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Satisfaction at last: Evidence for the "satisfaction" account for multiple-target search errors

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ABSTRACT

Multiple-target visual searches, where several targets may be present within a single search array, are susceptible to Subsequent Search Miss (SSM) errors—a reduction in second target detection after a first target has been found (an effect previously called Satisfaction of Search). SSM errors occur in critical search settings (e.g., radiology and airport security screening), creating concerns for public safety. To eradicate SSM errors it is vital to understand their cause(s), and the current study investigated a key proposed mechanism—searchers prematurely terminate their search after finding a first target. This proposed mechanism, termed the satisfaction account, was proposed over 50 years ago but there are no conclusive supporting data to date. "Satisfaction" has been typically assessed by comparing the total time spent on multiple-target trials to the time spent on single-target trials or by examining if search was immediately terminated after finding a first target. The current study investigated the satisfaction account by exploring variability in the time participants spent searching between finding a first target and self-terminating their search without finding a second target. This individual differences approach revealed that accuracy on a multiple-target search task related to how long participants searched after finding a first target. The relationship was highly significant, even when accounting for variation in participants' attentional vigilance. This study provides evidence for the previously elusive satisfaction account and it adds to the growing understanding that SSM errors are a multifaceted problem.

KEYWORDS

subsequent search misses, satisfaction of search, visual search, vigilance

1. BACKGROUND

Multiple-target visual searches, where several targets may be present within a single search array, are especially error-prone such that additional targets are more likely to be missed after a first target has been detected[1,2]. This phenomenon, originally called Satisfaction of Search[3], and recently renamed the Subsequent Search Miss (SSM) effect[4], can present a very real problem for professional searchers. For example, radiologists may be more prone to miss a cancer if a previous abnormality was detected and baggage screeners may be more likely to miss a gun if a water bottle was previously found. Over 50 years of research into the nature of SSM errors has sought to delineate the underlying causes, and, to date, two potential mechanisms have received empirical support—the "resource depletion" and "perceptual set" accounts. According to the resource depletion account, a second target is more likely to be missed because the first target consumes cognitive resources, leaving less available to process additional targets[3,5-7]. The perceptual set account posits that second targets are missed due to attentional priming created by the first detected target[6,8].

Interestingly, the original proposed mechanism for SSM errors (and the source of the original name), has not received any conclusive supporting evidence[6,9,10]. It was originally hypothesized that second targets were missed in multiple-target search due to observers becoming "satisfied" with the meaning of the search display after finding a first target. This "satisfaction" was thought to cause observers to prematurely discontinue their search, even if the entire image had not been fully inspected[2,3]. While this satisfaction account is logical, it has not yet been empirically demonstrated. In a study that evaluated search time before, between, and after first target detection there was no evidence

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to support the satisfaction account as observers searched for the same amount of time on single and multiple-target trials[6]. Likewise, another study examined observers' quitting behavior after finding a first target and found no evidence for a satisfaction account as observers rarely terminated search immediately after finding a first target[9]. Finally, another study found response time effects consistent with premature quitting, however the effects were difficult to interpret given that observers timed-out on over 80% of trials[10].

From a theoretical perspective, knowing whether SSM errors are (at least partially) driven by a satisfaction account can help inform visual search theories. For example, such evidence can speak to issues of attentional processing and reasons why observers quit searching[11]. From an applied perspective, it is important to reduce SSM errors in practice as they can cause critical misses in life-saving professions (e.g., radiology and baggage screening), so it is critical to understand the causes.

The current study explored the satisfaction account by taking an individual differences approach—examining if participants' search behavior might predict their rate of SSM errors. Specifically, the participants' average time spent searching between finding a first target and their termination of search without finding a second target was compared to their SSM error rates. A satisfaction account would predict that participants who are faster to terminate search after finding a first target would commit more SSM errors. Such a finding might suggest that those individuals who are more willing to continue to search after finding a first target (i.e., those who try harder), are those who are less likely to commit SSM errors.

The current study's primary prediction is that there will be a relationship between SSM error rates and the time participants spend searching after finding a first target. However, there are other factors that could potentially mediate such a relationship, such as the participants' state of vigilance—their ability/willingness to sustain attention[12,13]. To control for this potential influence of attentional engagement, participants in the current study also completed a vigilance task after completing the multiple-target search task.

2. METHODS

2.1 Participants and data cleaning procedures. Sixty-seven members of the Duke University community participated in a 90-minute testing session wherein they completed a visual search task, an attentional blink task, and a vigilance task. The total number of participants was dictated by the number of individuals who were successfully recruited for this study during the Spring and Fall semesters of 2011 at Duke University. Data from the search task have been reported elsewhere for orthogonal research purposes[14], and the attentional blink data are not reported here as they were collected for a different research questions[5,15]. Participants received either course credit or $15. Data were removed from analyses from one participant for having over 20% timeouts in the search task, from three participants for having over 20% false-alarms in the search task, and from one participant for having over 50% false alarms in the vigilance task. Data were analyzed from the remaining 62 participants (mean age= 20.60 years, SD=2.08; 25 females). Research was conducted in accordance with the Declaration of Helsinki and was approved by Duke University's Institutional Review Board.

2.2 General procedures. Participants sat 57cm from a 20-inch CRT monitor and used a chin rest to maintain a consistent viewing distance. Stimuli were presented with Matlab software and Psychophysics Toolbox version 3.0.8[16] on a Dell Inspiron computer. The search task always preceded the vigilance task so as to not tire out participants before the search task.

2.2.1 Multiple-target visual search task. In the search task[4] (Figure 1a), participants searched for target "T's" amongst distractor "pseudo-L's" on a white background. Half of the targets and 5% of the distractors were high salience (57–65% black) and the remainder were low salience (22–45% black). There were 25 items (1.3° × 1.3°) per display with either one or two targets per trial. Participants were aware that there were either one or two targets present in a given search display, but they were not informed of the precise distribution. Search trials began with a 250ms fixation dot and were followed by a search display that appeared for 15s. Participants were instructed to click on items they believed were targets (a blue, 0.3° in diameter, unfilled circle appeared after each click) and press the space bar when they felt that all targets were found. There were 25 practice trials with feedback and 250 experimental trials with no feedback. SSM errors were calculated by taking the difference between accuracy (hit rate) on low-salience, single-target trials and accuracy for low-salience targets after a high-salience target was first detected on dual-target trials. Satisfaction was calculated as the time spent searching between finding a high-salience target and terminating search on trials (both on single- or dual-target) in which no low-salience target was detected (see Table 1). Trials in which a participant timed out (trials where the 15s time limit was reached without pressing the space bar; 4.01% of total trials) or false-alarmed (trials were at least one distractor was clicked on; 2.20% of total trials) were not included in the analyses.

2.2.2 Vigilance task. In the vigilance task[13] (Figure 1b), participants viewed light grey letters (45% black) presented in a serial visual presentation stream in the center of the screen. The stimuli (0.8° × 0.8°) appeared for 40ms each with an inter-stimulus interval of 960ms. Stimuli consisted of a target letter "O" and a distractor letter "D," either forward or backward, on top of a visual mask of small black circles (0.2° in diameter). Twenty-four targets and 96 distractors were displayed per block and participants had 1s to press the space bar when a target appeared. Presses after a distractor appeared were considered false alarms. Participants completed one practice block and six experimental blocks of two minutes each, for a total task time of 14 minutes. No feedback was provided, but an experimenter observed the practice block and answered any potential questions. A sensitivity index of target detection was used as the measure of vigilance, and it was calculated by taking the difference between the inverse of the normal distribution of hit and false alarm rates (d')[17].

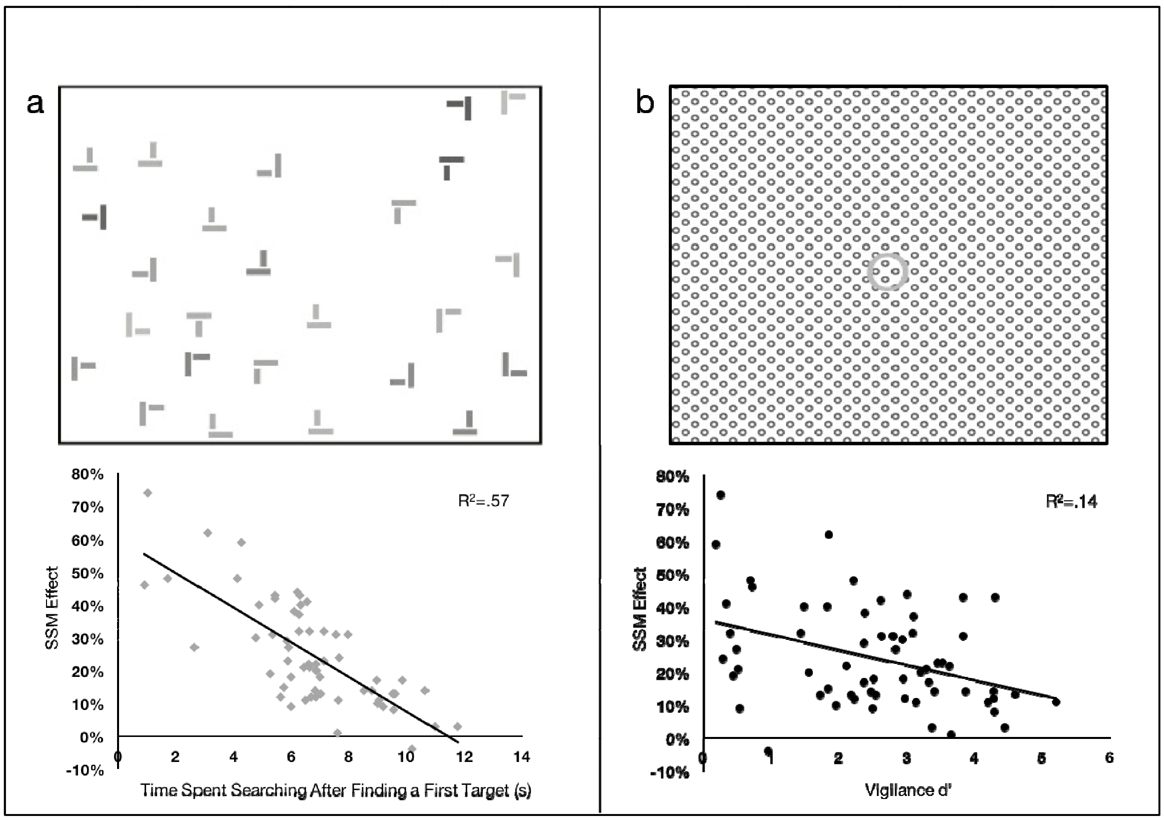

Figure 1. Sample (a) multiple-target visual search display (top) and correlation between the Subsequent Search Miss (SSM) effect and time spent searching after finding a first target (bottom). Sample (b) vigilance task display (top) and correlation between SSM effect and vigilance sensitivity (bottom).

3. RESULTS

A typical SSM effect was found, with lower accuracy for low-salience targets after a high-salience target was found (M=68.07%, SD=20.13%) compared to accuracy for low-salience targets on single-target trials (M=92.62%, SD=11.85%; $t(61)=12.00$, $p<.001$, $d=3.07$; See Table 1). There were significant correlations between time spent searching after finding a high-salience target and SSM errors ($r(61)= -.76$, $p<.001$; See Figure 1a), between vigilance sensitivity and SSM errors ($r(61)= -.38$, $p=.002$; See Figure 1b), and time spent searching after finding a high-salience target and vigilance sensitivity ($r(61)=0.47$, $p=.001$). That is, participants who searched for a shorter period of time without finding a second target, and participants who were less vigilant, were more likely to make SSM errors. Also, participants who searched for less time were less vigilant.

To examine whether SSM errors were related to satisfaction above and beyond a participants' current state of attentional engagement (i.e., vigilance), a two-stage hierarchical multiple regression was conducted with SSM errors as the dependent variable and vigilance sensitivity as the first level of the regression and satisfaction as the second level of the regression. Multicollinearity was not a concern (Tolerance=0.78). At stage one of the model, vigilance sensitivity significantly contributed, $F(2,61)=10.15$, $p=.002$, accounting for 14.50% of the SSM error variation. At stage two, searching for a shorter period of time without finding a second target explained an additional 43.10% of the SSM error variation (a significant R^2 change; $F(1,59)=40.13$, $p<.001$), suggesting satisfaction accounted for SSM errors above and beyond vigilance sensitivity.

Accuracy	**Mean Accuracy (and Standard Deviation)**
Single-target, high-salience	97.03% (5.06%)
Single-target, low-salience	92.62% (11.85%)
Dual-target, low-salience	68.07% (20.13%)
Subsequent Search Miss errors	24.55% (15.72%)
Response Time	**Response Time (and Standard Deviation)**
Single-target, high-salience	2.87s (0.81s)
Single-target, low-salience	5.76s (0.97s)
Dual-target, low-salience	6.46s (1.03s)
High-salience target found first detection time	3.26s (1.03s)
High-salience target found first quit time	9.62s (2.34s)
"Satisfaction" measure	**Response Time (and Standard Deviation)**
High-salience target detection time minus quit time	6.38s (2.18s)

Table 1: Mean accuracy and response time measures for multiple-target visual search task. Accuracy and response time measures were based on the hit rates for target(s) with false alarms and time outs filtered out. The *dual-target, low-salience* measure was calculated as the hit rate for low-salience targets after a high-salience target was detected first on dual target trials. The *Subsequent Search Miss errors* measure was calculated by taking the difference between the hit rate for low-salience targets on single target trials and the hit rate for low-salience targets on dual-target trials—after a high-salience target was detected first. The *high-salience target found first detection and quit time* measures were calculated from trials where only a high-salience target was found—single-target, high salience trials and dual-target trials where no low-salience target was detected.

4. DISCUSSION

The current study suggests that SSM errors are driven, in part, by a satisfaction account—second targets are more likely to be missed in a multiple-target visual search due to participants not fully searching after finding a first target. Across the participants, there was a significant correlation between time spent searching after finding a first target and SSM errors, suggesting that participants who spent more time searching after finding a first target were less likely to make SSM errors. Importantly, this satisfaction relationship accounted for a large amount of variation in the SSM error rate (43%) above and beyond that of vigilance sensitivity, signifying that satisfaction is different than one's state of attentional engagement. These findings change how SSM errors should be viewed as the original "satisfaction" account finally has empirical support. While previous research investigated the average search time differences between single- and multiple-target trials found no support for the satisfaction account[6,9], here an investigation focusing on *individual differences* in the time participants spent searching after finding a first target yielded positive evidence.

To best counteract a satisfaction-based SSM errors, it is important to understand the underlying factors. At first glance, these findings could appear to suggest that the relationship between satisfaction and SSM errors reflects a speed-accuracy tradeoff (i.e., participants whom search longer are more accurate). However, the SSM measure is a difference score between the hit rates for low-salience targets on single- and dual-target trials. An increase or decrease in general search speed would not explain a change in the SSM effect across individuals, as participants would likely get better (or worse) in both single and dual-target trials. Furthermore, previous research explicitly looked at a speed-accuracy trade off account for SSM errors and found that it was not common for participants to terminate their search immediately after finding a first target in multiple-target searches[9].

One possible explanation for the satisfaction effect is that it represents a participants' willingness to "try"—those who are more engaged and conscientious will be more likely to keep searching (and to keep searching effectively). To test this hypothesis a correlation was conducted between the current measure of satisfaction and conscientiousness. Fifty-six of the study participants completed the NEO-FFI personality test[18] as part of a larger project conducted by the Duke Visual Cognition Lab. Satisfaction significantly correlated with the NEO-FFI conscientiousness factor ($r(55)=.37$, $p=.003$, one-tailed), with higher self-reported conscientiousness relating to longer search times after finding a first target. This relationship suggests variation in conscientiousness might be a possible explanation as to why participants may or may not terminate search prematurely after finding a first target. Since SSM errors occur in searches where many targets may appear, such as those performed by radiologists and airport baggage screeners, an effort to employ individuals who are more conscientious might be worth exploring further.

5. CONCLUSION

SSM errors are a real and existing threat that can have life or death consequences. The current study adds to a growing literature of possible causes of SSM errors by suggesting that satisfaction (operationally defined as the time spent searching after finding a first target) may be a significant underlying cause of SSM errors. Since SSM errors are already known to be caused by both resource depletion (i.e., finding a first target consumes cognitive resources leaving less available to find additional targets)[4,7] and perceptual priming (i.e., finding a first target primes participants to find targets similar to that of a first target)[8] the current results further suggest that SSM errors are a multifaceted problem. Future research will need to account for the many causes of SSM errors and develop a comprehensive response to this pervasive problem.

6. ACKNOWLEDGMENTS

6.1. Author contributions. All authors developed the study concept and contributed to the study design. S. H. Adamo conducted the testing and data collection. S. H. Adamo performed the data analysis and interpretation under the supervision of S. R. Mitroff. S. H. Adamo drafted the manuscript, and M. S. Cain and S. R. Mitroff provided critical revisions. All authors approved the final version of the manuscript for submission.
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