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Visual Search Array Structure and Satisfaction of Search Errors: Evidence from Eye Movements

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Abstract

Multiple-target visual searches are susceptible to errors when the recognition of one target hinders the detection of another. This phenomenon is known as "satisfaction of search" (SOS; Tuddenham, 1962) or more recently "subsequent search misses" (SSM; Cain, et al., 2013). Although this phenomenon was first identified in radiology, SSM errors extend beyond the medical domain. Exploring SSM errors in proofreading, this study examines whether the discovery of one misspelled word interferes with the detection of a second misspelled word amongst other correctly spelled words. Manipulating the display structure of the task, it is hypothesized that the pattern of SSM errors may be different when the words are presented in a random array (i.e., with no distinct search pattern) versus a structured array (i.e., with a linear search pattern of proofreading left to right). We contrast two theories: the satisfaction of search account, which suggests that participants will conduct a less thorough search after detecting the first target because they become "satisfied" with the meaning of their search (Tuddenham, 1962), and the resource depletion theory which suggests, that finding a target hinders the detection of a second target by depleting cognitive resources (Adamo et al., 2013). Results showed that structure of the array had no effect on SSM errors, but when the participant detected a high-salience typo first (an easily detected typo), they conducted a less thorough search and were less likely to identify a low-salience typo (difficultly detected typo), which supports the SOS Account for SSM errors.

Key words: eye tracking, multiple-target searches, Satisfaction of Search (SOS), Subsequent Search Misses (SSM), structure of array

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Introduction

Visual search tasks are performed every day. They can range from but, are not limited to looking around a crowded room for a friend, looking for a car in a parking lot, to looking for a pencil in a backpack. With such a great frequency in our lives, cognitive scientists study how the eyes and brain are linked in hopes of understanding how people perceive the world and how they find particular targets in it. Experimentation has discovered that visual search tasks are prone to errors, especially when there is more than one target to look for. These multiple-target searches take place in academics, through editing and proofreading, and in many other professions, such as radiology, military searches, baggage screening, etc. When performing a search where there are multiple-targets one must worry about when to terminate a search and how to track what areas have already been searched, while also keeping previous targets in memory — all of which affect cognitive processes (Cain & Mitroff, 2013). This complexity of multiple-target searches burdens cognitive resources and creates a greater source of error (Cain & Mitroff, 2013). A phenomenon known as “Satisfaction of Search” has been established from these observations. This phenomenon refers to the findings that searchers prematurely discontinue their search after finding a target because of feelings of “satisfaction” with regard to the “meaning” of the display and do not complete a thorough search for potential targets (Tuddenham, 1962).

Satisfaction of Search (SOS), was discovered in the field of radiology, where a specific target, such a tumor, is more likely to be missed when it is accompanied by an additional abnormality than when it’s the only target (Tuddenham, 1962). These errors are suggested to account for between 1/5 to 1/3 of errors in radiology (Anbari, 1997; Berbaum, Franken, Caldwell, & Schartz, 2010; Krupinski, 2010) in subfields such as in chest radiography (Berbaum et al., 1998; Samuel, Kundel, Nodine, & Toto 1995), multiple trauma patients (e.g., Berbaum et al., 1994) and cytological searches (Bowditch, 1996). Similar findings occur in other diagnostic medicines where these errors were known as “premature closure” (Kuhn, 2002; Voytovich, Rippey, & Suffredini, 1985).

SOS errors were shown in both medical and non-medical domains with individuals of different skill levels, signifying that Satisfaction of Search errors influence tasks on a global scale (Fleck et al., 2010). Through simulated driving tasks (Sall & Feng, 2016), luggage screening (Fleck et al., 2010; Mitroff et al., 2014), and moving display tasks (Stothart, Clement, & Brockmole, 2017), SSM errors have been documented, but little evidence suggests that the searchers are becoming “satisfied” with their searches. There is research showing inconsistencies with the SOS explanations (Berbaum, 2012), because the SOS theory doesn’t account for searchers who continue to search after the successful detection of a preliminary target (Berbaum, Dorfman, Franken, & Caldwell, 2000; Berbaum et al., 1991; Cain, Adamo, & Mitroff, 2013; Fleck et al., 2010). Given that SOS errors are not necessarily due to a single underlying cause, and could stem from multiple factors, (Berbaum, 2012; Berbaum et al., 2010; Cain et al., 2013), the satisfaction of search errors has been relabeled to a more theoretical neutral label: Subsequent Search Misses (SSM; Cain et al., 2013). The new term includes errors that take place because of a complex interaction between the searcher’s basic perceptual, sensory and cognitive limitations, and not necessarily because of some “satisfaction” on the searchers behalf (Sall & Feng, 2016).

There have been many investigations about why a target might be overlooked, including the relative frequency of different target types, external pressures of reward, time constraint, and expectations regarding the number of targets present (Fleck et al., 2010). Manipulations of relative frequency occur when the searcher is told they are looking for a certain number of targets or they have a specified number of targets to look for in a given time period. Global pressures, such as contextual factors and information about the trials (Clark et al., 2014a), affect SSM errors when the instructions of the task are presented to the searcher in different ways. An example of this is when a searcher is instructed to get through as much of a task as possible or finish a task as fast as possible: the accuracy of detection of subsequent targets is much greater when the searcher is given a longer time frame to complete the task rather than instructed to finish a task in the shortest possible amount of time (Clark et al., 2014a). Another factor influencing SSM errors is inter-target distance, which is an experimental manipulation where the spatial array influences detection of targets. As the physical distance between targets increases, searchers are less likely to identify the second target (Gorbunova & Konyuhova, 2016). Other documented SSM error factors include visual clutter (Adamo, Cain, & Mitroff, 2015b), searcher anxiety (Cain, Dunsmoor, LaBar, & Mitroff, 2011), attentional blink (Adamo, Cain, & Mitroff, 2013), and motivation (Clark, Cain, Adcock & Mitroff, 2011; 2014b).

Of relevance to academia and other professions with a writing component, the current study examines SSM effects in proofreading. Proofreading is an important multiple-target search task that requires cognitive resources to complete. In proofreading, a searcher is given an excerpt in which they are targeting misspelled words within an array of correctly spelled words as distractors. Much of the prior work in proofreading, (e.g., Pilotti, Chodorow, Agpawa, Krajniak, & Mahamane, 2012; Frankish & Turner, 2007), looked at what type of errors people were making when proofreading. There is a limited amount of investigation on how the detection of one misspelled word affects the detection of following misspelled words. Barach and Sheridan (2018), were the first to investigate the SSM errors in proofreading by showing evidence of the Satisfaction of Search account using eye tracking measures. Their key finding was that after a participant correctly detected a misspelled word, they were less likely to identify a following misspelled word and had shorter fixations and were faster to terminate a trial than when there was a typo presented by itself. This shows evidence that the participants became prematurely satisfied with their search, supporting the SOS account for SSM errors.

Exploring SSM errors in proofreading is valuable in research, not only to further understand this complex phenomenon, but also because of the great ecological validity of proofreading. It is important to understand the visual cognition of proofreading, since these findings can be linked to other similar tasks that have the same structure of search and clear targets of interest, thus utilizing the same order of processing. Many previous studies examining the SOS account for SSM errors have used the overall reaction time (RT) of multiple and single target trials, time spent searching after finding the first target, and subsequent trial termination (Berbaum et al., 1991; Adamo, Cain & Mitroff, 2015a). In the present study, the eye tracking methodology is implemented to detect eye movements down to the millisecond and thus improve sensitivity to the underlying causes of errors. Eye tracking can be used to potentially explore a variety of theories of SSM errors, including the Satisfaction of Search account (Smith, 1967; Tuddenham, 1962; Adamo, Cain, & Mitroff, 2015a), Perceptual Set Theory (Berbaum et al., 1990; Berbaum et al., 1991; Berbaum et la., 2010; Mitroff et al., 2014), and Resource Depletion Theory (Adamo, Cain, & Mitroff, 2013; Berbaum et al., 1991; Cain & Mitroff, 2013; Stothart, Clement, & Brockmole, 2017).

When performing a visual search task, the searcher's focus can shift with detection of a target, leading to SSM errors (e.g., Berbaum et al., 2010; Fleck et al., 2010). Perceptual Set Theory suggests that as searchers find a target, their subsequent searches become influenced by the first target, and they look for additional targets that are like the first (Berbaum et al., 2010). An example of this in radiology would be a doctor finding a tumor on a chest X-ray, the doctor then goes into “tumor” mode and does not notice other abnormalities in the x-ray such as a fracture (Berbaum et al., 1990; Berbaum et al., 1991; Berbaum et la., 2010; Mitroff et al., 2014). SSM errors have be seen to account for this theory, but in tasks where all targets in the display are similar, there is still evidence of SSM errors. In proofreading, where the searcher is identifying only misspelled words, this theory may not be sufficient to explain SSM errors.

There has been support for resource depletion theory when it comes to SSM errors. This theory states that when a searcher finds a target, they are less successful in finding other targets because of depleting cognitive resources (Adamo et al., 2013; Berbaum et al., 1991; Cain & Mitroff, 2013). The brain uses working memory when performing these visual search tasks, and when the searcher needs to remember the identity (Solman, Cheyne, & Smilek, 2001) and location (Oh & Kim, 2004; Woodman & Luck, 2004) of a target, they have less resources to aid them in the remainder of their search. It is also the case that knowing how many targets the participant needs to be looking for constrains cognitive resources in the task, suggesting that memory resources are used beforehand to find the first target (Körner & Gilcrhist, 2008). A possible way to reduce some of the load on the working memory would be to perform only single target searches (see Cain, Biggs, Darling & Mitroff, 2014) or highlighting found targets in the display (Cain & Mitroff, 2013).

Although there has been only limited support for the Satisfaction of Search account, this theory explains SSM errors as a searcher terminates their search prematurely due to a “satisfaction” with the task at hand. In the context of proofreading, the searcher will find a misspelled word and decide that finding the first typo is sufficient to fulfil the task, and thus they will not conduct as thorough of a search for the remainder of the task. Although a majority of studies performed in radiology (Berbaum, et al., 1990) and in more abstract tasks (Fleck et al., 2010), do not support SOS as being the primary cause of SSM, there is evidence that searchers may intentionally terminate a search early when they believe the likelihood of finding a target is not high enough to justify the continuation of the search (Cain, Vul, Clark, & Mitroff, 2012). Evidence of SOS is found when reaction times show that searchers spend less time searching after finding the first target (Adamo, Cain & Mitroff, 2015a). A recent study looking at individual differences shows that participants who don't prematurely terminate their search after finding the first target were less likely to make SSM errors (Adamo, Cain & Mitroff, 2018). This shows that participants' who fall under the SOS account and are quicker to terminate a trial, are less likely to find a second target. Barach & Sheridan (2018), also found evidence supporting the SOS account in proofreading as searchers spent less time looking for subsequent errors and less time looking through the excerpt, in general, when testing the searcher's ability to find misspelled words in a paragraph.

Still, there is very little evidence supporting the SOS account, especially in other domains of visual search tasks beyond proofreading and medicine. When looking at moving displays, searchers who identify a preliminary target will miss subsequent targets due to cognitive resource depletion theory (Cain & Mitroff, 2013; Stothart, et al., 2017). When instructed to find multiple "T" shaped targets in a moving display, searchers were much less likely to find those errors in a moving display than in a static display (Stothart, Clement, & Brockmole, 2017). A greater amount of working memory resources are needed in tracking moving targets (Allen, Mcgeorge, Pearson, & Milne, 2004; 2006; Tombu & Seiffert, 2008), and in remembering the identity (Solman et al., 2011) and location of a target (Oh & Kim, 2004; Woodman & Luck, 2004). In general, visual searchers are more adversely affected by location-based memory loads than by featured-based memory loads (Beck, Peterson, & Vomela, 2006; Oh & Kim, 2004;

Woodman & Luck, 2004). By manipulating a standard proofreading experiment, so as to contrast structured arrays with distinct lines and patterns of reading with a more randomized structure with no linear pattern to the display, it's possible to examine if the structure of the array can influence SSM errors as one reason for which such errors may be occuring. Thus, cognitive resource depletion theory and satisfaction of search accounts can be contrasted by manipulating whether or not the array is linearly structured.

As previously found, SSM errors are prevalent in visual search tasks, proofreading included. Looking at misspelled words in a group of correctly spelled distractor words, the accuracy is predicted to be worse for trials with two misspelled words than with one misspelled word. Specifically, this task explores misspelled words that have varying noticeability or salience. High-salience typos are words in the array that are obviously misspelled and low-salience typos are words that are subtly misspelled. When looking at a low-salience typo (subtle typo) in a trial, the accuracy of discovering this typo decreases when there is a high-salience typo (obvious typo) presented with it. If a searcher is able to detect the high-salience typo, and then experiences longer total reaction times, longer fixation and more refixations of the low-salience typo, then SSM errors can be attributed to cognitive resource depletion theory (Barach & Sheridan, 2018). In contrast, if a searcher is able to detect a high-salience typo and then experiences quicker total reaction times, shorter fixations and less refixations of the low-salience typo, then SSM errors can be attributed to the SOS account (Barach & Sheridan, 2018), which would replicate Barach and Sheridan (2018), who found support for the SOS account for proofreading in the structured array of a paragraph. In the present study we ask what happens when the same misspelled target words are presented in a spatially more randomized layout like x-rays? The aim of this study is to examine whether the structure of the array, randomized or structured, impacts SSM errors by continuing to support the SOS account or instead supports cognitive resource depletion theory. It is hypothesized that the SSM errors in the randomized array might show evidence of resource depletion theory because the use of working memory resources, and the SSM errors in the structured array, following Barach and Sheridan (2018), will show evidence of the SOS account.

Methods

Participants

Sixty native-English speaking undergraduate students (31 females, 29 males, age range = 18-53 years old, M = 21.02 years old) with normal or corrected-to-normal vision were recruited from the SUNY Albany SONA System or fliers. Participants' average total years of education was 16.7 years. All participants gave informed consent and received course credit or paid compensation for their participation.

Materials and Design

This experiment used easily identifiable misspelled words (known as high-salience words) and subtly misspelled words (known as low-salience words). These words served as the target stimuli in the study. A sample high-salience target would be, *beahc*, and a sample low-salience target would be, *distence*. When exploring SSM errors, the searcher had to identify a preliminary error in order to see if following errors would be recognized. So, when proofreading, it would have been very likely that a searcher would notice the misspelling of "*beahc*" making this a good preliminary word to test SSM errors, or the detection of subsequent targets after the successful detection of the first. There were 224 high-salience targets and 224 low-salience targets, each contained between five and eight letters with a mean letter length of 6.25 letters.

This study incorporated a total of 224 trials containing high and low-salience target words along with filler words (words with no potential spelling errors). Each trial contained, one high-salience target, one low-salience target, and four filler words. There were four typo conditions for the targets in this experiment: (1) The dual typo condition, in which the trial presented a misspelled high-salience target and a misspelled low-salience target, (2) the high-salience single typo condition, in which the trial presented a misspelled high-salience target and correctly spelled low-salience target, (3) the low-salience single typo condition, in which the trial presented a misspelled low-salience target and correctly spelled high-salience target, (4) the no error condition, in which the trial presented the correctly spelled high-salience and low-salience targets. Within these four typo conditions, there were two possible six-word arrangements, which is displayed in Figure 1. They were arranged in one of two formations: (1) Using randomly determined locations, with the center of each word at least 100 pixels away from the four edges of the screen (Figure 1.2), or (2) in a structured array, in which all six words were presented in a straight line that was centered vertically and horizontally on the screen (Figure 1.1). Each of the four typo conditions occurred in the randomized and structured array which resulted in eight conditions total: Randomized Dual Typo condition, Structured Dual Typo condition, Randomized High-Salience Typo condition, Structured High-Salience Typo condition, Randomized Low-Salience Typo condition, Structured Low-Salience Typo condition, Randomized No Error condition, and Structured No Error condition. Each word occurred in all conditions with the formations counterbalanced so that each participant only saw one version of a given formation for a particular target. Randomization of the words were created through a MATLAB coding sequence in which different x, y coordinates were determined for each trial and each participant. There were no two participants with the same word arrangement. The position of high-salience and low-salience targets varied throughout the experiment.

Apparatus and Procedure

Eye movements were measured with an SR Research EyeLink 1000 Plus system with a sampling rate of 1000 Hz. Viewing was binocular, but only the right eye was monitored. A chin rest and forehead rest were used to minimize head movements. Proper calibration was required, and the average gaze-position error had to be less than 0.5º. The trial displays were presented on a 24-inch Asus VG248QE monitor with a refresh rate of 144 Hz and a screen resolution of 1920 x 1080 pixels. All letters were lowercase and were shown in bold 3.5 spaced Courier New font. The letters were presented in size 18-point black font on a white background. Participants were seated 92 cm from the monitor and 3.2 characters equaled approximately 1 degree of the visual angle.

At the beginning of a trial, participants were required to fixate on a cross. In the structured array condition, the cross was located on the left-hand side of the screen in the same location as the first word of the line. In the random array condition, the cross was located in the center of the screen, positioned within the array of words. Participants would then press a button while fixating on the cross; this triggered the text to appear. After looking at the word array, participants pressed one of three button choices to indicate whether they found 0, 1, or 2 spelling errors in the passage. If participants pressed the button that corresponded to an answer of zero errors, then the trial ended and they began the next trial. If participants indicated that they found one or two errors, before they could begin the next trial, they were required to indicate which word or words were misspelled. Participants were asked to fixate on the misspelled word and press a button to communicate their answer. If they found two errors, then they were required to do this twice to indicate the two spelling errors they found. After each button press a sound was played to inform the participant that their answer had been recorded. There were 8 practice trials followed by 224 experimental trials that were presented in a randomized order. Following the completion of all trials, participants were then administered a spelling test to assess spelling ability. This spelling test was made from a list compiled by Burt and Tate (2002), that assessed the participants' ability to spell low frequency words. Previous studies exploring eye movements and reading used this spelling test and found a relationship between reading skill and spelling ability (Veldre & Andrews, 2014). The spelling test was administered on the computer where the participant would hear 20 words spoken aloud and type each word. The accuracy measures for the spelling test showed a mean of 34% accuracy, with a 0.23 standard deviation, and a range of from 0%-100%.

Results

The novel question in the investigation explored whether or not the structure the array had an effect on SSM error detection. Barach and Sheridan (2018), found that proofreading was susceptible to SSM errors and found evidence for the Satisfaction of Search account. However, when misspelled words were presented in a non-linear proofreading display, similar to X-Rays and radiological scans, it was unknown whether support would be found for the Satisfaction of Search account for SSM errors in proofreading. With the inclusion of a random display, it was predicted that there would be a greater burden on working memory, since the location of the typo could not be isolated to a specific line in the array, and thus would permit the possibility of support for Resource Depletion Theory as a potential factor in driving SSM errors.

Accuracy Measures

To examine the occurrence of SSM errors in the proofreading tasks, we contrasted typo selection accuracy (Barach & Sheridan, 2018) for the low-salience typo in dual typo trials, in which the high-salience typo was detected, to accuracy for the low-salience typo in low-salience single typo trials (Cain, Adamo, & Mitroff, 2013). We examined SSM errors by conducting a 2 x 2 analyses of variance (ANOVA) on the data (2 [Array: Randomized/Structured] x 2[Typo Condition: Dual/Low-salience typo only]). It revealed a significant main effect of typo condition- (F(1,59) = 21.64, p <.001), which supports an SSM effect where accuracy for the low-salience typo was worse when the high-salience typo was detected in the dual typo condition than when the low-salience typo was presented alone in the low-salience typo only condition. There was no main effect of the array (F(1,59) = .231, p = .63) and there was no significant interaction with accuracy (F(1,59) = 1.81, p = .18).

Eye Tracking Measures

To examine the impact of detection of the high-salience typo on processing of the low-salience typo we examined the following eye tracking measures used by Barach & Sheridan (2018), (1) first fixation duration (the duration of the participant's first fixation on the low-salience typo), (2) gaze duration (the sum of all first-pass fixations on the low-salience typo), (3) total time (the sum of all fixations on the low-salience typo including regressions back to the typo), (4) probability of a refixation (the probability that the low-salience typo will be refixated again at a later point in the trial), (5) trial skipping (the proportion of trials in which the participant never fixates on the low-salience typo at all over the full duration of the trial). These measures omit trials where a blink occurred immediately preceding, following, or on a first fixation on the low-salience typo. There were 6,720 trials between the dual typo condition and the low-salience typo condition, and out of these trials there were 112 trials in which a blink occurred (0.02% of trials). Following Barach & Sheridan (2018), the relationship between SSM errors and eye movements was assessed by including only trials where the high-salience target was detected, because SSM errors can only occur when the detection of the first target hinders the detection of a subsequent target. With these criteria established, we examined processing of the low-salience typo after detection of the high-salience typo by conducting a 2 x 2 analyses of variance (ANOVA) on the data (2 [Array: Randomized/Structured] x 2[Typo Condition: Dual/low-salience typo only]). Detection of the high-salience typo resulted in reduced processing of the low-salience typo, which supports the SOS account for SSM errors as revealed by a main effect of typo condition for: gaze duration, total time, probability of refixation, and trial skipping. Table 1 summarizes the ANOVA results, means and standard errors for each of the dependent measures.

For gaze duration, participants exhibited a shorter sum of total first-pass fixations when the low-salience typo was presented after the detection of the high-salience typo than when the low-salience typo was presented alone. Total time showed that the participants exhibited shorter total time fixating on the low-salience typo after detecting the high-salience typo than when the low-salience typo was presented alone. Probability of refixation showed that there was a lower probability of the participant refixating the low-salience typo when the low-salience typo was presented after the detection of the high-salience typo than when the low-salience typo was presented alone. Skipping rates showed that the participant was more likely to skip the low-salience typo after the detection of the high-salience typo than when then low-salience typo was presented alone. These measures support the SOS account for SSM errors. The remaining eye tracking measure of first fixation duration did not exhibit a main effect of SOS typo condition (see Table 1, $F = .48$, $p = .49$).

There was also a main effect of array for first fixation duration, gaze duration, and total time which revealed reduced processing of the low-salience typo in the randomized array compared to the structured array. For these eye tracking measures, the participants exhibited a shorter first fixation duration, gaze duration, and total time on the low-salience typo in the randomized condition than the structured condition. The remaining measures (probability of refixation and trial skipping) did not exhibit a main effect of array (as displayed in Table 1, all Fs< .27, all ps>.61). Table 1 shows ANOVA results, means, and standard errors for measures looking at main effect of array. These measures show that the structure of array does influence the participants' search behaviors as seen in the trend that participants spent less time in the randomized array than the structured array. But, since there is no significant difference in accuracy detection for the array, we cannot make any conclusions that the structure of array influences SSM errors. There were no significant interactions for any eye tracking measures (all Fs<2.75, all ps>.10).

Reaction Time Measures

Considering the measure of reaction time (time from triggering the start of the trial to submitting the misspelled words), how long participants spent on each trial was measured. We examined the overall processing by conducting a 2 x 2 analyses of variance (ANOVA) on the data (2 [Array: Randomized/Structured] x 2[Typo Condition: Dual/low-salience typo only]). Supporting the SOS account, the participant exhibited a faster trial termination in trials that contained a detected high-salience typo followed by a low-salience typo than when the low-salience typo is presented by itself. This is revealed by a main effect of typo condition for RT. Table 1 shows ANOVA results, means, and standard errors for the reaction time measure.

The RT measure did not exhibit a main effect of array (as displayed in Table 1, $F = .34$, $p = .56$). Table 1 shows ANOVA results, means, and standard errors for all measures looking at main effect of array. There were no significant interactions for reaction time measures ($F = .13$, $p = .72$).

Discussion

In 1962, Tuddenham founded the Satisfaction of Search Theory that hypothesized that a visual search task is discontinued once the searcher finds a target and becomes “satisfied” with the “meaning” of the task and does not complete a thorough search for other potential targets. Fifty years later, the current study supports this claim. When examining misspelled words as when examining chest abnormalities, evidence is still showing that the detection of one target will negatively affect the detection of a second target. This change in domain (from radiology to proofreading) supports that these errors reflect a global search heuristic (Fleck et al., 2010). Most evidence in the field finds that SSM errors are occuring because of resource depletion theory or perceptual priming, but these new empirical studies in proofreading are showing evidence for the SOS account, further supporting that SSM errors are a multifaceted problem (Adamo, Cain, & Mitroff, 2018).

In a traditional proofreading task, where participants were instructed to read a paragraph and find spelling errors, the SSM errors were supported by the SOS account (Barach & Sheridan 2018). Predictions of the cognitive resource depletion theory contrast with the SOS account and predicts that because participants should spend more time looking at the low-salience typo and more time searching through the display after detecting the high-salience typo than when the low-salience typo is presented by itself (Barach & Sheridan, 2018).

Manipulation of the structure of the array in the present study was to determine what the role of cognitive resource depletion theory would be for SSM errors. The prediction was that when participants needed to remember misspelled words in a less structured display than the standard proofreading task with English text (i.e., reading from left to right, line by line), the brain would require more working memory resources and this would be reflected in longer eye movement measures and longer reaction times (RTs) and this would show greater evidence of cognitive resource depletion. In this study, the randomized array did not show greater evidence of resource depletion theory than the structured array. One limiting factor may be that the display contained only six targets. With so few targets in the display, perhaps the participants could remember the location of each target without excessively taxing the working memory. Further experimentation using displays with more distractor targets may force the searcher to utilize more location-based memory loads (Beck, Peterson, & Vomela, 2006; Oh & Kim, 2004; Woodman & Luck, 2004). Even though this study has not provided evidence of resource depletion theory, its null effect cannot rule out future explanations that include resource depletion when looking for the cause of SSM errors.

Even with this increasing presence of the SOS account, evidence of resource depletion theory is also presenting itself. Outside of proofreading, high-salience and low-salience targets are utilized in multiple-target searches to explore SSM errors. Studies of static (Cain & Mitroff, 2013) and moving displays (Stothart et al., 2017) are finding that participants who correctly detect the first target are having trouble finding a subsequent target. Studies of the nature are showing that there is an increase workload on the working memory because of the participant’s need to remember the identity (Solman et al., 2011) and location (Oh & Kim, 2004; Woodman & Luck, 2004) of the target. Cain and Mitroff (2013), conducted a study in which the accuracy of detecting a second target significantly improved when the first target was removed from the display after it was detected than when the first target was left in place after detection of the target. This provides evidence that when the first target is removed from the display, it is also removed from working memory, and the search is less impaired—supporting resource depletion theory. Any manipulation that will decrease working memory demands should decrease the rate of SSM errors (Cain & Mitroff, 2013).

Helpful to the current investigation, high-salience and low-salience targets outside of proofreading are showing support for the SOS account when exploring SSM errors. Adamo et al., (2015; 2018), conducted visual search tasks that required participants to find target "T" shapes in a random array of "L" shapes and found evidence supporting the SOS account when directly compared to cognitive resource depletion. Similarly, a co-registration study of eye-tracking and electroencephalography (EEG) found that after the detection of a high-salience typo, the low-salience typo had reduced processing, shorter fixations, and quicker trial termination (Körner et al., 2014). So, although the current study is among the first to find evidence of the SOS account for SSM errors in proofreading, the argument of "searcher satisfaction" is becoming more and more widespread through experimentation.

Finally, Adamo, Cain, & Mitroff (2018), found evidence of SSM errors explained by the SOS account in individual differences of the participants. They explored whether or not the participant's motivation — how engaged and conscientious they were — caused them to keep searching effectively beyond the detection of the first target. They observed that self-reported conscientiousness as assessed by a personality test was associated with longer search times after finding the first target (Adamo, Cain, & Mitroff 2018). Looking at the difference in time it took for participants to terminate the search after they detected the high-salience target, those who spent a longer time looking at each trial (not falling for the SOS account) were found to be more conscientious people. It is worth further exploring whether or not personality contributes to a decrease in SSM errors. SSM errors occuring in fields such as radiology and baggage screening, can have serious consequences that can potentially hurt people. Every study performed gets us one step closer to understanding why SSM errors are happening.

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Table 1

Eye tracking and reaction time measures for the low-salience typos

Measure	Typo Condition		Array Structure Condition		Significance		
	Dual Typo Condition*	LS Typo Condition	Randomized Condition	Structured Condition	Typo Condition	Array Structure Condition	Typo Condition x Array Condition
First Fixation Duration (ms)	306.05 (6.98)	309.79 (7.21)	281.69 (6.52)	334.15 (8.27)	$F(1,59) = .48$, $p = .49$	**$F(1,59) = 55.24, p < .001$**	$F(1,59) = .1.94$, $p = .17$
Gaze Duration (ms)	935.74 (42.81)	997.12 (43.46)	892.62 (41.21)	1040.24 (44.78)	**$F(1,59) = 5.98$, $p < .05$**	**$F(1,59) = 36.68$, $p < .001$**	$F(1,59) = 2.75$, $p = .10$
Total Time (ms)	1559.57 (73.91)	1767.31 (80.17)	1560.55 (73.56)	1766.22 (81.06)	**$F(1,59) = 25.70$, $p < .001$**	**$F(1,59) = 22.68$, $p < .001$**	$F(1,59) = .09$, $p = .76$
Probability of Refixation	.91 (.009)	.95 (.006)	.93 (.007)	.93 (.007)	**$F(1,59) = 41.14$, $p < .001$**	$F(1,59) = .27$, $p = .61$	$F(1,59) = 1.15$, $p = .29$
Trial Skipping	.004 (.002)	.001 (.001)	.003 (.001)	.002 (.001)	**$F(1,58) = 5.92$, $p < .05$**	$F(1,58) = .14$, $p = .71$	$F(1,58) = .03$, $p = .86$
Reaction Time (ms)	6109.04 (259.17)	6467.19 (272.19)	6312.76 (252.93)	6263.47 (273.93)	**$F(1,59) = 11.07$, $p < .05$**	$F(1,59) = .34$, $p = .56$	$F(1,59) = .13$, $p = .72$

* When the high-salience target was a typo, it had to be detected in order for the trial to be included the data analyses. Standard errors are presented in the parenthesis. The means and standard errors shown are based off the by-participant analyses. All significant effects are shown in bold. More details are found in text.

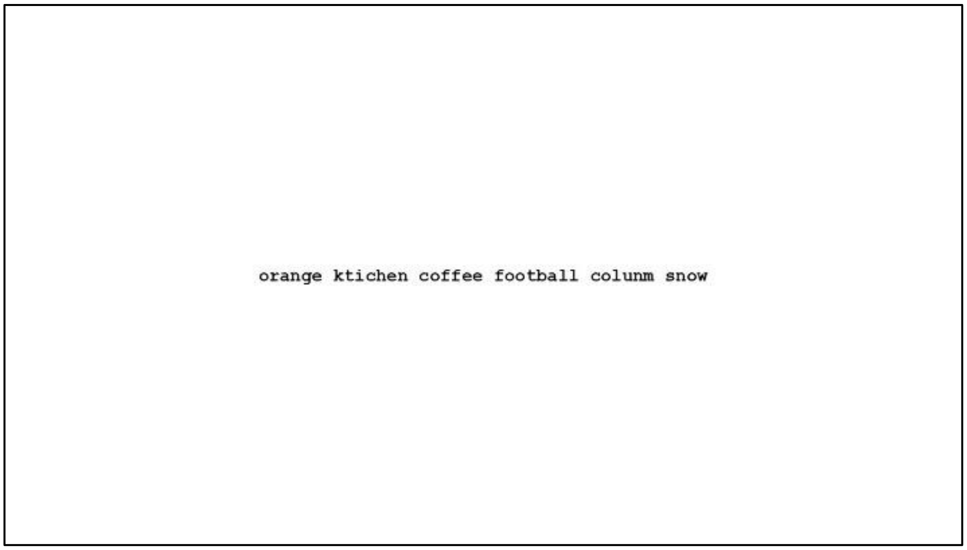

Figure 1.1- Presentation of stimuli in the dual typo condition with structured array. There are six words: four of which are distractor words (*orange, coffee, football, snow*), one is a misspelled high-salience target (*ktichen*), and one is misspelled low-salience target (*colunm*). The words are located in the horizontal and vertical center of the screen.

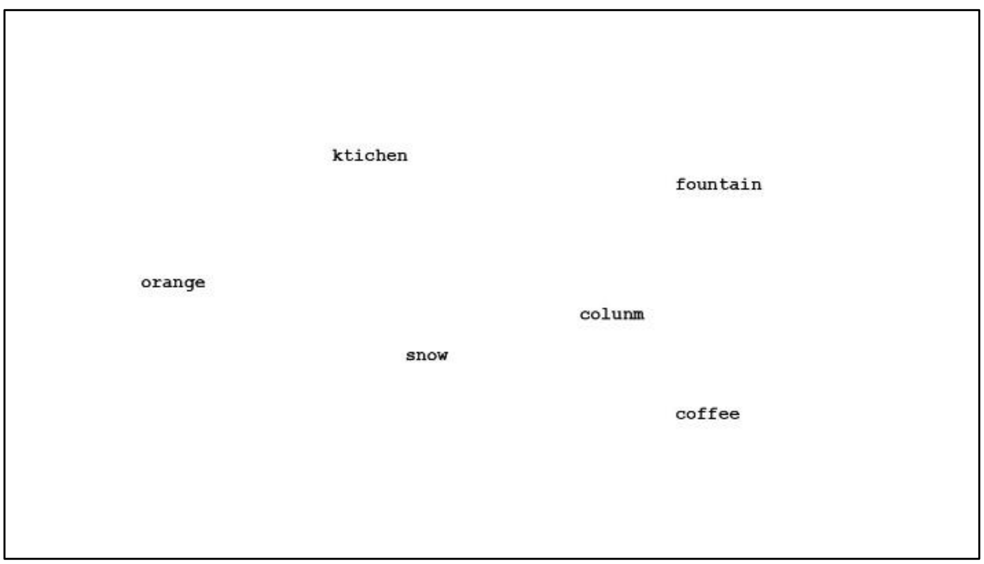

Figure 1.2- Presentation of stimuli in the dual typo condition with random array. There are six words: four of which are distractor words (*orange, snow, fountain, coffee*), one is a misspelled high-salience target (*ktichen*), and one is misspelled low-salience target (*colunm*). The words are located randomly about the screen and the position of misspelled words varied.