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An individual differences approach to multiple-target visual search errors: How search errors relate to different characteristics of attention

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ABSTRACT

A persistent problem in visual search is that searchers are more likely to miss a target if they have already found another in the same display. This phenomenon, the Subsequent Search Miss (SSM) effect, has remained despite being a known issue for decades. Increasingly, evidence supports a resource depletion account of SSM errors—a previously detected target consumes attentional resources leaving fewer resources available for the processing of a second target. However, "attention" is broadly defined and is composed of many different characteristics, leaving considerable uncertainty about how attention affects second-target detection. The goal of the current study was to identify which attentional characteristics (i.e., selection, limited capacity, modulation, and vigilance) related to second-target misses. The current study compared second-target misses to an attentional blink task and a vigilance task, which both have established measures that were used to operationally define each of four attentional characteristics. Second-target misses in the multiple-target search were correlated with (1) a measure of the time it took for the second target to recovery from the blink in the attentional blink task (i.e., modulation), and (2) target sensitivity (d') in the vigilance task (i.e., vigilance). Participants with longer recovery and poorer vigilance had more second-target misses in the multiple-target visual search task. The results add further support to a resource depletion account of SSM errors and highlight that worse modulation and poor vigilance reflect a deficit in attentional resources that can account for SSM errors.

1. Introduction

1.1. Background

Visual search, the act of looking for targets amongst distractors, is an integral part of everyday life. Searches can be as trivial as a person looking for groceries in the supermarket or as serious as a radiologist searching for tumors in a radiograph. Visual search is a well-researched paradigm (see Eckstein, 2011 and Nakayama & Martini, 2011 for recent reviews), and much is known about situations that lead to better or worse performance. Unfortunately, one type of visual search has consistently given rise to poor perfor mance—multiple-target visual search. Multiple-target visual search is when more than one target can potentially be present in a given search display. These searches can give rise to one specific type of error—observers are much more likely to miss an additional target if they had already detected a target earlier in the search display (Tuddenham, 1962). This phenomenon, previously known as the Satisfaction of Search effect (Smith, 1967) and recently renamed the Subsequent Search Miss (SSM; Adamo, Cain, & Mitroff, 2013) effect, can be a real problem in visual searches where target detection is critical, such as those conducted by radiologists and airport security personnel.

SSM errors can account for up to one-third of some types of radiological errors (Anbari & West, 1997) and can occur in a wide variety of radiological exams including abdominal radiography, skeletal radiography, chest radiography, and multiple-trauma patient scans (e.g., Ashman, Yu, & Wolfman, 2000; Berbaum et al., 1994, 1998; Franken et al., 1994; Samuel, Kundel, Nodine, & Toto, 1995). Given the critical nature of SSM errors in radiological searches, a variety of attempts have been made to ameliorate the effects. For example, target detection tools such as computer-aided detection and contrast enhanced imaging have been investigated as possible tools to reduce SSM errors. However, computer aided detection was found to have no effect on alleviating SSM errors (Berbaum, Caldwell, Schartz, Thompson, & Franken, 2007)

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and contrast enhanced imaging was found to possibly even exacerbate these errors (Franken et al., 1994). A better understanding of SSM errors is critical, as failing to detect targets could be a matter of life-and-death.

A core means to counter SSM errors is to understand its primary cause(s). By determining the cognitive mechanisms that give rise to these errors, it might be possible to enact steps to eliminate them. To date, there are three proposed theoretical accounts of SSM errors: the Satisfaction account, the Perceptual Set account, and the Resource Depletion account (Berbaum et al., 1991; Biggs, Adamo, Dowd, & Mitroff, 2015b; Cain & Mitroff, 2013; Samuel et al., 1995; Smith, 1967). Below, each of these theoretical accounts is briefly discussed.

1.1.1. Satisfaction account

Originally, radiological researchers exploring the SSM phenomenon proposed that errors arose when an observer became "satisfied" with the meaning of a search display after finding a target, causing them to prematurely terminate their search (Smith, 1967; Tuddenham, 1962). Since then, there has been mixed support for the Satisfaction account (Adamo, Cain, & Mitroff, 2015a; Berbaum et al., 1990, 1991; Cain, Adamo, & Mitroff, 2013; Samuel et al., 1995). The evidence against a Satisfaction account has demonstrated that, on average, observers search for the same amount of time regardless of how many targets are in the search display (Berbaum et al., 1991) and observers rarely quit searching immediately after finding a first target (Cain et al., 2013). However, there is recent evidence in support of a Satisfaction account, which demonstrated that when observers searched for longer after finding a first target, they were more likely to find a second target, compared to observers who searched for less time (Adamo et al., 2015a).

1.1.2. Perceptual Set account

The Perceptual Set account posits that once a first target is detected, an observer is biased to search for targets that share similar characteristics to that of the first target (Berbaum et al., 1990, 1991; Biggs et al., 2015). Therefore, after finding a target of one type (e.g., a tumor), the observer may be less likely to find a target of a different type (e.g., a fracture). Again, there has been mixed support for the Perceptual Set account. On one hand, results have not supported this account finding that observers committed an equivalent amount of SSM errors regardless of whether two targets in the same array were similar or different in salience (e.g., if both targets were a lighter shade of gray or one target was a lighter shade of gray and one was a darker shade of gray; Fleck, Samei, & Mitroff, 2010) or rotation (e.g., if one target was rotated 90 degrees and the other was rotated 180 degrees; Cain et al., 2013). On the other hand, when SSM errors were assessed in a visual search environment that contained many different target possibilities (i.e., akin to how airport security personnel search for scores of different types of dangerous items in carry-on bags), it was demonstrated that a second target is more likely to be detected if it is identical to a detected first target (Mitroff et al., 2014). Moreover, second targets were also more likely to be detected if they were the same color or the same category as that of the first target (Biggs et al., 2015b).

1.1.3. Resource Depletion account

The Resource Depletion account posits that once a first target is found, it consumes cognitive resources, such as working memory and attention, leaving less available to process a second target (Berbaum et al., 1991; Cain & Mitroff, 2013; Samuel et al., 1995). To date, this account has received the most support. For example, if a first target is immediately removed from the display once it is detected, there is an increase in accuracy for detecting a second target (Cain & Mitroff, 2013). This finding has been interpreted to suggest that a found target is held in working memory, and thus can hinder the processing of other targets. As such, once the item is physically removed, working memory resources previously allocated to the found target can become available again, aiding in the processing of other targets. With respect to attention, a first target has been shown to induce an attentional blink (i.e., a decrease in second target accuracy when it appears 200–500 ms after a detected, first target) in a multiple-target search (Adamo et al., 2013). This study suggests that a detected, first target consumes attentional resources that are necessary for second target processing. Research on SSM errors has also demonstrated that a found, first target amplifies the effects clutter (i.e., distractors within a close vicinity to a target) has on second target processing (Adamo, Cain, & Mitroff, 2015b). Theoretically, this finding suggests that if a found, first target is already consuming attentional resources, attentional distractions have a greater impact on target accuracy compared to if no first target was found.

1.2. Current study

While there is substantial support that cognitive resources can be consumed by a detected first target, there is still ambiguity as to what is actually meant by "resources." The terms "working memory" and "attention" are often broadly defined and can describe overlapping cognitive constructs (e.g., Chun, Golomb, & Turk-Browne, 2011; Kiyonaga & Egner, 2012), and this has left the field with considerable uncertainty about what exactly is affected after the detection of a first target. The goal of the current study was to better understand how attention is affected after detecting a first target by identifying which characteristics of attention relate to second-target misses.

Chun et al. (2011) have provided a framework that offers a nice way to delineate the various aspects of attention. Specifically, they divide attention into four different characteristics: (1) Limited Capacity—attention is a finite cognitive resource that can be used to process only a subset of the visual world; (2) Selection—attention is needed to choose which visual information is selected from the visual world to receive additional processing within working memory; (3) Modulation—attention is needed to facilitate the processing of visual information within working memory so that it can be acted upon and later remembered in long-term memory; and (4) Vigilance—attention must be sustained over extended periods of time to complete demanding tasks.

The experimental logic for the current study was to investigate the relationship between attention (as defined by the four characteristics described above) and SSM errors by taking advantage of individual difference measures. People vary along a number of factors, and it can be highly informative to explore how these individual differences relate to measures of cognitive performance. For example, much has been learned about working memory and its underlying mechanisms by exploring individual differences in executive attention (see Kane & Engle, 2002 for a review). Here, SSM errors calculated from a multiple-target visual search task were assessed in light of individual differences in performance on two established attentional paradigms—an attentional blink and vigilance task. These tasks exhibit the four attentional characteristics outlined above (Chun et al., 2011), making them a potentially powerful tool for better understanding SSM errors.

An attentional blink (AB) is defined as a decrease in second target accuracy when a second target is presented 200–500 ms after a first target in a rapid serial visual presentation stream (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). Many measures can be extracted from the AB paradigm and three of them will be used to operationally define three of the four attentional characteristics (Chun et al., 2011; See Fig. 1). The first measure is