Targets Need Their Own Personal Space: Effects of Clutter on Multiple-Target Search Accuracy

Article *in* Perception · August 2015

DOI: 10.1177/0301006615594921

3 authors, including:

Stephen H Adamo
Duke University

Stephen R Mitroff
George Washington University

Article

PERCEPTION

Perception
2015, 0(0) 1–12

DOI: 10.1177/0301006615594921
pec.sagepub.com

Targets Need Their Own Personal Space: Effects of Clutter on Multiple-Target Search Accuracy

Stephen H. Adamo
Department of Psychology and Neuroscience, Center for Cognitive Neuroscience, Duke University, NC, USA

Matthew S. Cain
U.S. Army Natick Soldier Research, Development, and Engineering Center, MA, USA

Stephen R. Mitroff
Department of Psychology and Neuroscience, Center for Cognitive Neuroscience, Duke University, NC, USA

Abstract

Visual search is an essential task for many lifesaving professions; airport security personnel search baggage X-ray images for dangerous items and radiologists examine radiographs for tumors. Accuracy is critical for such searches; however, there are potentially negative influences that can affect performance; for example, the displays can be cluttered and can contain multiple targets. Previous research has demonstrated that clutter can hurt search performance and a second target is less likely to be detected in a multiple-target search after a first target has been found, which raises a concern—how does clutter affect multiple-target search performance? The current study explored clutter in a multiple-target search paradigm, where there could be one or two targets present, and targets appeared in varying levels of clutter. There was a significant interaction between clutter and target number: Increasing levels of clutter did not affect single-target detection but did reduce detection of a second target. Multiple-target search accuracy is known to be sensitive to contextual influences, and the current results reveal a specific effect wherein clutter disproportionally affected multiple-target search accuracy. These results suggest that the detection and processing of a first target might enhance the masking effects of clutter around a second target.

Keywords

visual search, subsequent search misses, clutter

Corresponding author:

Stephen H. Adamo, Department of Psychology and Neuroscience, Center for Cognitive Neuroscience, Duke University, B203 LSRC, Box 90999, Durham, NC 27708-0754, USA.
Email: stephen.adamo@duke.edu

Visual search, looking for targets amongst distractors, is an activity conducted in a wide variety of contexts. Searching can be as mundane as a child looking for apple juice in the refrigerator or as serious as a radiologist looking for signs of cancer in a radiograph. While visual search has been extensively studied in laboratory settings (for recent reviews, see Eckstein, 2011; Nakayama & Martini, 2011), there are many challenges encountered when moving beyond the laboratory to explore what factors influence search in *real-world* settings (see Clark, Cain, Adamo, & Mitroff, 2012, for a recent review). For example, professional searchers often search for an unknown number of targets—radiologists search for multiple possible abnormalities (e.g., a radiograph can contain more than one tumor) and airport security personnel often search for multiple possible types of contraband (e.g., an X-ray image of a carry-on bag can contain both a water bottle and a gun; e.g., Menneer, Barrett, Phillips, Donnelly, & Cave, 2007).

Unfortunately, searching for multiple targets is susceptible to the *satisfaction of search* effect—a target is more likely to be missed after another target has already been detected in the same search display, compared to if it were the only target present in the display (Tuddenham, 1962). For example, a radiologist is more prone to miss a tumor if another tumor was already found in the same radiograph (Berbaum, 2012). This phenomenon, which we have recently relabeled the *subsequent search misses* (SSM) effect (Adamo, Cain, & Mitroff, 2013), is troubling as it has been suggested to account for approximately one third of misses under certain radiological conditions (Anbari & West, 1997).

Research from academic radiology and cognitive psychology has focused on understanding the nature of these errors so that they can be overcome (Cain, Adamo, & Mitroff, 2013; Samuel, Kundel, Nodine, & Toto, 1995). With studies examining the underlying mechanisms of SSM errors (e.g., Adamo et al., 2013; Berbaum et al., 1990, 1991; Cain et al., 2013) and studies examining what situational factors are most likely to give rise to the errors (e.g., Biggs & Mitroff, 2014; Cain, Biggs, Darling, & Mitroff, 2014; Cain & Mitroff, 2013; Clark, Cain, Adcock, & Mitroff, 2013), important facts about SSM have begun to accumulate. Below, we briefly review three proposed theories of SSM errors, as well as review several situational factors that have been found to have relatively strong influences on multiple-target visual search performance compared to single-target visual search performance.

Theories of SSM Errors

Three primary theories have been proposed for why SSM errors arise in multiple-target visual search: satisfaction, perceptual set, and resource depletion.

Satisfaction account. SSM errors were first proposed to arise from searchers becoming *satisfied* with the meaning of a search after finding a target—once one target was found, searchers would prematurely terminate their search without fully searching for any additional targets (Smith, 1967; Tuddenham, 1962). While this account is plausible, measurements of overall search times for single-target and multiple-target arrays have not fully supported it (e.g., Berbaum et al., 1991). Moreover, eye-tracking metrics were used in a recent study, and the results suggested that a *satisfaction* account only explains a small percentage of multiple-target search errors (e.g., Cain et al., 2013). As such, the original name for the phenomenon is a bit of a misnomer, and that is why we have adopted the mechanistically agnostic label of *subsequent search misses* (Adamo et al., 2013).

Perceptual set account. The perceptual set account posits that a found target biases searchers to look for similar targets (Berbaum et al., 1990, 1991). That is, once a target has been detected, it may *prime* searchers such that they are subsequently more likely to find similar items. The downside of such priming, though, is that searchers would then be more likely to miss dissimilar targets. While this account has not received great support in the literature (e.g., Cain et al., 2013), recent evidence suggests a significant role of target similarity for multiple-target search errors (Biggs, Adamo, Dowd, & Mitroff, 2015; Mitroff et al., 2014).

Resource depletion account. The resource depletion account posits that once a target is detected in a search, attentional resources are consumed, which makes the searcher less likely to find additional targets (Berbaum et al., 1991). Attention is a limited resource, so the logic of this account is that the attention allotted to identifying a found target subsequently leaves less attention available for the process of trying to detect additional targets. Expanding this theory, it has also been suggested that the depletion of working memory resources is a potential cause for SSM errors (Cain & Mitroff, 2013); as the locations and identities of found targets are stored in working memory, the searcher's limited working memory resources are consumed, leaving less available for finding additional targets.

Situational Influences on SSM Errors

While much can be gained by examining the theoretical underpinnings of SSM errors, it is also valuable to explore what factors do and do not affect multiple-target search performance; by understanding what can influence SSM errors, it may be possible to counteract the influences and improve performance. Several studies have recently revealed situational influences that appear to primarily affect multiple-target searches and not single-target searches (e.g., Adamo, Biggs, & Mitroff, 2014; Cain et al., 2014; Cain, Dunsmoor, LaBar, & Mitroff, 2011). For example, SSM errors were found to increase when searchers were anxious, yet this manipulation had no effect on single-target accuracy (Cain et al., 2011). Similarly, SSM errors increased when multiple search arrays were crowding one another (akin to how multiple bags might be crammed together on a conveyor belt at an airport security checkpoint), but this did not affect single-target accuracy (Adamo et al., 2014). Conversely, SSM errors were effectively eliminated by separating multiple-target searches into several single-target searches (Cain et al., 2014).

Current Study

While situational influences on visual search are helpful in offering potential measures that can be taken to reduce SSM errors in real-world searches, there is still more work to be done. In the current study, we looked to address one potential influence on multiple-target visual search accuracy that has not been directly examined before—clutter. Clutter can be broadly defined as either the number of items or the organization of the items present within the vicinity of a target, with the implication that greater levels of clutter (i.e., more items or more complex organizations of items) makes finding a target more difficult (Rosenholtz, Li, & Nakano, 2007). Take the example of airport security personnel tasked with finding contraband in X-ray images of carry-on luggage. Not all carry-on bags are the same; some bags are extremely cluttered with many items inside (e.g., a briefcase filled with electronics, cables, notebooks, pens, etc.) while other bags are sparse (e.g., a mostly empty duffle bag containing a few items of clothing).

Previous research on both the nature of clutter (e.g., Rosenholtz et al., 2007) and common sense would suggest that visual search will be more difficult in a cluttered search array than a sparse array, but exactly how does clutter affect multiple-target search? This is an especially important question to address, as a shift in airline policy has likely made carry-on bags more cluttered than ever before; with many airlines now charging extra fees for checked bags, passengers are likely more inclined to overfill their carry-on bags to avoid checking their bags.

Given that influences such as anxiety and the proximity of search arrays to one another have a particularly strong influence on SSM errors relative to single-target search performance (Adamo et al., 2014; Cain et al., 2011), might the clutter around a second target have a particularly strong influence on performance? To address the current question, we employed a standard cognitive psychology multiple-target search experiment (e.g., Fleck, Samei, & Mitroff, 2010) while incorporating logic from the visual clutter literature.

Measuring clutter in real-world images is not necessarily straight forward, and several modeling techniques have been proposed for determining appropriate calculations of clutter, including sub-band entropy, edge density, and feature congestion (see Rosenholtz et al., 2007 for a review). These models have primarily been used to measure the clutter of an entire scene (e.g., Henderson, Chanceaux, & Smith, 2009); however, more recently, a sub-band entropy model was used to calculate clutter in a restricted region around a target (Asher, Tolhurst, Troscianko, & Gilchrist, 2013). Being able to apply a restricted clutter calculation is the most relevant to our current goals here, and it was found in the previous study that a 6° to 7° radius around a target was the most sensitive to clutter (Asher et al., 2013). This 6° to 7° radius effect is interesting because it is also the general area that is sensitive to other visual phenomena such as visual crowding and lateral masking (e.g., Asher et al., 2013; Levi, 2008).

In the present study, we adopted the radius-specific clutter approach from Asher et al. (2013) and used a simplified search array. This allowed us to define clutter purely as a function of the number of items near a target. Clutter has been shown to impact single-target search performance (e.g., Asher et al., 2013), but how might it affect multiple-target search performance? If a second target appeared within a cluttered location in a search array, would there be a greater SSM effect than if it appeared in a less cluttered location?

Methods

Participants

The current study involved 106 members of the Duke community, who participated for course credit or $10 per hour. Participants were recruited either as part of an eye-tracking experiment (Adamo et al., 2013; Cain et al., 2013) or a large-scale, multisession study conducted in the Duke Visual Cognition laboratory that was focused on assessing individual differences for a variety of behavioral tasks. As such, the participants completed additional tasks that are not discussed here, and some of the current data have been published elsewhere (Adamo et al., 2013; Cain et al., 2013) and may serve as the basis for future publications. Twenty-seven of the participants were run in a version of the search task that incorporated eye-tracking measurements, but these measures were not incorporated into the current analyses. Sixteen participants' data were removed from the analyses following the filters of Adamo et al. (2013): Data from five participants were removed because they had greater than 15% high-salience, single-target errors, four for having greater than 20% false alarms, and seven for having greater than 20% timeouts (not finishing within the 15-s time limit), leaving a total of 90 participants (age range 18–25, mean = 20.2 years). Research was conducted in accordance with the Declaration of Helsinki.

Stimuli and Apparatus

The stimuli were based off of previous SSM studies (e.g., Fleck et al., 2010). All items were pairs of perpendicular rectangles, with a small gap between them, that created "T" or "L" shapes and were 1.3° × 1.3°. The targets had the rectangles perfectly aligned so as to create a T-shape. The distractors had the rectangles offset from perfect alignment by 1 to 4 pixels so that they appeared as either a perfect "L" or a misaligned "L" shape. Items were presented in one of four possible orientations (0°, 90°, 180°, or 270° rotations) on a white background. A total of 25 items were displayed on an invisible 8 × 7 grid with each item offset from perfect grid alignment by 0 to 5 pixels. Half of the targets and 5% of distractors were *high salience*—they were relatively dark compared to the white background (57%–65% black), which made them more visually salient. The other half of the targets and 95% of distractors were *low salience* (22%–45% black), appearing as light gray against the white background. Two levels of salience were implemented to create a bias wherein participants would be more likely to find high-salience targets first (e.g., Fleck et al., 2010).

Stimuli were presented with Matlab via PsychToolbox 3 (Kleiner, Brainard, & Pelli, 2007). Sixty-three participants performed the task on a 20-in. CRT monitor and 27 participants, who were part of an eye-tracking study, viewed the task on a 17-in. LCD monitor. All participants were seated 57 cm away from the monitor and used a chin rest to keep the viewing distant constant.

Procedure

Participants were instructed to search for one or two T-shaped targets among pseudo L-shaped distractors (see Figure 1). There were 250 trials evenly split across 10 blocks in addition to a practice block of 25 trials. Ten percent of the total trials were high-salience, single-target trials, 10% were low-salience, single-target trials, and 80% were dual-target trials with one high- and one low-salience target. This trial distribution was used to create a high number of dual-target trials in which the second target was cluttered. Participants had 15 s to search each display and were asked to press the space bar when they were finished.

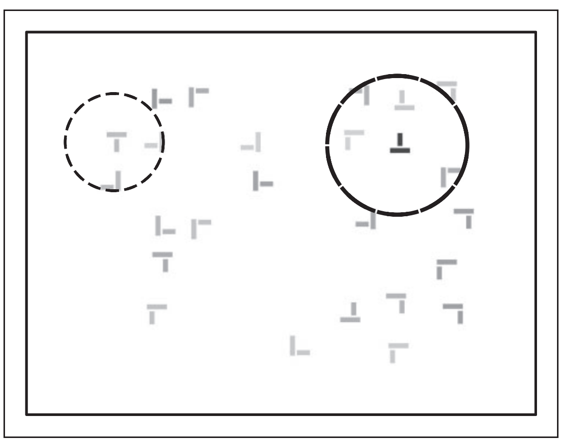

Figure 1. Sample multiple-target search display. The dashed lines (not present in the actual displays) represent the area where items were considered *clutter.* The short dashed circle around the low-salience target "T" represents the 100-pixel radius and the long dashed circle around the high-salience target "T" represents the 200-pixel radius. In this image, the 100-pixel radius is a 2-item example and the 200-pixel radius is a 4/5-item example.

If they failed to press the space bar within the 15-s time limit, this was considered a *time out*. Participants made a mouse click on each item they believed was a target and a small blue circle (0.3°) appeared after each click. This circle has been shown not to affect search performance (Cain & Mitroff, 2013).

Data Preparation and Planned Analyses

We measured clutter for two different spatial areas around a target: a 100-pixel radius (3.25°) and a 200-pixel radius (6.5°) around the center of a target. Items were considered *clutter* if their center point fell within these radii. This 100-pixel range represented the smallest area wherein one item could be near another item in the current displays, thus allowing us to explore only the closest items to a target (see Figure 1). The area within the 200-pixel radius is comparable to the area in which distracting items have previously been demonstrated to influence the detection of a target (Asher et al., 2013).

Within the 100-pixel radius, we explored three different levels of clutter: 0, 1, and 2 items within the radius. For the 200-pixel radius analyses, we grouped sets of items into three different levels of clutter: 2 or 3 items, 4 or 5 items, and 6 or 7 items. We focused on these levels because the majority of trials had between 2 and 7 items within a 200-pixel radius area of a target, with relatively few trials having less than 2 or more than 7. Grouping into three levels of clutter also served to improve the reliability of our measurement (i.e., providing more trials to each level of clutter) and to mirror the three levels of clutter from the 100-pixel radius analyses.

Results

Data Filtering

Mouse clicks within a 40-pixel radius (approximately 1.3°) from the center of a target were considered correct. Any clicks that fell outside of that radius were considered false alarms, and trials with a false alarm (2.0% of all trials) were not included in further analyses. An additional 3.8% of trials were removed due to participants timing out by reaching the 15-s time limit. Of the remaining trials, SSM errors were calculated as the difference in accuracy for detecting low-salience targets on single-target trials versus on dual-target trials after a high-salience target was detected first (e.g., Adamo et al., 2013). This led to the removal of 4.4% of dual-target trials in which the high-salience target was not found and an additional 16.2% of dual-target trials, where the low-salience target was found before the high-salience target.

The distribution and layout of the distractor items were not experimentally manipulated, which resulted in a variable distribution of trials for the different levels of clutter. As a result, not every participant contributed data to each analysis: In the 100-pixel radius calculations, 87 participants contributed to the high-salience, single-target trial analyses, 88 participants contributed to the low-salience, single-target analyses and SSM calculation, and 90 contributed to the dual-target analyses; In the 200-pixel radius calculations, 89 participants contributed to the high-salience, single-target analyses, 87 participants contributed to the low-salience, single-target analyses and SSM calculation, and 90 contributed to the dual-target analyses[1].

Accuracy

Participants performed well on single-target trials with a hit rate of 99.2% on high-salience, single-target trials and 93.6% on low-salience, single-target trials (see Table 1A and B).

Table 1. Accuracy and Response Time Metrics for Experiment 1 (with *SE*s).

		100-pixel radius				200-pixel radius			
		Number of items				Number of items			
Measure	Overall average	0	1	2	Sig.	2/3	4/5	6/7	Sig.
A. High-salience, single-target hit rate	99.23% (0.23%)	98.64% (0.57%)	99.55% (0.26%)	99.84% (0.16%)	$p = .08$	98.78% (0.59%)	99.42% (0.29%)	99.40% (0.43%)	$p = .45$
B. Low-salience, single-target hit rate	93.63% (1.10%)	93.89% (1.49%)	93.46% (1.30%)	94.28% (1.48%)	$p = .87$	93.59% (1.15%)	92.93% (1.77%)	93.65% (1.71%)	$p = .89$
C. Low-salience, second target hit rate	69.66% (1.86%)	72.41% (1.93%)	69.43% (1.85%)	67.52% (2.05%)	$p < .01^{**}$	71.61% (1.85%)	69.49% (1.93%)	66.92% (2.03%)	$p < .01^{**}$
D. SSM effect (B minus C)	23.97% (1.58%)	21.78% (1.99%)	24.52% (1.85%)	27.24% (1.96%)	$p < .01^{**}$	22.30% (1.82%)	23.74% (2.02%)	27.03% (2.06%)	$p = .05^{*}$
E. High-salience, single-target response time	3.33 s (0.13 s)	3.28 s (0.15 s)	3.40 s (0.14 s)	3.38 s (0.19 s)	$p = .70$	3.27 s (0.15 s)	3.50 s (0.17 s)	3.11 s (0.15 s)	$p = .04^{*}$
F. Low-salience, single-target response time	5.99 s (0.10 s)	5.98 s (0.19 s)	5.87 s (0.15 s)	6.12 s (0.20 s)	$p = .57$	6.00 s (0.20 s)	6.02 s (0.15 s)	5.61 s (0.18 s)	$p = .18$
G. Low-salience, second target response time	6.42 s (0.09 s)	6.41 s (0.10 s)	6.43 s (0.09 s)	6.49 s (0.11 s)	$p = .48$	6.43 s (0.10 s)	6.34 s (0.10 s)	6.46 s (0.11 s)	$p = .20$
H. Time between first and second target click	3.82 s (0.06 s)	3.83 s (0.08 s)	3.82 s (0.07 s)	3.81 s (0.08 s)	$p = .85$	3.82 s (0.07 s)	3.75 s (0.07 s)	3.85 s (0.08 s)	$p = .27$
I. Time between first target click and done time	6.61 s (0.21 s)	6.62 s (0.22 s)	6.66 s (0.22 s)	6.59 s (0.21 s)	$p = .77$	6.63 s (0.22 s)	6.51 s (0.21 s)	3.62 s (0.23 s)	$p = .52$

Note. The amount of distractors is indicated underneath the two radii analyses. Each *p*-value represents a within-subjects, one-way analysis of variance with the main effect of clutter for each radius analysis.
$^{*}p \leq .0.05$, $^{**}p \leq .0.01$

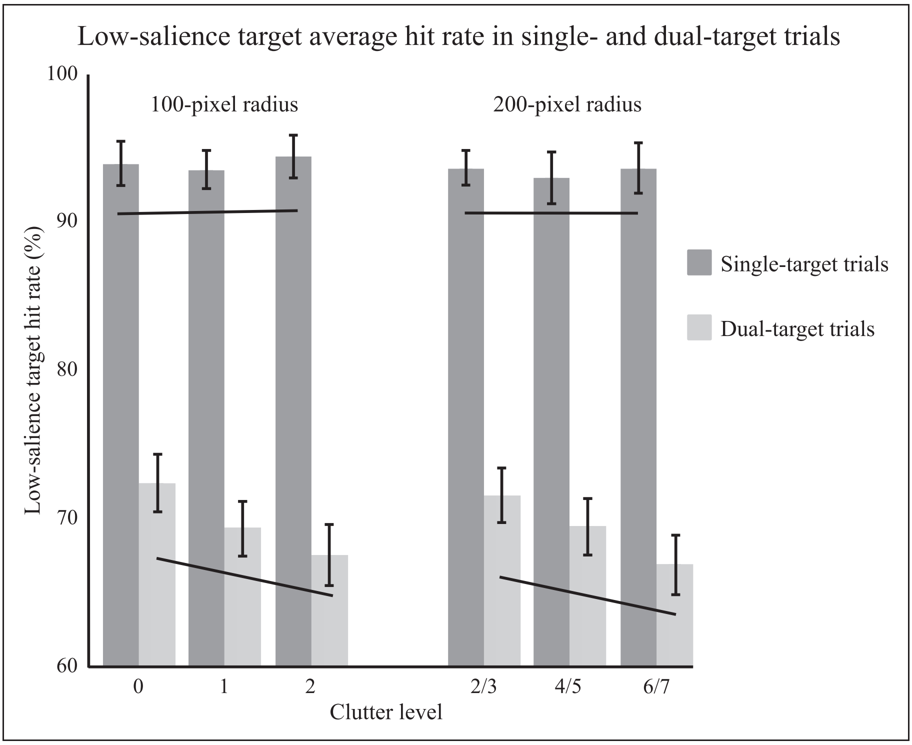

Figure 2. Hit rates for low-salience targets in the single-target (dark gray) and dual-target (light gray) conditions as a function of clutter level for both the 100-pixel (3.25°) and 200-pixel (6.5°) analyses. The hit rate for dual-target trials is for trials in which a high-salience target was previously detected. Error bars represent the standard error of the mean and the lines represent the trend line for clutter level across single- and dual-target trials.

Likewise, the hit rate for high-salience targets on dual-target trials was high at 95.6%. However, the hit rate for low-salience targets on dual-target trials after a high-salience target had already been found was 69.7% (Table 1C), resulting in a significant SSM effect of 24.0% ($t(89) = 15.18$, $p < .01$; Table 1D).

The high-salience and low-salience, single-target hit rates did not significantly vary by clutter level, for either the 100-pixel or 200-pixel radii (see Table 1A and B). In contrast, hit rate for the low-salience targets on dual-target trials in which the high-salience target had already been found significantly decreased as the level of clutter increased for both the 100-pixel and 200-pixel radii (Table 1C and Figure 2). As a result, there was a significant increase in the magnitude of the SSM effect as the clutter level increased (100-pixel radius: $F(1.92, 170.8) = 14.2$, $p < .01$, $\eta^2 = .138$; 200-pixel radius: $F(1.88, 169.1) = 11.3$, $p < .01$, $\eta^2 = .112^2$; see Table 1D). The influence of clutter did not differ between the 100-pixel and 200-pixel condition ($F(1, 87) = .03$, $p = .87$).

Response Time

There were no significant influences of clutter level on the response time data (see Table 1E to H) except for one analysis—response times for the high-salience, single-target trials significantly decreased as the clutter level increased for the 200-pixel radius analysis ($F(1.\ 95,\ 171.3) = .31$, $p = .04$, $\eta^2 = .036$; Table 1E). This effect appears to be driven by a significant difference between the 4/5 and 6/7 items condition ($t(88) = 2.48$, $p = .02$) as the other possible combinations (i.e., comparing 2/3 to 4/5 and 2/3 to 6/7 conditions) were nonsignificant (p's $> .09$).

General Discussion

In many critical, real-world visual search settings, professionals are tasked with searching for an unknown number of targets in cluttered environments. The cost of failure can be high—there are potentially fatal implications of a missed tumor in a radiological examination or a prohibited item making it through an airport security screening. SSM errors, the failure to detect a target after a previous target was already found, are a known problem for professional searchers (e.g., Berbaum, 2012) and the current study found that the errors can be exacerbated by visual clutter. SSM errors were present for all levels of clutter tested, and the error rate significantly increased as the amount of clutter increased around a second target.

There are multiple hypotheses for the underlying mechanisms that produce SSM errors and we briefly discuss each of them with respect to the current results. The *satisfaction* account (Smith, 1967; Tuddenham, 1962) does not appear to account for SSM errors in conjunction with clutter, as time spent searching after finding a first target did not change across different levels of clutter (see Table 1I). It is also unlikely that the perceptual set account (Berbaum et al., 1990, 1991) could explain the current results as the targets only differ in luminance and orientation. Previous research, using a subset of these data (Cain et al., 2013), found that orientation (i.e., whether the first and second target were the same orientation) did not significantly account for a difference in second target detection. However, we cannot fully rule out the perceptual set account, in general, as recent work has found evidence for both perceptual and conceptual sets guiding second-target detection in multiple-target visual search (Biggs et al., 2015). Specifically, this study assessed performance via a mobile technology app that allowed for testing visual search across a large numbers of possible targets. This target variability reduced the chances that a small number of targets would be *chronically* primed across an experiment, and perceptual and conceptual set evidence arose (Biggs et al., 2015).

The current data appear to most closely align with a resource depletion account of SSM errors (e.g., Berbaum et al., 1991; Cain & Mitroff, 2013). Previous research has demonstrated that finding a target in a visual search array can tax cognitive resources, such as attention (Adamo et al., 2013) and working memory (Cain & Mitroff, 2013), which leaves the searcher more vulnerable to missing additional targets. In a similar theoretical vein, previous research has also demonstrated that crowding, the inability to detect items in cluttered displays, can tax attentional resources (e.g., Dakin, Bex, Cass, & Watt, 2009; Scolari, Kohen, Barton, & Awe, 2007; Whitney & Levi, 2011), thereby requiring attention to reduce the distance over which distractors affect detection accuracy (Yeshurun & Rashal, 2010). The current experiment also appears to support the notion that as clutter increases, so does the need for attention. In relation to the resource depletion account, if the first target is draining attentional resources, clutter can impose an additional load on attention, leaving even *less* attentional resources to detect a second target.

Previous research has demonstrated an impact of visual clutter on search performance in single-target searches (e.g., Rosenholtz et al., 2007) and, more recently, within a 6° to 7°

radius around a target (Asher et al., 2013). However, the current results did not demonstrate a significant effect of clutter on the low- or high-salience, single-target hit rates or response time measures. More work is needed to fully elucidate this difference, but our hypothesis is that we did not find an effect of clutter on single-target trials because the current searches were relatively simple and there was always at least one target present per search. This is easily seen when looking at the overall accuracy for single-target trials—the high-salience, single-target accuracy was at ceiling (99.2%) and the low-salience, single-target accuracy was also very high (93.6%), which leaves little room to assess effects of clutter. We purposely manipulated the nature of the high-salience and low-salience targets to make the high-salience items easy to detect (to allow for an investigation of the low-salience targets on dual-target trials), but this was not optimal for assessing the impact of clutter on the single-target trials. Moreover, there were relatively few single-target trials, which limited the experimental power for this question.

Going beyond theoretical accounts of SSM, it is noteworthy that the results reported here are similar to the phenomena of crowding and lateral masking. In general, when viewing a target in the periphery surrounded by distractors, crowding can be defined as impairment in the ability to recognize a target and lateral masking can be defined as impairment in the ability to distinguish target features. As mentioned in Asher et al. (2013), clutter within a 6° to 7° radius around a target likely leads to masking of the target, either due to crowding or lateral masking, which may ultimately result in a lower target hit rate. While eye movements could be made in our experiment (unlike typical crowding and lateral masking experiments), it could be that eye movements were less likely to actually land on or near the second target due to masking. In our experiment, the masking of a second target may be harder to overcome if the attentional resources needed to help counteract masking were being consumed by the first target (i.e., as predicted by the resourced depletion hypothesis; Cain & Mitroff, 2013).

To summarize, the current study found that clutter had a selective influence on second-target accuracy in visual search—there was an increase in SSM errors as clutter increased around a second target. This result has direct implications for critical, real-world searches such as those conducted in radiology and baggage screening; professional searchers often encounter cluttered search displays and SSM errors are a persistent and troubling concern in both radiology (Berbaum, 2012) and airport baggage screening (Biggs, Cain, Clark, Darling, & Mitroff, 2013). Clutter may exasperate the SSM effect, and SSM errors can be better accounted for through a better understanding of the role of clutter.

Conflict of Interest

None declared.

Funding

S.H.A. was supported by pre-doctoral fellowships from the National Science Foundation and Ford Foundation. This work was partially supported by the Army Research Office (#54528LS) and through a subcontract with the Institute for Homeland Security Solutions, a research consortium sponsored by the Resilient Systems Division in the Department of Homeland Security (DHS) through Contract No. HSHQDC-08-C-00100. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the official policy or position of DHS or of the U.S. Government.

Notes

1. To make sure participant inclusion did not affect the outcome, all analyses were also recalculated using only data from participants who contributed to every measure ($N = 85$). The pattern of results remained the same.
2. All analyses of variance were Greenhouse Geisser corrected.

References

Adamo, S. H., Biggs, A. T., & Mitroff, S. R. (2014). *Bags need their own personal space*. Manuscript submitted for publication.

Adamo, S. H., Cain, M. S., & Mitroff, S. R. (2013). Self-induced attentional blink: A cause of errors in multiple-target search. *Psychological Science*, *24*(12), 2569–2574.

Anbari, M. M., & West, O. (1997). Cervical spine trauma radiography: Sources of false-negative diagnoses. *Emergency Radiology*, *4*(4), 218–224.

Asher, M. F., Tolhurst, D. J., Troscianko, T., & Gilchrist, I. D. (2013). Regional effects of clutter on human target detection performance. *Journal of Vision*, *13*(5), pii: 25, 1–15.

Berbaum, K. S., Franken, E. A. Jr., Dorfman, D. D., Rooholamini, S. A., Coffman, C. E., Cornell, S. H., . . . Kao, S. C. (1991). Time course of satisfaction of search. *Investigative Radiology*, *26*(7), 640–648.

Berbaum, K. S., Franken, E. A. Jr., Dorfman, D. D., Rooholamini, S. A., Kathol, M. H., Barloon, T. J., . . . Montgomery, W. J. (1990). Satisfaction of search in diagnostic radiology. *Investigative Radiology*, *25*(2), 133–140.

Berbaum, K. S. (2012). Satisfaction of search experiments in advanced imaging. *Proceedings of SPIE*, *8291*(1), 82910V.

Biggs, A. T., Adamo, S. H., Dowd, E. W., & Mitroff, S. R. (2015). Examining perceptual and conceptual set biases in multiple-target visual search. *Attention, Perception, & Psychophysics*, *77*(3), 844–855.

Biggs, A. T., Cain, M. S., Clark, K., Darling, E. F., & Mitroff, S. R. (2013). Assessing visual search performance differences between Transportation Security Administration Officers and nonprofessional visual searchers. *Visual Cognition*, *21*(3), 330–352.

Biggs, A. T., & Mitroff, S. R. (2014). Improving the efficacy of security screening tasks: A review of visual search challenges and ways to mitigate their adverse effects. *Applied Cognitive Psychology*, *29*, *142–148*.

Cain, M. S., Adamo, S. H., & Mitroff, S. R. (2013). A taxonomy of errors in multiple-target visual search. *Visual Cognition*, *21*(7), 899–921.

Cain, M. S., Biggs, A. T., Darling, E. F., & Mitroff, S. R. (2014). A little bit of history repeating: Splitting up multiple-target visual searches decreases second-target miss errors. *Journal of Experimental Psychology: Applied*, *20*(2), 112–125.

Cain, M. S., Dunsmoor, J. E., LaBar, K. S., & Mitroff, S. R. (2011). Anticipatory anxiety hinders detection of a second target in dual-target search. *Psychological Science*, *22*(7), 866–871.

Cain, M. S., & Mitroff, S. R. (2013). Memory for found targets interferes with subsequent performance in multiple-target visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(5), 1398–1408.

Clark, K., Cain, M. S., Adamo, S. H., & Mitroff, S. R. (2012). Examining influences on applied visual search performance. In M. D. Dodd, & J. H. Flowers (Eds.), *The influence of attention, learning, and motivation on visual search* (Vol. 59, pp. 147–181). New York, NY: Springer.

Clark, K., Cain, M. S., Adcock, R. A., & Mitroff, S. R. (2013). Context matters: The structure of task goals affects accuracy in multiple-target visual search. *Applied Ergonomics*, *45*(3), 528–533.

Dakin, S. C., Bex, P. J., Cass, J. R., & Watt, R. J. (2009). Dissociable effects of attention and crowding on orientation averaging. *Journal of Vision*, *9*(11), pii: 28, 1–16.

Eckstein, M. P. (2011). Visual search: A retrospective. *Journal of Vision*, *11*(5), pii: 14, 1–36.

Fleck, M. S., Samei, E., & Mitroff, S. R. (2010). Generalized "satisfaction of search": Adverse influences on dual-target search accuracy. *Journal of Experimental Psychology: Applied*, *16*(1), 60–71.

Henderson, J. M., Chanceaux, M., & Smith, T. J. (2009). The influence of clutter on real-world scene search: Evidence from search efficiency and eye movements. *Journal of Vision*, *9*(1), pii: 32, 1–8.

Kleiner, M., Brainard, D. H., & Pelli, D. (2007). What's new in Psychtoolbox-3? *Perception, 36* ECVP Abstract Supplement.

Levi, D. M. (2008). Crowding—An essential bottleneck for object recognition: A mini-review. *Vision Research*, *48*(5), 635–654.

Menneer, T., Barrett, D. J. K., Phillips, L., Donnelly, N., & Cave, K. R. (2007). Costs in searching for two targets: Dividing search across target types could improve airport security screening. *Applied Cognitive Psychology*, *21*(7), 915–932.

Mitroff, S. R., Biggs, A. T., Adamo, S. H., Dowd, E. W., Winkle, J., & Clark, K. T. (2014). What can 1 billion trials tell us about visual search? *Journal of Experimental Psychology: Human Perception & Performance*, *41*, 1–5.

Nakayama, K., & Martini, P. (2011). Situating visual search. *Vision Research*, *51*(13), 1526–1537.

Rosenholtz, R., Li, Y., & Nakano, L. (2007). Measuring visual clutter. *Journal of Vision*, *7*(2), 1–22.

Samuel, S., Kundel, H. L., Nodine, C. F., & Toto, L. C. (1995). Mechanism of satisfaction of search: Eye position recordings in the reading of chest radiographs. *Radiology*, *194*(3), 895–902.

Scolari, M., Kohen, A., Barton, B., & Awh, E. (2007). Spatial attention, preview, and popout: Which factors influence critical spacing in crowded displays? *Journal of Vision*, *7*(2), pii: 7, 1–23.

Smith, M. J. (1967). *Error and variation in diagnostic radiology*. Springfield, IL: C.C. Thomas.

Tuddenham, W. J. (1962). Visual search, image organization, and reader error in roentgen diagnosis. *Radiology*, *78*(5), 694–704.

Whitney, D., & Levi, D. M. (2011). Visual Crowding: A fundamental limit on conscious perception and object recognition. *Trends in Cognitive Sciences*, *15*(4), 160–168.

Yeshurun, Y., & Rashal, E. (2010). Precueing attention to the target location diminishes crowding and reduces the critical distance. *Journal of Vision*, *10*(10), pii: 16, 1–12.