge of the cognitive systems involved in visual search to improve performance of complex visual search tasks. The characteristics of baggage screening search tasks will be discussed in order to understand the informational load encountered by operators performing complex search tasks. Research regarding the role of visual working memory (VWM) in search tasks will be explored to understand this critical cognitive component of visual attention involved in search processes. Finally, the significance of visual clutter in complex search tasks will be considered before introducing the current experiment.

Characteristics of Baggage Screening

Airport security personnel are tasked with the difficult job of visually inspecting x-ray images of bags for threatening objects in an efficient manner. This is an example of one of the more difficult visual search tasks carried out by modern operators on a routine basis. Numerous task characteristics contribute to the demanding nature of baggage screening. The baggage screening search space includes items that are partially occluded by overlapping items, disrupting the ability to identify precisely individual items. The search space is dense with color and object information that results in a highly cluttered display. Search through such a cluttered display can impose significant demands on limited perceptual and cognitive resources (McCarley, Kramer, Wickens, Vidoni, & Root, 2004). In addition, the arrangement of items within the bag lacks consistency from bag to bag; therefore, screeners cannot reliably leverage contextual information to guide their search process and improve performance. Moreover, threatening targets rarely occur. For example, in 2011, the Transportation Safety Administration (TSA) reported that, on average, only four firearms were found per day by security screeners across the United States (Jansen, 2012). The rare occurrence of targets in a screening task can make it difficult for operators to remain engaged in the search process (Hogan, Bell, & Olson, 2009). Finally, threatening objects can take a nearly infinite variety of forms, and items can be expertly disguised to appear as non-threatening objects. Thus, screeners must be able to identify evolving target types, further contributing to the high informational load associated with screening passenger bags.

To understand the demands of baggage screening, the characteristics of the work environment in which security screeners operate must also be considered. The failure of operators to find a threatening object can have disastrous consequences as the safety of airline passengers depends on their ability to ensure that threatening objects do not pass security checkpoints. In addition to safety considerations, screeners must be sensitive to the time-pressure involved in transferring passengers through security checkpoints to prevent unnecessary delays. Thus, screeners must balance the safety of all passengers with not introducing delays due to an excessive screening process. The confluence of safety and time constraints complicates the operator's inherently difficult search task, introducing additional demands on limited cognitive resources.

The challenges associated with baggage screening search tasks highlight the importance of understanding the cognitive components employed during such tasks. Furthermore, knowing how limited capacity mechanisms such as visual working memory (VWM) are implicated in search processes can reveal the extent to which cognitive resources are available to the operator for sustaining a high degree of performance.

The Role of Visual Working Memory in Visual Search

As we search our environment for information, visual stimuli are theoretically briefly processed in a high capacity iconic memory store before entering a limited capacity VWM store (Bradley & Pearson, 2012). The capacity of VWM can vary depending on the individual and the particular visual objects, but capacity estimates are generally believed to be four items (Luck & Vogel, 1997). In addition, information maintained in VWM can include specific object features (e.g., color) as well as the object's spatial location (Al-Aidroos, Emrich, Ferber, & Pratt, 2012). In the context of visual search, the ability to integrate newly acquired information with stored items would suggest a rather prominent role for VWM in search processes.

However, the precise role of VWM has been the subject of considerable debate as some research has suggested that visual search does not rely on memory. In one such study, Horowitz and Wolfe (1998) had participants complete a visual search task with either static or dynamically changing arrays of objects that changed locations at a rate of 100 ms. The authors argued that if VWM significantly contributed to search performance, search efficiency in the static condition should increase as information regarding object locations accumulated in VWM. Essentially, the static array would allow distractor item locations to accumulate in VWM, thus increasing search efficiency because the potential target locations were reduced as search progressed. Results revealed that search efficiency was equivalent for the static and dynamic conditions, suggesting only a minor role of VWM in search. However, this study was heavily critiqued as researchers later showed that the results were likely due to the limited size of the search array as well as a speed-accuracy tradeoff in the dynamic condition (Woodman & Chun, 2006).

Studies implicating VWM in search processes have since accumulated, indicating a rather prominent role for VWM (e.g., Emrich, Al-Aidroos, & Pratt, 2010; Oh & Kim, 2004; Peterson, Beck, & Vomela, 2007; Woodman & Luck, 2007). Although the precise role of VWM is not entirely clear, research has shown that the spatial component of VWM is particularly important for search. A pair of independent studies targeted this spatial component of VWM using a dual task paradigm involving change detection and visual search tasks (Oh & Kim, 2004; Woodman & Luck, 2004). In this dual task paradigm, the trial procedure began with the presentation of a memory array consisting of four squares appearing in random locations; participants were instructed to remember the locations of each of the four squares. Next, participants searched for an upright L-shaped target among rotated L-shaped objects. Lastly, a memory test probe was displayed as the participant determined if the probe location corresponded to the location of one of the four memory array squares. Across the experiment, participants would complete dual task trials involving both tasks, as well as trials involving only the search task. Search efficiency (measured as the slope of search reaction time function) under the dual task condition was significantly reduced in comparison to trials in which participants completed the search task in isolation. These results indicated that search relied on the acquisition of spatial information maintained in VWM.

It is evident from these studies that maintaining spatial information unrelated to the primary search task in VWM tends to inhibit search performance. However, if the VWM load is relevant to the search task, search performance can be facilitated by the presence of a VWM load. The facilitation of search performance due to a concurrent

VWM information load has been demonstrated using the preview search paradigm established by Watson and Humphrey (1997). In the preview search paradigm, a subset of distractor objects are briefly displayed to the participant before the primary search task begins. For example, Al-Aidroos et al. (2012) had participants search for a target letter among distractor letters. A comparison of the preview and no-preview conditions revealed that search was facilitated when distractor letters were previewed. The preview allowed participants to visually mark the distractors because the distractors maintained their current spatial position, thereby reducing the number of items requiring inspection during search. Moreover, search performance was optimal when the previewed set size was limited—within the estimated capacity of VWM (i.e., four items). The results from Al-Aidroos et al. (2012) indicate that maintaining search relevant information in VWM can be used to guide search processes and consequently improve search performance.

The visual attention literature provides ample evidence implicating VWM in search processes. However, to study precise cognitive mechanisms, researchers often sacrifice ecological validity in favor of increased internal validity through the use of simple stimuli with limited generalizability. Therefore, it can be difficult to determine how these results transfer to complex search tasks that involve a multitude of variables, such as baggage screening.

Perceptual Complexity of Visual Objects

Although the definition of a visual object is not always clear, it can be useful to consider a visual object as "a connected and bounded region of matter that maintains its connectedness and boundaries when it moves" (Eng, Chen, & Jiang, 2005, p. 1127). Using this definition, object features can be identified to determine the corresponding degree of perceptual complexity. Some of these features include color, spatial orientation, and perceived 3-dimensional depth created by the connection of object boundaries. Simple visual objects are generally distinguished from complex objects by occupying a single feature rather than a conjunction of features. For example, the connection of lines forming a basic shape such as a square is a relatively simple object. Conversely, a picture of a human face includes numerous visual features and is thus exceedingly complex by comparison.

Research has shown that processing complex visual objects increases the information load placed on VWM. As a result, VWM capacity is reduced for complex objects compared with simple objects. Eng et al. (2005) demonstrated this capacity reduction in a study involving separate change detection and visual search tasks. For the change detection task, each trial began with a brief presentation of a memory display containing an array of objects that varied in perceptual complexity from trial to trial. After a retention interval, two objects were displayed to the participant who was tasked with identifying the non-memory array-matching object. Accuracy across trials for each stimulus type was pooled and used to calculate the estimated VWM capacity for each stimulus type. Results showed that estimated memory capacity was lower for complex stimuli (e.g., faces) than simple stimuli (e.g., letters). In a similar study, Luria, Sessa, Gotler, Jolicœur, and Dell'Acqua (2010) used a combination of behavioral (i.e., accuracy and reaction time) and electrophysiological measures (i.e., sustained posterior contralateral negativity amplitude) of VWM, and found converging evidence for a reduction in VWM capacity due to stimulus complexity. Considering the prominent role of VWM in visual search processes, these findings have implications for visual search performance involving complex displays.

Analysis of the visual search data from Eng et al. (2005) revealed a similar reduction in performance attributable to the perceptual complexity of visual objects. Specifically, the results of the visual search task indicated a significant increase in the mean and slope of the reaction time (RT) function for search arrays containing complex objects. Likewise, Luria et al. (2010) found that mean RT increased as stimulus complexity increased. To summarize the results of the search data in these studies, the increased informational load associated with processing complex objects had a clear negative impact on visual search performance.

Baggage screeners as well as other operators often complete complex search tasks that impose high informational loads, impacting search performance. Changes to the operator's visual search protocol might alleviate some of the performance limitations in completing complex search tasks. For example, preview search might allow operators to search complex displays with greater efficiency by occupying VWM with search relevant information, subsequently guiding their search process.

In the visual attention literature, studies have investigated the effect of preview on the search of digitized images of real world scenes (e.g., Castelhano & Henderson, 2007; Hollingworth, 2009; Võ & Schneider, 2010). These studies provide insight into how contextual and specific object location information that is accumulated in VWM during preview can facilitate search. In addition, the use of real-world scenes can be useful for understanding how preview effects might transfer to search tasks involving complex displays. For example, experiment 1b of Hollingworth (2009) had participants search scenes under no-preview, 2 s, or 500 ms preview conditions; participants were then shown a target probe for 1.5 s. Next, participants began the timed primary search task for the cued target probe. Results showed that previewing scenes facilitated search performance in comparison to the no-preview control condition. The mean RT for 2 s and 500 ms previews did not significantly differ, indicating that a brief preview of a scene can facilitate search.

In experiment 2 of Hollingworth (2009), target presence within the preview was manipulated to distinguish the effects of memory for scene context from memory for specific target locations. An overall preview effect was observed, and search efficiency further increased when the target was present in the preview. These results indicate that memory for an overall scene context as well as the binding of target objects to specific locations was accumulated in VWM during preview. Furthermore, preview effects can involve the integration of image information at both the global (i.e., context generated from the spatial arrangement of image features) and local (i.e., object location information) levels (Vogel, Schwaninger, Wallraven, & Bulthoff, 2007; Wolfe, Vo, Evans, & Greene, 2010). Thus, the presence of a preview effect involving real world scenes suggests that, despite the increased perceptual complexity of objects, people are able to maintain global and local image information in VWM during preview that can then be used to facilitate search.

Although previewing real world scenes can facilitate search, there are some important limitations when considering the extent to which these findings generalize to operators carrying out complex search tasks. The use of real world scenes allows top down knowledge of scene context to integrate with bottom up information gained from the preview. Top down influences can effectively guide search processes by reducing the search space based on previous experience (Woodman & Chun, 2006). For example, when searching a kitchen scene for a toaster, search might begin at counter top surfaces rather than unlikely locations such as the kitchen floor (Eckstein, Drescher, & Schimozaki, 2006). In regards to baggage screening, the random nature of item arrangement in bags prevents the screener from leveraging top down knowledge during search. Also, screeners are not informed of specific targets during search; thus, the priming of search targets is not an option for baggage screeners.

The Impact of Visual Clutter on Search Performance

To further understand the demands of searching complex displays, it is important to consider how clutter impacts search processes. Visual clutter can be defined as an increase in information density due to the crowding and masking of items, resulting in increased difficulty associated with identifying information in a display (Beck, Lohrenz, & Trafton, 2010). Depending on the degree of target-distractor discriminability, search array set size can provide a good estimate of search difficulty; however, the set size of a complex display is often difficult to determine (Rosenholtz, Li, & Nakano, 2007). Therefore, calculating the degree of clutter in a display can be useful for determining the degree of search difficulty associated with complex displays, as well as identifying particular areas of the display that are highly cluttered. Numerous methods for calculating visual clutter have been developed and assessed in visual search experiments (e.g., Bravo & Farid, 2008; Lohrenz, Trafton, Beck, & Gendron, 2009; Rosenholtz et al., 2007). Although methods tend to differ in terms of the variables included in the clutter calculations, a majority of clutter algorithms prove to be useful for computing display clutter and estimating search difficulty.

Several studies have demonstrated how search performance is disrupted due to the presence of visual clutter (e.g., Beck et al., 2010; Neider & Zelinsky, 2011; Rosenholtz et al., 2007; Wickens & Carswell, 1995). For instance, Beck et al. (2010) used a clutter algorithm to develop complex search displays with varying degrees of global (low, medium, and high) and local clutter (low and high). Global clutter was defined as the amount of clutter across the entire display, and local clutter as specific to the area surrounding a particular target item. Figure 1 depicts the variation in global and local clutter for search displays used in that study. Results from the search task showed that search performance decreased as either global or local clutter increased. Specifically, performance decreased as global clutter increased from low to medium, but not from medium to high. Interestingly, the effect of global clutter primarily disrupted search performance if the target was also embedded in a high degree of local clutter.

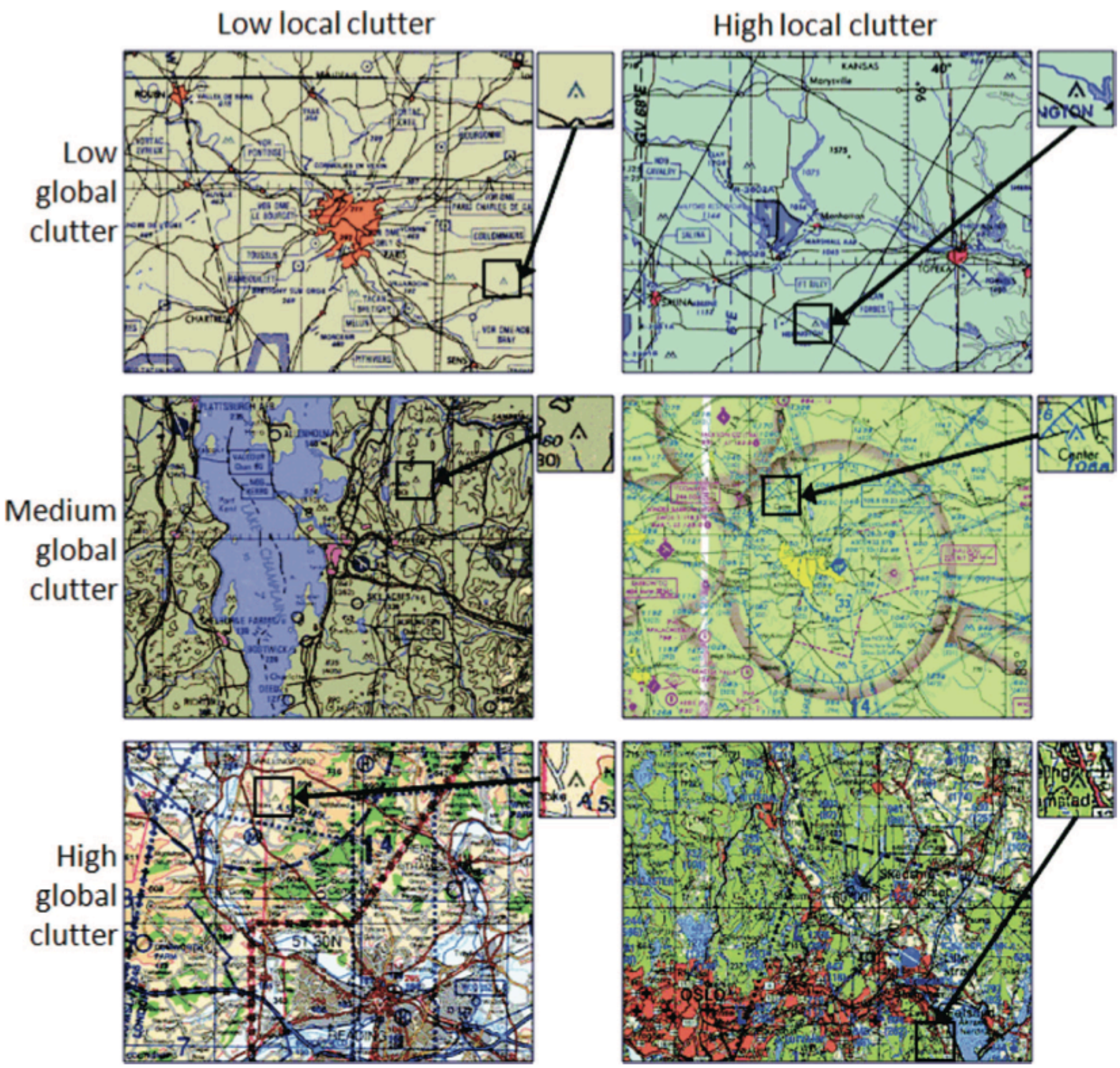

Figure 1. Examples of search displays used in Beck, Lohrenz, and Trafton (2010). Columns represent differences in local clutter, and rows represent varying levels of global clutter.

Within the domain of baggage screening, researchers have explored the impact of several image-based factors on weapon detection performance (Schwanninger, Michel, & Bolfing, 2007; Schwanninger et al., 2008). Using two methods of measuring image-based factors, human ratings and a computational method, Schwanninger and colleague’s research suggests that clutter is only minimally involved in predicting weapon detection performance. However, the authors’ measure of clutter included fewer features than the previously mentioned clutter algorithms (i.e., Beck et al., 2010; Rosenholtz et al., 2007). Moreover, other researchers have used somewhat rudimentary measures of clutter to demonstrate the negative effects of clutter on baggage screening performance (Fiore, Scielzo, Jentsch, & Howard, 2006; Sellers, Rivera, Fiore, Schuster, & Jentsch, 2010). Specifically, these researchers measured clutter by simply counting the number of overlapping luggage items to categorize bags into low- and high-clutter. Surprisingly, well-established and empirically validated clutter algorithms have not been used to fully explore the effect of clutter in the context of baggage screening. Therefore, given these unclear results regarding the impact of clutter in baggage screening, and in combination with research demonstrating deleterious effects of clutter in complex search tasks (e.g., Beck et al., 2010), further investigation of potential clutter effects on baggage screening performance is warranted.

The Current Study

In the current study, participants searched x-ray images of bags for weapon items in a low fidelity baggage screening simulation. Weapon items were systematically assigned to bag regions to ensure that an equal number of weapons appeared in each level of clutter (low-, medium-, and high-clutter). A preview manipulation involved presenting a predetermined portion of the bag to the participant. Two of three preview conditions were based on the output of a clutter manipulation. Using the output of a clutter algorithm, a low-clutter preview condition presented a region of the bag associated with the lowest degree of clutter while the remainder of the bag was displayed in a reduced contrast gray-scale format. The second clutter-based condition, a high-clutter preview, contained the region of the bag with the highest degree of clutter. The third condition, a control condition, displayed the entire bag for the duration of the preview and search phases of the trial. This control condition constituted a baseline, revealing any performance differences that might otherwise be attributable to increased exposure to the bag during the preview phase. The preview manipulation provided insight into how the strategic use of clutter information can impact search processes.

In the context of baggage screening, the results from Beck et al. (2010) suggest that search performance will likely decrease if a threatening object is embedded in high local clutter. Because highly cluttered local regions require additional processing, operators could benefit by having visual attention guided toward the high-clutter region at the onset of search display. Studies using preview search paradigms have demonstrated how the contents of VWM can be used to guide search processes. Therefore, the formation of a preview display based on the output of a clutter algorithm could provide a means for biasing the operator's visual attention towards a particularly cluttered region of the bag that requires significant processing time in order to verify the presence of a weapon. Examination of baggage screening performance for each preview condition will provide insight regarding potential preview effects in a complex search task.

Performance for the low- and high-clutter preview conditions will be compared with the control condition to determine if a clutter-based preview can facilitate search beyond the traditional search procedures, represented by the control condition. For the high preview condition, a preview effect is predicted in that weapon detection performance will be superior to the control condition. The rationale for this prediction stems from the notion that because highly cluttered local regions require additional processing, search performance should increase by guiding attention toward that region at the onset of the bag display. For the low preview condition, no preview effect is predicted as performance is expected to be approximately equal between the low preview and control conditions. Any potential low-clutter preview effect is likely to be negligible because weapons located in low-clutter are relatively easy to identify due to reduced competition arising from low levels of visual noise surrounding the weapon. Moreover, low-clutter weapons are likely to be amenable to detection via a pop-out effect wherein the weapon template is easily discriminated from the surrounding luggage items. In other words, the low preview effect facilitates the detection of weapons that would have otherwise been easy to recognize.

Examining performance for each preview condition will provide insight regarding the operative cognitive mechanism underlying potential preview effects. The combination of a high-clutter preview effect and the absence of a significant low-clutter preview effect would suggest that the preview facilitation is primarily due to the guidance of attention toward the previewed region rather than maintaining the previewed information within VWM for processing during the preview phase. Presumably, the perceptual complexity inherent in the high-clutter region overwhelms VWM capacity; thus, potential benefits associated with a high-clutter preview effect are likely to be driven by the biasing of selective visual attention toward the previewed region. By comparison, the low-clutter region is more amenable to VWM capacity limitations; consequently, participants are more likely to efficiently process the low-clutter region during the preview phase and determine if a weapon is present. If it is the case that no low-clutter weapon is present, then participants could inhibit processing the low-clutter region during the search phase, thereby contributing to increased search efficiency. Therefore, the combination of a high-clutter preview effect with no effect of low-clutter preview would indicate a prominent role of attention guidance in facilitating search processes rather than VWM capacity limitations.

With regard to preview effects, two alternative outcomes are considered. First, it is possible that a reversal of the predicted preview effects (as outlined above) will occur. That is, preview effects could be isolated to the low preview condition with no differences between the high preview and control conditions. In this alternative series of results, the low-clutter preview effect would be driven by superior low-clutter weapon detection performance, with no performance costs associated with other weapon locations. In contrast to the primary hypothesis, this outcome would suggest that the cognitive mechanism underlying the preview effect is the limited capacity of VWM. The low-clutter region necessarily contains the least perceptually complex information, thereby allowing the participant to reliably maintain the previewed information in VWM so that it can be efficiently processed. As a result, the participant will be more likely to use the contents of their VWM during the preview phase to determine if a weapon is present in that region, and if not, inhibit processing that region during the search phase in order to begin scanning other bag regions.

A second alternative prediction for consideration is the potential outcome of null results. It could be the case that neither low or high preview condition facilitates search performance beyond the control condition. Of course there are numerous potential explanations for such null results, both theoretical and methodological; however, one might expect such an outcome if the preview process disrupted the formation of a global representation of the search space that is important for subsequent search processes. As research has indicated (Vogel et al., 2007), distinct global and local processes are involved in processing and categorizing real world scenes. Generalizing from real world scenes to baggage screening, it is tenable that by restricting the bag image during the preview process, global image processing is thwarted, forcing the low and high preview conditions to wait until the preview phase has ended before forming a global representation of the search space. Presumably, this effect would lead to performance reductions attributable to locating weapons outside the corresponding previewed regions for the low and high preview conditions.

In summary, analyses of baggage screening performance and eye tracking data will provide insights regarding the efficacy of using visual clutter information to facilitate search processes as well as the cognitive mechanism involved in potential preview effects.

CHAPTER 2

METHOD

Participants

A total of 97 undergraduates enrolled in psychology courses participated during the Fall 2013 and Spring 2014 semesters. Participants elected to participate using the Sona experiment scheduling system. Participants received course credit as compensation for participating. All participants reported having normal or corrected to normal vision.

Of the 97 participants, seven were excluded. Two participants were excluded from all analyses due to a software error that occurred during the experimental session. In addition, one participant was excluded for having a color vision test score that was more than 2.5 standard deviations below the mean for two of three color vision scales; no other participants met these exclusion criteria. Furthermore, four participants that had their eye movements recorded were excluded from analyses for having an insufficient percentage of trials that were successfully tracked by the eye tracking system. Participants with less than 70% of the trial successfully tracked by the system were replaced (N=4) until there were eight participants with valid eye movement data per preview condition. Ultimately, 90 participants (52 male), with a mean age of 19.89 years (SD = 2.15), participated in the study, with 24 of them randomly selected to provide eye movement data.

Apparatus

The experiment was conducted with computers running Windows 7 operating system. The experimental procedure was programmed using E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) and Paradigm Elements (Perception Research Systems Inc., Teaneck, NJ). All stimuli were displayed on Dell 22" LCD monitors configured with a resolution of 1280 x 1024 pixels and refresh rate of 60 Hz. An Applied Science Laboratories EYE-TRAC D6 remote eye tracker (Applied Science Laboratories, Bedford, MA) was used to record eye movement data. The D6 eye tracker unobtrusively records eye movements at a 120 Hz sampling rate with a spatial resolution of 0.5°.

Stimuli Construction

The stimuli used in this study consisted of x-ray images of bags compiled from an image set used by Merritt and Illgen (2008). The image set used in this study contained 46 empty bags, 235 luggage items, 25 clothing wads, and 15 weapons (9 guns, 6 knives). Luggage items included a wide array of objects that could be carried onboard an airplane including personal hygiene, travel games, books, and various electronic devices. A variety of potential orientations were associated with each luggage item image including 0°, 45°, 90°, 135°, 225°, 270°, and 315°. Thus, luggage items had multiple unique images for each orientation. In total, there were 1107 unique images of luggage items used to create bags. For weapons, careful consideration was given to the selecting the 15 weapon images. All weapon images included in the set depicted the weapon from the side rather than a top or bottom view in order to provide the most informative view regarding the weapon's shape. Compiled bags were displayed to participants at a size of approximately 15° width and height of visual angle from an assumed distance of 60 cm from the monitor.

Bag Construction Procedure

The procedure for constructing bags was scripted in python and a total of 685 unique bag images were compiled. The procedure began by randomly selecting an empty bag image without replacement from the set of 46 unique bag images. Five clothing items were then randomly selected and assigned to a random location that was determined by a pair of randomly generated X and Y coordinates that fell within the bag boundaries. Next, 20 to 25 luggage items were randomly selected without replacement then assigned to a location based on a pair of randomly generated X and Y coordinates that fell within the bag boundaries. Consequently, luggage items could overlap with previously assigned luggage and clothing items. No additional measures were taken to ensure that the arrangement of items reflected realistic packed bags. After each item image in a set had been used, the selection process was repeated with all items; thus, bag, clothing, and luggage item images were re-used during the bag construction procedure to arrive at 685 bags.

Compiled bag images were analyzed using the feature congestion clutter algorithm (Rosenholtz et al., 2007) before weapons were assigned. Each bag image was quartered, dividing the bag into four equally sized images. Each quarter was separately analyzed using the clutter algorithm.

The output of the clutter algorithm provided a number that constituted a measure of the clutter, with increasing clutter values indicating increased levels of clutter. Clutter values were assessed in order to identify one of the four bag regions categorized as high- (i.e., largest clutter value) and one as low-clutter (i.e., smallest clutter value); the remaining two regions were categorized as medium-clutter. Within each bag, the difference in clutter values between the highest and lowest cluttered regions was computed. However, due to the randomization involved in the bag construction process, the precise clutter value associated with each clutter category varied. Therefore, a difference criterion of 1.5 clutter value units was used to ensure each bag included in the experiment had high- and low-clutter regions that substantially differed in clutter values. Of the 289 bags that met the difference criterion, 235 were randomly selected and used in the study. The mean clutter value associated with each clutter category for the bags used in the current study are presented in Table 1.

Table 1

Mean Clutter Values for Each Bag Region Clutter Category

Bag Region Clutter Category	Clutter Value	
	M	*SD*
Low-Clutter	4.949	0.731
Medium-Clutter 1	5.912	0.762
Medium-Clutter 2	5.981	0.817
High-Clutter	6.965	0.641

<u>Weapon Assignment</u>

Weapon base rate was 22.5% for bags used in the experiment proper; thus, 45 of the 200 bags contained a weapon. Although the real world base rate for guns and knives in luggage screening is likely much lower (Hogan, Bell, & Olson, 2009), the justification for this higher base rate is due not only to the pragmatics of the experiment but to the fact that screeners are also required to check bags with less threatening contraband items such as scissors and liquids exceeding the permitted volume.

Weapon-present bags were randomly selected from the previously selected 235 bags that met the difference criterion. Each weapon was randomly selected from the set of 15 weapon images (9 guns, 6 knives) then randomly assigned without replacement to one of the three clutter categories. Although each bag contained four bag regions, each weapon had a one third probability of being assigned to the low-, high-, or medium-clutter regions. Thus, there were 15 bags with a weapon present in one of the three clutter categories, resulting in 45 unique weapon-present bags. For bags with the weapon assigned to a medium-clutter region, one of two medium-clutter regions was randomly selected to include the weapon; consequently, each medium-clutter region had a one sixth probability of a weapon being assigned to that region.

The precise weapon location within each bag was determined by generating a random set of X and Y coordinates that fell within the predetermined clutter region and the bag boundary. The top left pixel associated with each weapon image (i.e., X = 0, Y = 0) was used to position the weapon for the randomly generated X and Y coordinates. Consequently, it was possible that a portion of the weapon extended outside the selected clutter region. However, weapon locations were reviewed and only five weapon images extended outside the assigned region. Moreover, of these five cases, an average of 82% of the weapon image's pixels were contained within the assigned region thereby ensuring that the majority of the weapon was contained within the predetermined region.

Preview Conditions

Three preview conditions were used to assess the effect of previewing a bag region image before searching for a target. Preview conditions differed in terms of the method used for determining the previewed information. Based on the output of the clutter algorithm, high- and low-clutter regions of the bag were used to form two preview conditions. The third condition was the control condition that displayed the entire bag to the participant for the duration of the preview phase. The control condition served as a point of comparison for how participants would carry out search processes without a clutter-based preview intervention. Weapon presence within high and low previews was fixed at 7.5% across all trials to ensure that each preview condition contained an equal number of trials in which the weapon was present within the previewed region. The result was that 15 bags had a weapon in the high-clutter preview and 15 bags with the weapon present in the low-clutter preview. For the control condition, the entire bag was displayed in full color and contrast for the duration of the trial; thus, the weapon presence within the preview was equivalent to the experiment's weapon base rate. The total number of bag types defined by the weapon placement is depicted in Table 2. All participants screened the same bags across the experiment; therefore, all participants experienced an equal number of trials for each level of weapon placement.

As depicted in Figure 2, the previewed bag region was displayed in full color while the remaining bag regions were depicted in gray scale with a reduced contrast. The high- and low-clutter preview regions were displayed in the same position throughout the preview and search phases. After the preview phase ended, the entire bag was presented in full color, thus signaling the onset of the search phase.

Table 2

Bag Types for all Preview Conditions and Weapon Placements

	Weapon Placement				
Preview Condition	Low	Medium1	Medium2	High	Absent
Low	15 bag type A	15 bag type B	15 bag type C	15 bag type D	155 bag type D
High	15 bag type A	15 bag type B	15 bag type C	15 bag type D	155 bag type D
Control	15 bag type A	15 bag type B	15 bag type C	15 bag type D	155 bag type D

Note. A depiction of the bag types across the experiment. Bag types were repeated across each level of preview as all participants screened the same bags. The match between weapon placement and preview type determined whether the participant previewed an area that contained a weapon.

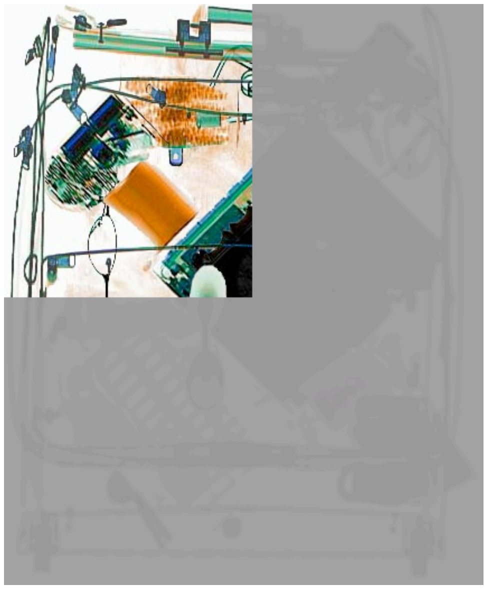

Figure 2. An example of the preview image with the remaining baggage regions displayed in reduced contrast.

Design

The experiment was a 3 (Preview [high, low, control]) by 4 (Weapon Location [low-, medium-, high-clutter, absent]) mixed design with preview manipulated between-subjects. Participants were randomly assigned to one of three preview conditions and were not informed of the alternative conditions. All participants screened the same bags across the experiment to control any effects attributable to individual bag characteristics. The order in which the bags were presented was randomized for each participant.

Three experimenters were involved in data collection, but only one experimenter was trained in using the eye tracking system. For each experimental session, one experimenter was present to collect data and guide the participant through the experiment. Thus, for each experimental session conducted by the qualified experimenter, one participant was randomly selected to have his or her eye movements recorded during the baggage screening task. Otherwise, participants would complete the task without eye movements recorded.

The dependent measures for baggage screening performance included target recognition accuracy (i.e., hit and false alarm rates) and reaction time (RT). RT was defined as the time taken to press a key that indicated whether a weapon was present, beginning at the onset of the bag image in the preview phase.

Eye movement data (i.e., percent fixation duration and first fixation time) were recorded to understand how the preview process and visual clutter impact search processes. For the participants who had their eye movements recorded, fixations were calculated using ASL Results Plus software (Applied Science Laboratories, Bedford, MA). Fixations were defined as beginning when a gaze is stable for a minimum duration of 100 ms in an area of 1° visual angle, and ends when more than three sequential gaze samples deviates from the start fixation position. Fixation duration and first fixation time were assessed in the context of areas of interest, operationalized as the bag clutter regions.

Procedure

The experimental session lasted approximately 2 hr and included informed consent, a color vision test, a task briefing, a block of 10 practice trials, a block of 200 experimental trials, a subjective workload assessment, a block of 25 transfer trials, a change detection task, and a post study questionnaire. After obtaining consent, participants were seated at a desk in an experimental room with a keyboard placed directly in front of the participants and a computer monitor situated approximately 60 cm from the edge of the desk. Participants were then instructed to complete a color vision test (Biyee SciTech) that was displayed on the computer monitor.

Participants were randomly selected to have their eye movements recorded. Experimental sessions were scheduled to accommodate two participants; however, sessions were not cancelled if only one participant arrived. If only one participant arrived and the experimenter was trained in using the eye tracking system, the participant would complete the experiment with the eye tracking apparatus unobtrusively located directly below the monitor. However, if two participants were scheduled for a session with the trained experimenter, one participant was randomly selected to have his or her eye movements recorded. The eye tracking system was calibrated immediately before the baggage screening practice trials.

Baggage Screening Task

During the task briefing, a detailed description of the task procedure was displayed on the monitor. Participants were informed that they were to conduct a baggage screening task that required visually inspecting each bag in order to determine whether it was safe to pass security. To familiarize participants with the task, an example of a compiled bag image as well as potential weapon items were presented to participants during the briefing.

In addition, general information regarding the preview condition was conveyed to participants. That is, all participants were informed that the previewed information was selected by the screening system, and that they should use this preview information to assist with the completion of the task to the best of their abilities. No further information regarding the purpose or validity of the previewed information was provided. Participants were told that their goal was to complete the screening task and make a decision as to whether the bag should be allowed to pass security as quickly as possible without making any errors. Moreover, participants were instructed to form their decision based only on whether the bag contained a weapon.

After reviewing the task instructions, participants completed a set of 10 practice trials. At the end of each practice trial, participants received feedback regarding the accuracy of their response. During the practice trials, participants experienced all four trial types to increase their familiarity with the task. Specifically, participants completed three weapon-present trials that covered the high-, medium-, and low-clutter weapon placements; the remaining seven trials were weapon-absent trials. Before and immediately after completion of the practice trials, participants had the opportunity to ask the experimenter questions related to the task instructions. Practice trials were identical to the experimental trials with two exceptions: During practice, participants received feedback regarding the accuracy of their response at the end of each trial, and were allowed to pause to ask the experimenter questions. Participants were not given such feedback nor were they given the opportunity to ask the experimenter questions during the experimental block.

The trial sequence for each preview type is displayed in Figure 3. Each trial began with a centered fixation cross for 1 s, followed by the preview image for 1.5 s. After the preview phase, the entire bag was displayed during the search phase as the participant completed a timed weapon detection task for either 10 s or until the participant indicated a response. For the control condition, the preview phase contained the entire bag; thus, there was no noticeable difference between the preview and search phases (see Figure 3, c). In all conditions, the participant's task was to accurately determine whether the bag contained a weapon and to do so as quickly as possible. Using the keyboard, participants indicated a screening decision by pressing the 'z' key if a weapon was present, or the 'm' key if no weapon was present indicating the bag was safe to move past security. After the participant formed a response, the trial terminated and the next trial began. If the participant failed to indicate a response within 10 s, the participant's response defaulted to "weapon absent" and the next trial would begin. However, to prevent participants from adopting a strategy of delaying to the end of a trial to form their response, participants were not informed that failing to respond within 10 s was equivalent to indicating that no weapon was present.

Subjective Workload Assessment

After participants completed all experimental trials, participants began a subjective workload assessment. For the workload assessment, participants completed a digital version of the NASA Task Load Index (TLX) displayed on the computer monitor (Hart & Staveland, 1998).

Baggage Screening Transfer Task

Next, participants began a block of 25 baggage screening transfer trials. The purpose of the transfer block was to determine the extent to which potential benefits of the preview process transferred to a screening task that no longer included a preview phase. Transfer trials were similar to the experimental trials with two exceptions: There was no preview phase and weapon placement was confined to only medium-clutter regions. Participants were informed that the preview phase was removed and that they must make their decisions within the confines of the 10 s search phase. Furthermore, participants were instructed to complete the task with the same goal as the experimental trials. In addition, weapon base rate was fixed at 20% across the transfer block with five weapon-present trials.

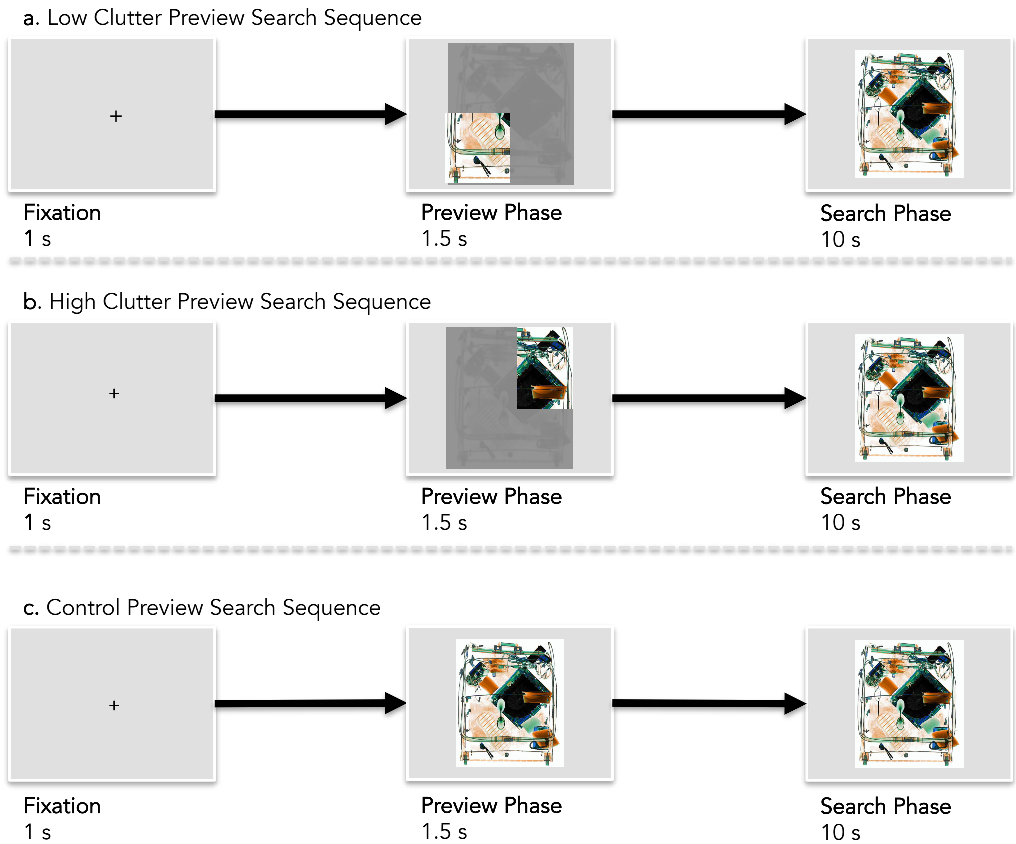

*Figure 3***.** A depiction of the trial sequence for a medium trial type in the (a) low clutter preview, (b) high clutter preview, and (c) control preview conditions. The search phase concludes when the participant indicates a response or the 10 s time limit is reached.

<u>Change detection task</u>

Upon completion of the transfer block, participants began a visual working memory span task to explore the role of VWM capacity in baggage screening performance. Modeled after Luck and Vogel's (1997) change detection task, the task involved the presentation of a sample array of 1, 2, 4, 6, 8, or 12 colored rectangles for 100 ms, followed by a 500 ms delay, and concluded with a test array of colored rectangles. The participant's task was to determine whether the sample and test arrays were the same or different. The array set size and the location of rectangles was randomized across trials. Half of all trials were change trials, in which the two arrays differed in the color of one rectangle. The number and location of rectangles were identical across the sample and test arrays. Participants completed 10 practice trials followed by 60 experimental trials.

A post study questionnaire was administered to all participants after completing the change detection task. The questionnaire included an open-ended question, asking the participant to explain how they went about completing the baggage screening task. In addition, the questionnaire included demographic information, specifically age and gender. Upon completion of the post study questionnaire, participants were assigned Sona credit and thanked for their participation.

CHAPTER THREE

RESULTS

Baggage Screening Task

For all baggage screening measures, data from the preview and search phases were combined. That is, for each trial, data from the preview phase was not distinguished from the search phase. Analyses were conducted using IBM Statistical Products and Services Solutions (SPSS) 21. Performance (i.e., sensitivity indexes and RT) data were analyzed to determine how preview conditions and visual clutter impact weapon detection performance. For all post hoc comparisons, the family wise error rate was corrected using the Bonferroni correction procedure. The descriptive statistics for all of the reported results are available in appendices A through G.

Sensitivity Index

In order to examine the overall effect of preview on baggage screening performance, an overall sensitivity index estimate (d') was computed for each participant. The overall sensitivity index estimate was collapsed across all levels of weapon location; therefore, no distinction was made between different weapon locations at this point. Each participant's sensitivity, hit rate, false alarm rate, and criterion were subjected to a one-way analysis of variance (ANOVA) with preview condition (low, high, control) as the factor. There were no significant effects of preview condition on overall sensitivity, hit rate, false alarm rate, or criterion (all ps $> .05$). Consequently, the hypothesis that preview would lead to improved search performance was not supported.

However, it is possible that each preview condition had subtle benefits associated with detecting weapons that appeared within the corresponding previewed region. Therefore, rough estimates of sensitivity indexes for each level of weapon location were computed for each participant by subtracting the participant's overall false alarm rate (i.e., the false alarm rate used in the above analysis of overall sensitivity) from his or her hit rate corresponding with each weapon location. For example, high-clutter weapon sensitivity was computed by subtracting the participant's overall false alarm rate from his or her high-clutter weapon hit rate. Overall false alarm rates were used to compute weapon location sensitivity because analyses at each weapon location level only involved weapon-present trials; thus, there was no opportunity for the participant to commit a false alarm for each level of weapon location.

The mean sensitivity value for each weapon location is displayed in Figure 4. To assess the effect of bag region clutter on weapon detection performance, weapon location sensitivity values were analyzed in a 3 x 3 (Weapon Location [low-, medium-, high-clutter]) x (Preview [low, high, control]) mixed-design ANOVA with preview as the between-subjects factor. The ANOVA revealed a significant main effect of weapon location on sensitivity, $F(2, 174) = 105.667$, $p < .001$, $\eta p2 = .548$, but no main effect or interaction of preview condition on target sensitivity values, $p > .05$. Post-hoc comparisons revealed a significant decrease in sensitivity as weapon location increased in clutter from low to medium and from medium to high (all $ps < .001$). In summary, these results replicate the deleterious effects of increasing visual clutter on weapon detection performance (Fiore et al., 2006; Sellers et al., 2010) and extend it by using a visual clutter algorithm. However, the combination of results from both the overall and weapon location sensitivity analyses indicate that giving participants a preview based on clutter does not facilitate weapon detection performance over and above simply seeing the entire bag for an equivalent amount of time.

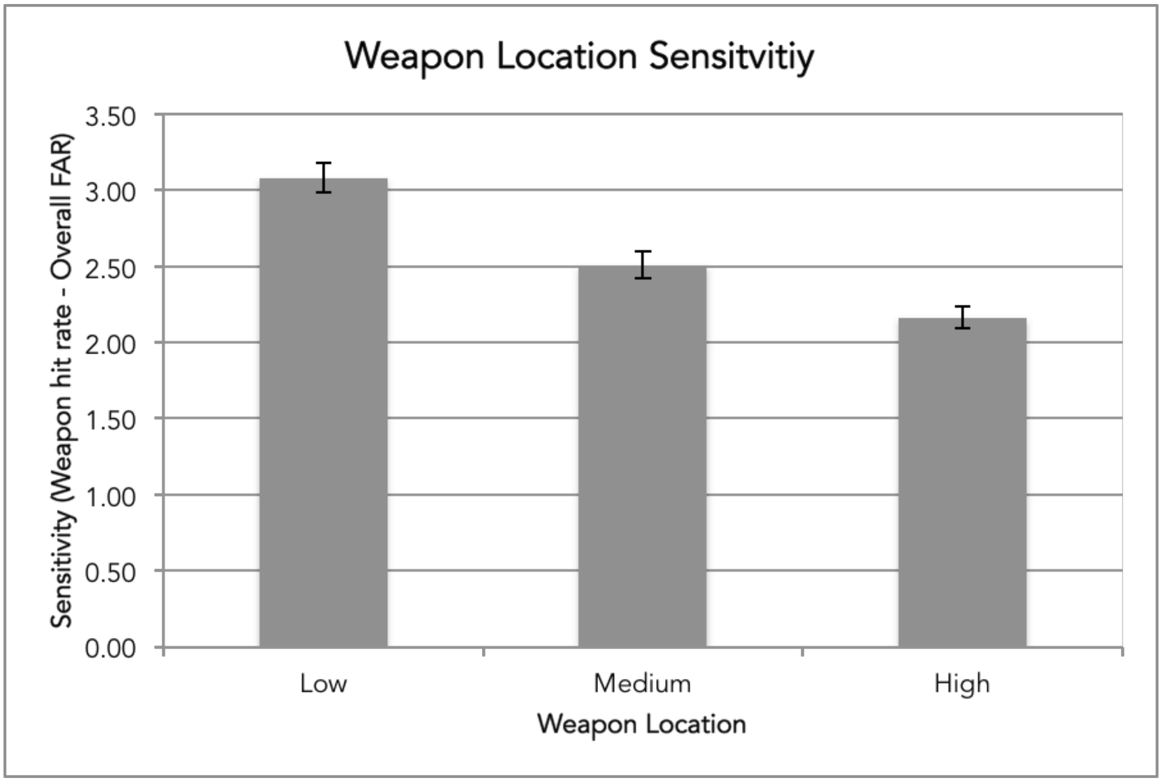

Figure 4. Mean sensitivity value for each weapon location (computed by subtracting weapon hit rate from overall false alarm rate for each weapon location) across preview conditions. Illustrates reduced weapon detection performance as weapon location clutter increases.

Reaction Time

As a measure of search efficiency, RT data were analyzed to determine how preview and weapon location impacted weapon detection efficiency. Although there were no effects of preview on weapon detection sensitivity, it is tenable that preview could improve the efficiency with which participants were able to detect weapons, particularly weapons located within the previewed region.

The mean RTs associated with each weapon location were computed for each participant and analyzed in a 4 x 3 (Weapon Location [low-, medium-, high-clutter, absent]) x (Preview [low, high, control]) mixed-design ANOVA with preview manipulated between-subjects. The mean RT for each weapon location is displayed in Figure 5 with separate data series for each preview condition. There was a significant main effect of weapon location on mean RTs, $F(3, 261) = 303.555$, $p < .001$, $\eta p2 = .777$, with significant increases in overall mean RT as the weapon location increased in clutter from low to medium, medium to high, and high to absent (all $ps < .001$). The main effect of weapon location supports the conclusions drawn from the sensitivity analyses, serving to highlight further the negative effects of increasing visual clutter on search performance.

In addition, the ANOVA revealed a significant main effect of preview on mean RTs, $F(2, 87) = 9.941$, $p < .001$, $\eta p2 = .186$, as well as a significant weapon location by preview interaction, $F(6, 261) = 9.431$, $p < .001$, $\eta p2 = .178$. As can be seen in Figure 5 and confirmed by post hoc comparisons, the interaction was driven by faster RTs for the control condition for weapons located outside of the previewed regions for the low and high preview conditions. That is, the control condition was faster than the low preview condition for weapons located in the medium- and high-clutter regions, $ps < .01$, with no difference for weapons located in the low-clutter region, $p = .468$. Similarly, for weapons located in the low- and medium-clutter regions, the control condition was faster than the high preview condition, $ps < .01$, but no difference for weapons in the high-clutter region, $p = .634$. To summarize, the control condition was always faster than the low and high preview conditions unless the weapon was located in the previewed region, in which case the preview condition was equally as fast as the control.

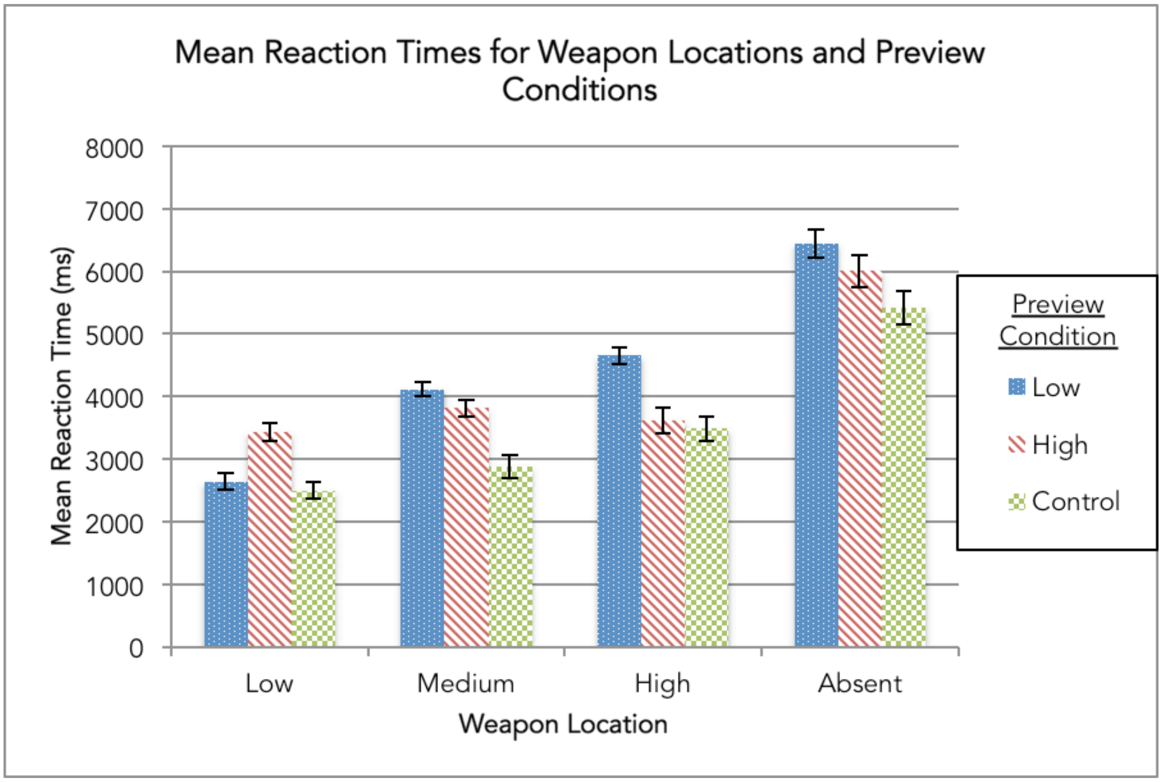

Figure 5. Mean reaction times (ms) for each weapon location with separate data series for each preview condition. This graph depicts the negative effects of weapon location clutter (i.e., local clutter) on weapon detection efficiency, as well as faster RTs for the control condition whenever weapons were located outside of the previewed region (i.e., non-previewed regions).

Post hoc comparisons of RTs for weapon absent trials revealed a significant difference between the low and control preview conditions. Specifically, the control condition was faster than the low preview condition, $p < .01$, with no significant difference between the control and high preview conditions was found, $p = .120$. In other words, the control condition was faster than the low preview condition at determining that no weapons were present in the bag, but the control and high preview conditions were equally as fast.

<u>Eye Movement Data</u>

Each participant's eye data were assessed to ensure that a minimum of 70% of trials had at least 70% of the participant's eye movements successfully tracked during the trial. For the participants that met these criteria, the mean percent of trials tracked for the low, high, and control preview conditions was 94%, 97%, and 93% respectively.

Raw eye movement data were assessed using ASL's Results Plus software to identify fixations that fell within each bag region on each valid trial. Fixations were defined as beginning when a gaze is stable for a minimum duration of 100 ms in an area of 1° visual angle, and ending when more than three sequential gaze samples deviated from the start fixation position. Furthermore, all eye movement measures include data from both the 1.5 s preview and the 10 s search phases.

Eye movement data were analyzed in the context of areas of interest (AOI). For each bag image, an AOI was created for each bag region based on the previously defined clutter categories. For example, an AOI was created for the low-clutter region to identify all fixations that fell within the lowest cluttered region of the bag. Furthermore, the medium-clutter region was divided into two distinct regions providing a total of four AOIs to capture the four equally sized bag regions. Dividing the medium regions in this manner was necessary in order to properly distinguish between the first fixation times in each medium-clutter region.

Fixation duration and first fixation time were computed for each bag clutter region. For each participant, I computed the percentage of the total fixation duration that fell within each bag region for each trial. Percentage, rather than total duration, was used to control for differences in time taken to search the bag. Finally, the mean percentage of total fixation durations for each bag region was computed for each weapon location.

The following analyses are confined to weapon-absent trials and trials with a weapon-region match. Weapon-region match refers to the data associated with a bag region that contains the weapon (e.g., low-clutter region for trials with a low-clutter weapon location). For each weapon location, the non-weapon regions (i.e., high- and medium-clutter regions for trials with a low-clutter weapon location) were not included in the analyses. The rationale for these analyses is that the presence of a weapon in one region could influence the number of fixations in other bag regions that do not contain the weapon, thereby inflating the number and sequence of fixations falling within a particular bag region. Thus, to limit the potential influence of the weapon's location on fixations of other regions, analyses were restricted to weapon-absent and weapon-region match trials. Consequently, this allowed for a direct assessment of the influence of weapon location and bag region clutter levels on eye movements. To analyze the mean percent fixation duration and first fixation time, separate 4 x 3 (Bag Region [low-, medium1-, medium2-, high-clutter]) x (Preview [low, high, control]) mixed ANOVAs were conducted for weapon-absent and weapon-region match trials.

Fixation Duration

The mean percent fixation duration within each bag region for weapon-absent trials is depicted in Figure 6. For weapon-absent trials, the ANOVA revealed a significant main effect of bag region on mean percent fixation duration, $F(3, 63) = 20.353$, $p < .001$, $\eta p2 = .492$, with no main effect or interaction involving preview. The main effect of bag region demonstrates a clutter effect for weapon-absent trials with percentage of total fixation duration increasing as the bag region increases in clutter. That is, for trials with no weapons, participants spent a greater percentage of time fixating regions with higher levels of clutter in order to confirm that weapons were absent. This result expands upon the conclusions drawn from the RT analyses by demonstrating that the increased duration associated with weapon-absent trials was due to participants examining heavily cluttered regions in order to confirm that a weapon was absent.

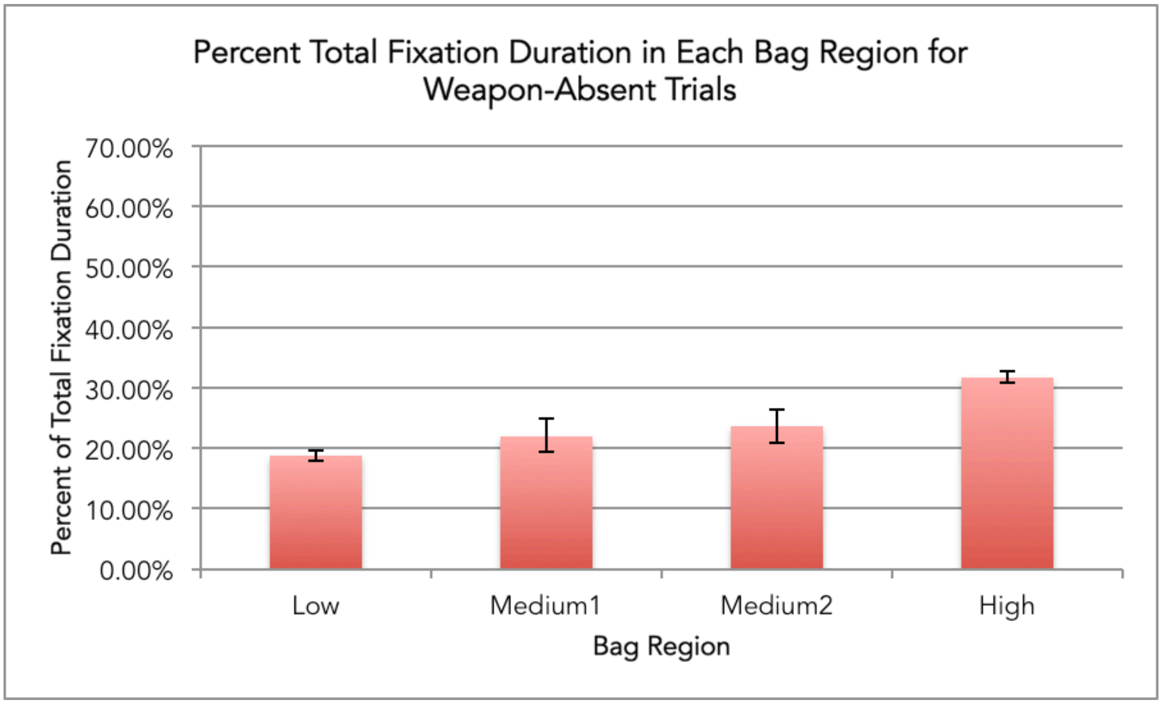

Figure 6. The mean percent total fixation duration associated with each bag region for weapon-absent trials across all preview conditions. Illustrates a clutter effect in that percent fixation duration increases as bag region increases in clutter. Note that fixations falling outside of these bag regions are not depicted; consequently, the total does not sum to 100%.

The mean percent fixation duration for weapon-region match trials is displayed in Figure 7 with bag region on the x-axis and separate data series for each preview condition. For weapon-region match trials, there were no main effects of bag region or preview condition, but there was a significant bag region by preview interaction for mean percent fixation duration, $F(6, 63) = 4.061$, $p = .002$, $\eta p2 = .279$. As can be seen in Figure 7, the mean percent fixation duration is relatively stable across bag regions for the low preview and control conditions. In comparison, for the high preview condition, percent fixation duration was relatively stable across low- and medium-clutter weapon-region match trials but spikes when the weapon was located in the high-clutter region. Indeed, a series of paired-samples t-tests revealed a significant difference in percent fixation duration between medium2 and high weapon-region match for the high preview condition, $t(7) = 4.597$, $p = .002$, with no such difference for the low preview or control conditions, $ps > .10$.

These results indicate that the high preview condition led to a significant change in the way in which participants carried out the search task while the low preview condition was more similar to the control condition. Presumably, the high preview condition led participants to spend more time fixating the high-clutter region due to the combination of attention being directed there during the preview phase as well as the increased perceptual complexity associated with the high-clutter region. In comparison, the reduced complexity associated with the low-clutter region allowed participants in the low preview condition to move on and spend a comparable percentage of time fixating other bag regions to locate the weapon. As a result, low preview participants were more likely to spend time fixating other bag regions in a manner that was more similar to the control condition.

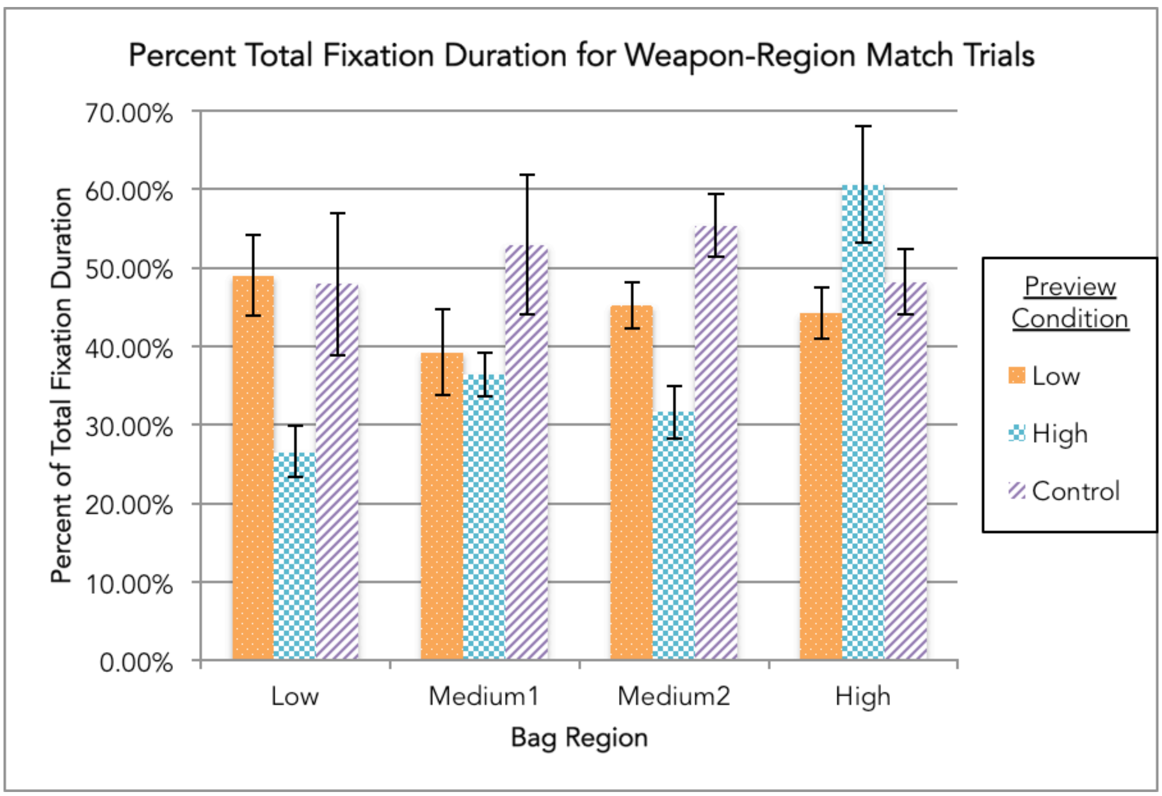

Figure 7. Mean percent of total fixation duration associated with each weapon-region match for each preview condition. Weapon-region match only includes the data from trials with a weapon in the given bag region, excluding the non-weapon region data from the percentage.

In summary, the percent fixation duration data provide insight into how participants allocated time fixating each bag region. Across all preview conditions, if the weapon was absent, participants spent time fixating each bag region in accordance with the level of clutter associated with that region. As the bag region increased in clutter, participants would spend more time fixating the region in order to confirm that weapons were indeed absent. For weapon-region match trials, low and control preview participants spent a comparable percentage of time fixating each bag region in order to identify the weapon. By comparison, participants in the high preview condition spent more time fixating the high-clutter region whenever the weapon was located there. These results suggest that the high preview led participants to spend a greater percentage of time fixating the high-clutter region because attention was directed there during the preview phase. Furthermore, because additional time is required to determine whether a weapon is present in the high-clutter region, a smaller percentage of fixation time was available to the high preview participants whenever a weapon was located within the low- or medium-clutter regions.

First Fixation Time

First fixation time constitutes the duration into the trial, at which point the participant first fixated a given bag region. First fixation time spans across the preview and search phases; therefore, first fixation time for a given region includes any fixations made during the 1.5 s preview phase or the 10 s search phase. Analysis of the first fixation time for each bag region provides insight regarding the sequence of fixations within each bag region.

The mean first fixation times of each bag region for weapon-absent trials is displayed in Figure 8. For weapon-absent trials, there was a significant main effect of bag region, $F(3, 63) = 10.152$, $p < .001$, $\eta p2 = .326$, no main effect of preview but a significant bag region by preview interaction, $F(6, 63) = 9.298$, $p < .001$, $\eta p2 = .470$. The main effect of bag region was qualified by the interaction that was driven by decreased first fixation times for the low- and high-clutter regions for the low and high preview conditions, respectively. As can be seen in Figure 8, first fixation time for the control condition is relatively stable across bag regions, suggesting that participants in the control condition are not biased to first fixate a particular region on a given trial. By comparison, first fixation times were faster for the low- and high-clutter regions when previewed, suggesting that low and high preview participants were likely to first fixated their corresponding previewed regions. However, to further decompose this interaction, separate one-way repeated measures ANOVAs were carried out for each preview condition to analyze the effect of bag region on first fixation time.

The ANOVAs revealed there was no significant effect of bag region on first fixation time for the control condition, but a significant effect of bag region was observed for the low, $F(3, 21) = 7.977$, $p = .009$, $\eta p2 = .533$, and high preview conditions, $F(3, 21) = 15.984$, $p < .001$, $\eta p2 = .695$. This pattern of results suggests that the participants' typical scanning sequence, represented by the control condition, involved first fixating any bag region on a given trial. Moreover, the results indicate that the preview manipulation was effective in terms of altering this typical scanning sequence by leading participants to first fixate the corresponding previewed region. In summary, if no weapon is present, participants first fixated any bag region on a given trial unless their attention was guided toward a specific bag region during the preview phase, as was the case for the low and high preview conditions.

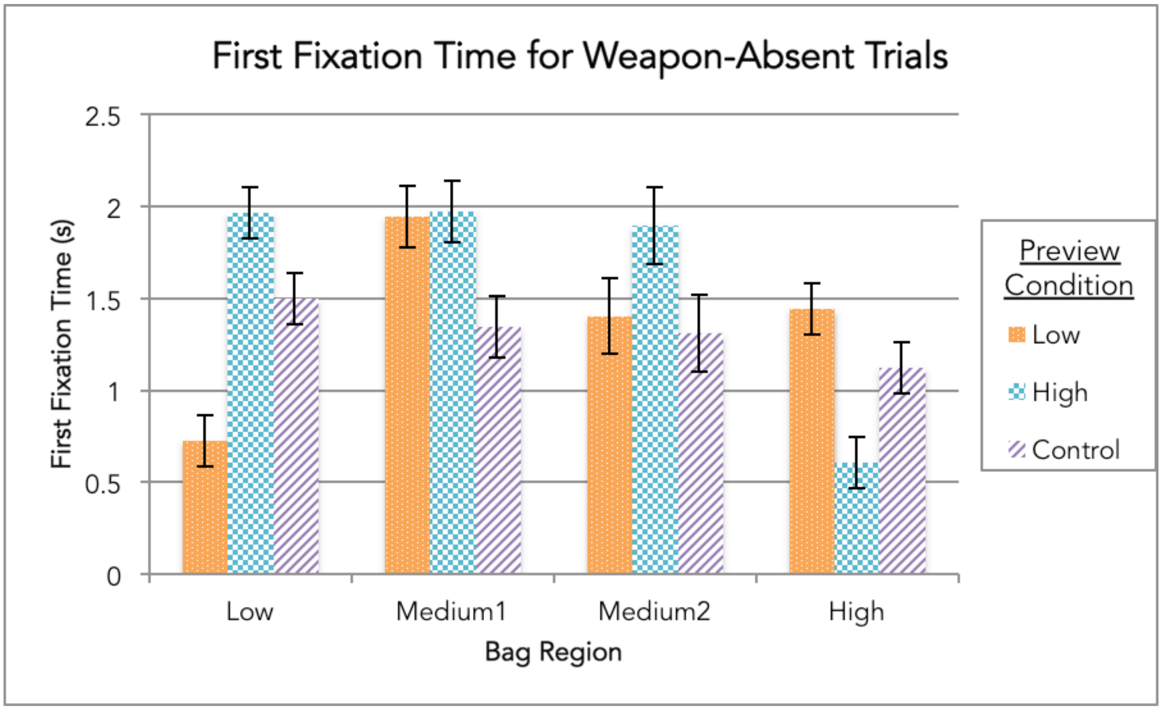

Figure 8. Mean first fixation time (s) of each bag region for weapon-absent trials with separate data series for each preview condition. This graph demonstrates significantly faster mean first fixation time for previewed regions (e.g., low-clutter region for low preview condition).

The mean first fixation time of each bag region for weapon-region match trials is displayed in Figure 9. For weapon-region match trials, there was no main effect of bag region, but a significant main effect of preview, $F(2, 63) = 5.836$, $p = .01$, $\eta p2 = .357$, as well as a significant bag region by preview interaction, $F(6, 63) = 8.741$, $p < .001$, $\eta p2 = .454$. Similar to weapon-absent trials, first fixation time was comparable across bag regions for the control condition but faster for the low and high previewed regions. To further examine the bag region by preview interaction, first fixation times were analyzed using separate one-way repeated measures ANOVAs for each preview condition with bag region as the factor. The results followed a similar trend to that of weapon-absent trials with no significant effect of bag region on first fixation time for the control, but a significant bag region effect for the low, $F(3, 21) = 4.056$, $p = .025$, $\eta p2 = .367$, and high preview conditions, $F(3, 21) = 13.957$, $p < .001$, $\eta p2 = .666$. This pattern of results suggest that participants first fixated any bag region on a given trial unless their attention was guided toward the low- or high-clutter region, as was the case for the low and high preview conditions, respectively.

In summary, the first fixation time data suggest that each preview condition led participants to adopt a different scanning process. For the control condition, first fixation time was comparable across bag regions, suggesting that attention was not consistently biased towards one particular region. By comparison, the low and high preview conditions demonstrated different forms of attention guidance during the screening task. For the high preview condition, participants tended to first fixate the high-clutter region before moving on to the medium- or low-clutter regions. In contrast, participants in the low preview condition demonstrated attention guidance toward the previewed region by first fixating the low-clutter region. In conclusion, the first fixation time data indicate that a clutter-based preview process can be effective at guiding visual attention to specific image regions during a complex visual search task.

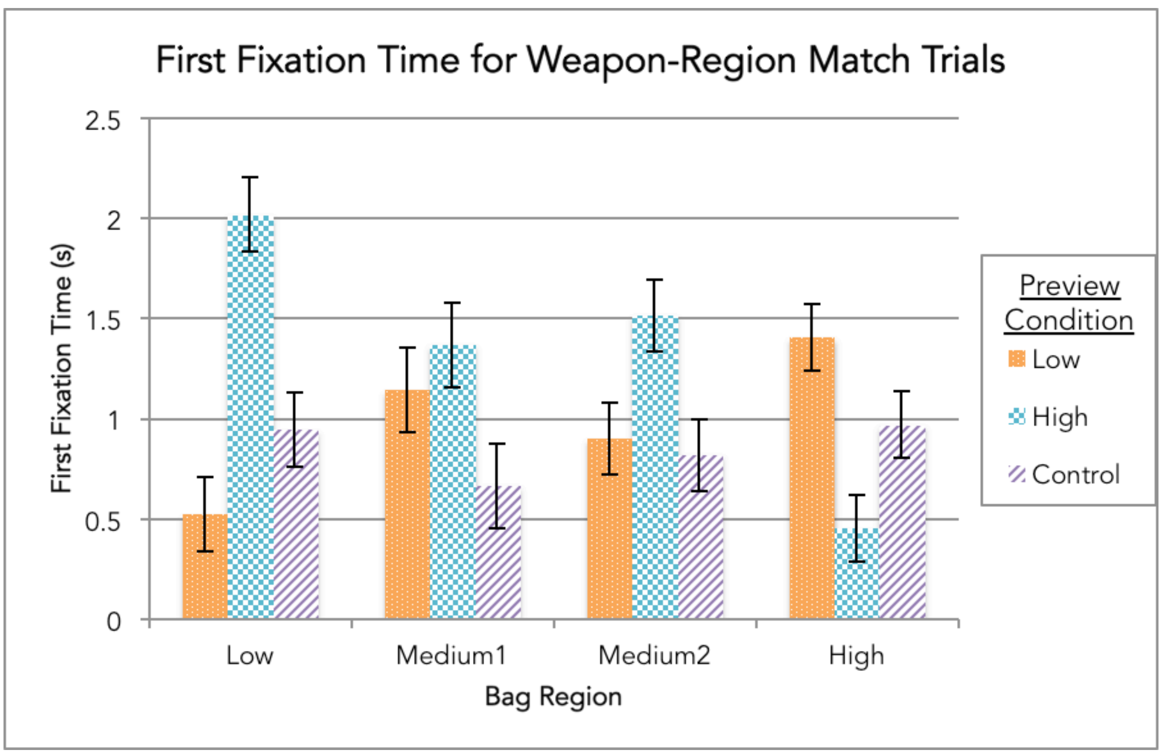

Figure 9. Mean first fixation time (s) of each bag region for weapon-region match trials with separate data series for each preview condition. This graph depicts faster first fixation times for previewed regions, but consistent first fixation times for each previewed region for the control preview condition.

Baggage Screening Transfer Task

Baggage screening performance during the transfer block was analyzed to determine whether the preview process produced enduring changes in weapon detection performance. Similar to the experiment proper, baggage screening performance was assessed by computing sensitivity and RT measures. However, weapon location was confined to medium-clutter regions so that performance was not biased toward a particular preview condition; therefore, sensitivity indexes for each weapon location were not computed. In addition, baggage screening performance measures associated with the last 50 trials of the experiment proper were computed and included in the following analyses to ensure that any potential effect of preview condition was not due to fatigue-related issues.

Sensitivity indexes (d'), false alarm rate, and hit rate were subjected to a 3 x 2 (Preview [low, high, control]) x (Block [experiment, transfer]) repeated measures ANOVA. There was no significant main effect or interaction involving the preview condition for any of the dependent measures, ps > .05. However, there was a significant main effect of block on false alarm rate, $F(1, 87) = 27.515$, $p < .001$, $\eta p2 = .240$. Across preview conditions, the proportion of false alarms in the transfer block ($M = .08$, $SD = .11$) increased compared to the last 50 trials of the experiment proper ($M = .06$, $SD = .08$). The significant effect of block on false alarm rates without a block by preview interaction indicates that all preview conditions experienced a similar performance decrement. This outcome suggests that it was unlikely that the performance decrement was due to the removal of the preview phase during the transfer block. Instead, it is more likely that the slight increase in false alarm rates was due to fatigue-related issues.

RT data for the transfer block were analyzed using a 2 x 3 (Weapon Presence [present, absent]) x (Preview [low, high, control]) repeated measures ANOVA. There was a significant main effect of weapon presence on mean RT, $F(1, 87) = 405.417$, $p < .001$, $\eta p2 = .823$, but no main effect of preview nor interaction. Participants spent more time searching the bag and forming a response for weapon-absent trials (M = 4,911 ms, SD = 142) compared with weapon-present trials (M = 1,916 ms, SD = 72). This result falls in line with the RT data from the experiment proper, and provides additional evidence that participants required additional time to confirm that there were no weapons present.

The sensitivity index and RT data from the transfer block further support the conclusions drawn from the experiment proper. As was the case in the experiment proper, there were no significant performance improvements associated with either the low or high preview conditions. The transfer block data show that neither preview condition led to lasting changes in the screening process that facilitated search performance when the preview phase was removed from the baggage screening procedure.

Subjective Workload Assessment

Subjective workload was assessed using the NASA TLX to examine potential differences in perceived workload that might be attributable to the preview conditions. To this end, each participant's overall workload and each of the NASA TLX subscales were analyzed in a one-way ANOVA with preview as the factor. There was no effect of preview on either overall workload or any of the subscales, all ps > .05. This result suggests that implementation of the preview process in baggage screening procedures would not substantially increase perceived workload.

Change Detection Task

Change detection task performance was assessed for each participant in order to estimate the participant's VWM capacity. Following the procedure described by Luck and Vogel (1997 & 2013), k was computed for each set size for each participant by multiplying the set size by the difference between the number of hits (i.e., indicating that no change had occurred on a no-change trial) and false alarms (i.e., indicating that no change had occurred on a change trial). Next, a mean k value was computed for each participant by averaging the k values across each set size. To set up a median split analysis, the median k value (median k = 2.82) was used to compare baggage screening performance in the experiment proper for low and high VWM capacity participants. To this end, performance data from the baggage screening task including overall sensitivity index, false alarm rate, and hit rate were analyzed in a one-way ANOVA with high and low VWM capacity as the factor. There were no significant differences between low and high VWM capacity participants for any of the baggage screening performance measures (all ps > .05). Thus, it appears that differences in VWM capacity do not significantly influence weapon detection performance.

CHAPTER FOUR

DISCUSSION

In an attempt to alleviate the deleterious effects of visual clutter on search performance, the current study used the output of a visual clutter algorithm to strategically guide the operator's visual attention to specific image regions, thereby facilitating search processes. However, analyses of the baggage screening performance data indicated that there were no significant benefits associated with the clutter-based preview manipulation. Specifically, there were no differences between preview and control conditions in overall or weapon location sensitivity index estimates; therefore, the null effect hypothesis could not be rejected. Furthermore, the preview manipulation did not produce any enduring changes in the participant's search process in terms of improved weapon detection performance, as evidenced by the null effect of preview in the baggage screening transfer block. Consequently, the use of low- and high-clutter information to guide search processes did not substantially improve weapon detection performance beyond the conventional baggage screening procedure of displaying the entire bag image for the duration of the search task.

Although there are likely to be numerous potential explanations for the null results, consideration of the processes involved in visual search provides a thorough account of the null effect observed in the current study. The rationale behind the hypothesized preview effect was that weapons located in high-clutter are hard to detect; therefore, guiding attention toward the high-clutter region should increase the likelihood of detecting these difficult to identify weapons. However, this explanation does not fully consider the relative contributions of search guidance and object recognition processes involved in visual search. In order to understand the null preview effect in the current study, it is useful to consider the role of search guidance and object recognition within the context of Wolfe's (2007) Guided Search 4.0 model.

According to Wolfe's (2007) model, visual search involves the early visual processing of global image features followed by object recognition processes. First, in the early stages of search, parallel processing of the display occurs and a limited set of global image features are acquired to form guidance signals that direct the subsequent allocation of visual attention. In this early stage, global image features such as the scene category (e.g., a kitchen) as well as basic perceptual features such as color, orientation, and motion are capable of guiding attention. If such feature information is conducive to the observer's current goal, it can be used to determine where attention will be guided. For example, if the observer is searching for a red T, parallel processing of the display will occur and the participant's attention will be guided toward red objects. Next, selective attention is required to fixate and examine individual objects in a serial manner. Once an object has been attended to, it can be processed in parallel with previously attended objects. In other words, object recognition involves the serial acquisition of objects that are then processed in parallel until recognition occurs.

Extending Wolfe's (2007) model to the current study provides a context for understanding how the preview manipulation impacted search processes. Considering the eye movement data that showed first fixation consistently fell within the corresponding previewed region (e.g., first fixation in the high-clutter region for the high preview condition), it is fair to assume that the preview process assisted the early stages of search. That is, the preview process supplanted the early stage of search involving the parallel processing of global image features by directing attention to the previewed region. Once the participant's attention arrived at the previewed region, the participant began the resource-intensive process of object recognition.

Thus, the preview manipulation served to facilitate the early stages of search, but did not assist object recognition processes beyond the conventional search procedure represented by the control condition. Presumably, after the preview phase of a trial, participants in the low and high preview conditions had sufficient time to search the remaining bag regions. In the case that the low or high preview disrupted early stages of search, participants were able to recover by re-forming an adequate global image representation after the preview phase; thus allowing for any extensive search processes that were necessary for confirming the presence of a weapon. This would explain the null effects observed in the current study. Furthermore, it offers an explanation for why the control condition was consistently faster than the low and high preview conditions in forming a response for weapons that appeared outside of the previewed region. For the control condition, early parallel processes were not disrupted; therefore, control participants were able to acquire global image features that were potentially informative for guiding attention, but not necessarily object recognition. As a result, the control condition led to increased search efficiency without improving weapon detection performance.

Considering the role of VWM in complex search tasks also provides insight regarding the null effect of preview. Previous research has shown that when VWM is occupied with search-relevant information, search performance generally increases (e.g., Al-Aidroos et al., 2012; Hollingworth, 2009). One explanation for such preview effects is that the spatial locations or object features (e.g., color and orientation) of the previewed information are marked and maintained in VWM, thus allowing the objects to be inhibited during subsequent search processes. However, these studies typically involve simple stimuli or digitized real world scenes that allow the participant to leverage top-down information, which further contributes to preview facilitation. By comparison, participants in the current study were required to process object features in addition to spatial locations during the preview phase in order to determine whether weapons were present within the previewed region. Consequently, it is tenable that attempting to maintain luggage item features and spatial locations overwhelmed VWM capacity, even for the low-clutter region. The null effect of preview suggests that the perceptual complexity associated with baggage screening displays served to limit the extent to which previewed information could be processed and maintained in VWM during the 1.5 s preview phase. In summary, complex search tasks impose significant demands on VWM capacity that in turn limits the extent to which previewed information can be used to improve search performance.

The null effect of preview in the current study serves to highlight the importance of considering the distinct processes involved in visual search. Conclusions regarding preview effects are limited to the specific preview method used in the current study. It is possible that refining the clutter-based preview process could lead to improved search performance; however, careful consideration should be given to whether the preview manipulation facilitates object recognition in addition to attention guidance. Furthermore, VWM capacity limitations influence the extent to which previewed information is efficiently processed and maintained. As evidenced by the baggage screening data in the current study, merely guiding attention toward a specific region is not sufficient for improving weapon detection performance. Thus, future research that explores methods for improving complex visual search performance should consider VWM capacity limitations and strive to improve both object recognition and search guidance processes.

A novel contribution of this study was demonstrating the effects of visual clutter on baggage screening performance using a well-established visual clutter algorithm. Previous attempts to quantify visual clutter and identify image-based factors contributing to baggage screening difficulty failed to find a significant effect of clutter on weapon detection performance (Schwanninger et al., 2007; Schwanninger et al., 2008). However, other researchers have found performance decrements due to increasing visual clutter whenever clutter was computed using a simple method of counting the number of overlapping luggage items (Fiore et al., 2006; Sellers et al., 2010). Moreover, previous research has shown performance decrements in complex search tasks due to increasing levels of visual clutter when computed with a clutter algorithm (Beck et al., 2010; Wolfe et al., 2011). Thus, it was predicted that baggage screening performance would decrease as visual clutter increased. Indeed, sensitivity index estimates decreased as weapon location clutter increased from low to medium and from medium to high. Likewise, RTs significantly increased as weapon location clutter levels increased. Therefore, the current study demonstrated that baggage screening performance and search efficiency decreased as visual clutter increased when clutter is computed using Rosenholtz et al.'s (2007) feature congestion clutter algorithm. These results provide additional evidence regarding the negative effects of visual clutter in complex search tasks while highlighting the importance of exploring potential methods that might assist operators that are required to search complex displays for information embedded in clutter.

With regard to the results of the baggage screening task, there are some important limitations that could have impacted the conclusions drawn from this data. Specifically, the sample consisted of undergraduates that had no previous baggage screening experience. Therefore, this limits the generalizability to novice operators that have little experience with such complex displays and search procedures. If the current study's results were generalized to novice airport security screeners in training, the results would suggest that the clutter-based preview process would not be effective for improving search procedures in the short nor long term. In addition, the participants' experience level could have exacerbated the negative effects of visual clutter observed in this study. Research has shown how training can mediate the effects of some image-based factors that contribute to search difficulty (Schwanninger et al., 2008). One explanation for why training might mitigate the effects of image-based factors in complex search is the ability to form accurate mental representations of target items (Koller, Drury, & Schwanninger, 2009; McCarthy et al., 2004). Acquiring robust target representations would serve to improve object recognition processes. Consequently, experienced operators are more likely to recognize a target that is embedded in high levels of visual clutter. Thus, it is possible that the clutter effects observed in this study are limited to inexperienced operators. Further research is necessary to uncover the role of training in mitigating such clutter effects.

Although the current study was unable to demonstrate improved weapon detection performance associated with the preview manipulation, the results are informative for understanding the cognitive processes involved in complex search. Results from the baggage screening task suggest that the early stages of visual search involving attention guidance can be influenced by a preview procedure without leading to improvements in target detection. This suggest that the difficulty associated with complex search tasks is not determining where to look, but rather identifying and recognizing the information once fixated. This appeared to be the case in the current study because weapons located in high-clutter regions were harder to detect; however, even when visual attention was directed toward the high-clutter region that contained the weapon, performance did not significantly improve. This outcome highlights the role of resource intensive object recognition processes involved in complex search tasks.

The practical implications of the current study involve the effects of visual clutter on search performance and the limitation of attention guidance in complex search tasks. The current study demonstrated that increasing visual clutter clearly disrupts search performance, both in terms of accuracy and efficiency. Research has demonstrated significant decrements in search efficiency due to increasing visual clutter (e.g., Beck et al., 2010), and the current study furthers this line of research by showing that the ability to actually determine whether target objects are present is also reduced. Evidenced by the overall sensitivity and RT data for the baggage screening task, both decision accuracy and search efficiency decreased as weapon location clutter levels increased. Therefore, display designers should carefully consider the degree of visual clutter on the display at a given moment in order to anticipate increases in search difficulty. Doing so would allow for timely interventions that might circumvent performance decrements and help ensure that critical information on the display is processed. Furthermore, the current study showed that a preview procedure could be used to strategically guide attention to specific display regions; however, such attention guidance alone was insufficient for improving performance. Therefore, designers should be aware that even if the display or search procedure is able to guide the operator's visual attention, it does not guarantee that critical information will be processed and recognized.

APPENDIX A

BAGGAGE SCREENING TASK PERFORMANCE MEASURES

Baggage Screening Task Performance Measures

Measure	Preview Condition	N	M	SD
Overall Sensitivity (d')	Low	30	2.291	0.703
	High	30	2.643	0.548
	Control	30	2.487	0.826
	Total	90	2.474	0.709
Overall Hit Rate	Low	30	0.773	0.117
	High	30	0.807	0.094
	Control	30	0.787	0.104
	Total	90	0.789	0.105
Overall False Alarm Rate	Low	30	0.101	0.123
	High	30	0.063	0.069
	Control	30	0.086	0.096
	Total	90	0.083	0.099
Overall Criterion	Low	30	0.340	0.359
	High	30	0.401	0.348
	Control	30	0.383	0.356
	Total	90	0.375	0.352
Sensitivity Estimate - Low Clutter Weapon Location	Low	30	2.990	0.938
	High	30	3.196	0.834
	Control	30	3.058	1.005
	Total	90	3.081	0.922
Sensitivity Estimate - Medium Clutter Weapon Location	Low	30	2.337	0.913
	High	30	2.663	0.598
	Control	30	2.531	0.916
	Total	90	2.510	0.824
Sensitivity Estimate - High Clutter Weapon Location	Low	30	1.956	0.674
	High	30	2.372	0.573
	Control	30	2.166	0.804
	Total	90	2.164	0.704
RT - Low Clutter Weapon Location	Low	30	2641.897	763.119
	High	30	3436.504	805.146
	Control	30	2498.976	751.199
	Total	90	2859.125	869.975
RT - Medium Clutter Weapon Location	Low	30	4115.782	639.331
	High	30	3817.522	736.822
	Control	30	2887.084	1022.304

	Total	90	3606.796	963.080
RT - High Clutter Weapon Location	Low	30	4657.306	731.181
	High	30	3622.757	1099.827
	Control	30	3488.468	1071.232
	Total	90	3922.844	1103.655
RT - Weapon-Absent	Low	30	6450.248	1250.449
	High	30	6006.843	1379.195
	Control	30	5420.958	1495.407
	Total	90	5959.350	1427.468

APPENDIX B

PERCENTAGE OF TOTAL FIXATION DURATION

Percentage of Total Fixation Duration

Preview Condition	Weapon Location	Bag Region	M	Std. Error
Low Preview	Weapon-Region Match	Low	0.49	0.051
		Medium1	0.392	0.055
		Medium2	0.452	0.03
		High	0.442	0.033
	Weapon-Absent	Low	0.217	0.017
		Medium1	0.198	0.018
		Medium2	0.271	0.023
		High	0.303	0.013
High Preview	Weapon-Region Match	Low	0.265	0.033
		Medium1	0.364	0.028
		Medium2	0.316	0.034
		High	0.606	0.074
	Weapon-Absent	Low	0.164	0.006
		Medium1	0.223	0.015
		Medium2	0.206	0.018
		High	0.344	0.027
Control Preview	Weapon-Region Match	Low	0.479	0.091
		Medium1	0.529	0.089
		Medium2	0.554	0.04
		High	0.482	0.042
	Weapon-Absent	Low	0.18	0.008
		Medium1	0.24	0.028
		Medium2	0.233	0.028
		High	0.306	0.009

APPENDIX C

FIRST FIXATION TIME

First Fixation Time

Preview Condition	Weapon Location	Bag Region	M	Std. Error
Low Preview	Weapon-Region Match	Low	0.521	0.187
		Medium1	1.141	0.212
		Medium2	0.9	0.179
		High	1.405	0.167
	Weapon-Absent	Low	0.725	0.14
		Medium1	1.943	0.167
		Medium2	1.404	0.208
		High	1.441	0.139
High Preview	Weapon-Region Match	Low	2.016	0.187
		Medium1	1.369	0.212
		Medium2	1.516	0.179
		High	0.452	0.167
	Weapon-Absent	Low	1.965	0.14
		Medium1	1.972	0.167
		Medium2	1.894	0.208
		High	0.605	0.139
Control Preview	Weapon-Region Match	Low	0.944	0.187
		Medium1	0.665	0.212
		Medium2	0.819	0.179
		High	0.968	0.167
	Weapon-Absent	Low	1.496	0.14
		Medium1	1.342	0.167
		Medium2	1.309	0.208
		High	1.124	0.139

APPENDIX D

NASA TLX WORKLOAD SCALES

NASA TLX Workload Scales

Measure	Preview Condition	N	M	SD
Mental Demand	Low	30	73.667	19.780
	High	30	63.000	26.346
	Control	30	70.167	17.835
	Total	90	68.944	21.846
Physical Demand	Low	30	16.833	14.293
	High	30	19.167	20.345
	Control	30	17.333	18.696
	Total	90	17.778	17.786
Temporal Demand	Low	30	64.667	21.613
	High	30	59.000	20.861
	Control	30	65.000	20.426
	Total	90	62.889	20.920
Performance	Low	30	56.167	19.594
	High	30	45.833	15.541
	Control	30	50.667	20.373
	Total	90	50.889	18.896
Effort	Low	30	67.500	18.743
	High	30	60.333	23.742
	Control	30	66.000	17.191
	Total	90	64.611	20.101
Frustration	Low	30	56.167	21.403
	High	30	52.333	25.008
	Control	30	45.167	23.062
	Total	90	51.222	23.396
Total Workload	Low	30	63.111	13.940
	High	30	63.122	16.115
	Control	30	62.522	12.733
	Total	90	62.919	14.172

APPENDIX E

CHANGE DETECTION PERFORMANCE DATA WITH MEDIAN SPLIT

Baggage Screening Performance for Low and High Visual Working Memory Capacity Participants				
Baggage Screening Performance Measures	**VWM Capacity**	**N**	**M**	**SD**
Overall Sensitivity (d')	Low Capacity	45	2.423	0.672
	High Capacity	45	2.525	0.748
Overall Hit Rate	Low Capacity	45	0.788	0.374
	High Capacity	45	0.936	0.403
Overall False Alarm Rate	Low Capacity	45	-1.635	0.534
	High Capacity	45	-1.588	0.640
Low-Clutter Weapon Location Sensitivity Estimate	Low Capacity	45	3.096	0.932
	High Capacity	45	3.067	0.922
Medium-Clutter Weapon Location Sensitivity Estimate	Low Capacity	45	2.364	0.710
	High Capacity	45	2.657	0.909
High-Clutter Weapon Location Sensitivity Estimate	Low Capacity	45	2.122	0.686
	High Capacity	45	2.207	0.727

APPENDIX F

PERCENTAGE OF TOTAL FIXATION DURATION

Baggage Screening Task Performance for Transfer Block and Last 50 Trials of the Experiment Proper				
Measure	**Condition**	**N**	**M**	**SD**
Sensitivity (d') for Last 50 Trials of Experiment Proper	Low	30	2.605	0.913
	High	30	2.973	0.865
	Control	30	2.917	1.286
	Total	90	2.831	1.040
Sensitivity (d') for Transfer Block	Low	30	2.603	0.704
	High	30	2.943	0.327
	Control	30	2.776	0.626
	Total	90	2.774	0.586
Hit Rate for Last 50 Trials of Experiment Proper	Low	30	0.874	0.666
	High	30	1.049	0.859
	Control	30	1.131	1.080
	Total	90	1.018	0.881
Hit Rate for Transfer Block	Low	30	1.194	0.179
	High	30	1.159	0.247
	Control	30	1.090	0.319
	Total	90	1.148	0.256
False Alarm Rate for Last 50 Trials of Experiment Proper	Low	30	-1.730	0.608
	High	30	-1.924	0.464
	Control	30	-1.786	0.529
	Total	90	-1.814	0.537
False Alarm Rate for Transfer Block	Low	30	-1.410	0.622
	High	30	-1.784	0.260
	Control	30	-1.633	0.495
	Total	90	-1.609	0.502

APPENDIX G

REACTION TIME DATA FOR BAGGAGE SCREENING

TRANSFER BLOCK

Baggage Screening Task Reaction Time Data for Transfer Block				
Weapon Presence	**Preview Condition**	**N**	**M**	**SD**
Weapon-Absent Trials	Low	30	5119.129	1245.113
	High	30	4672.026	1253.884
	Control	30	4942.012	1531.824
	Total	90	4911.056	1347.670
Weapon-Present Trials	Low	30	1956.178	640.422
	High	30	1766.719	543.898
	Control	30	2025.605	840.447
	Total	90	1916.167	687.240

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