Chapter #22

MISSING TARGETS IN MULTIPLE-TARGET SEARCH

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ABSTRACT
When searching for more than one target object in the visual environment, a subsequent target is often overlooked once a first target has been found. Here we were interested in whether subsequent search misses (SSMs) are caused by a semantic set bias. According to this bias, a target that is different from the semantic category of the first target should be missed more often than a target of the same category. We asked 26 participants to search for drawings of none, one, or two targets (dangerous objects) within a set of 18 – 20 everyday objects presented on a computer display. If there were two targets in the display, they could have been from either the same category (two guns or two thrust weapons), or from different categories (one gun, one thrust weapon). The findings showed that the search lasted longer when only one target was present, as compared to when two or no targets were present. However, search accuracy did not differ in regards to the target category (same or different). We also did not observe an effect of SSMs. This suggests that there is, at least with the current set of stimuli, no semantic set bias in multiple-target search.

Keywords: attention, visual search, multiple-target search, subsequent search miss error.

1. INTRODUCTION

We are regularly required to search for one or more objects (so-called targets) in our visual environment. For instance, when we search for a pen on our desk or two of our friends in the crowd, we perform a visual search. Regardless of whether it is one target (single-target search) or more targets (multiple-target search) that we are searching for, visual search is not only an everyday behavior, but also one of the most valuable cognitive tasks that is used to investigate the deployment and allocation of attention (e.g., Wolfe, 1998). That is, if we are searching for a target in a complex environment, we are moving our eyes from one object to the next and rejecting all non-targets (distractors), and in doing so, needing to shift our attention.

In the current experiment we were interested in determining why we miss some of the targets that we search for. In particular, we investigated a very specific type of error that occurs during searches when it is necessary to search for more than one target. As compared to single-target searches, in multiple-target searches research has consistently shown that a subsequent (second) target is missed with a higher probability once a first target has been found (e.g., Cain, Adamo, & Mitroff, 2013). Such subsequent search misses (SSMs) were demonstrated in the field of radiology (Tuddenham, 1962), in airport security (cf. Biggs & Mitroff, 2014) and in laboratory settings (Fleck, Samei, & Mitroff, 2010). In the current research, we tested whether these type of errors are affected by the conceptual/semantic relationship of the target items.

2. BACKGROUND

Previous research has indicated that several factors (i.e., object color and object orientation) guide our attention during visual search (see Wolfe & Horowitz, 2017, for a recent review). For instance, when the pen we are searching for is red, our attention is guided towards all red objects; if we search for a ruler, we will most likely attend to longer objects on the desk. Visual search is also guided by (short-term) memory processes (e.g., Kristjánsson, 2000; Peterson, Kramer, Wang, Irwin, & McCarley, 2001). For example, previous research has indicated that a target can be found faster when it had been recently inspected (as a distractor) in a previous search (Höfler, Gilchrist, & Körner, 2014, 2015; Körner & Gilchrist, 2007). Furthermore, long-term memory is also involved during search. There is evidence that knowledge about an object and its visual environment is used to guide a search (e.g., Võ & Wolfe, 2013). Because of this knowledge we search at those locations in the environment where the target object is most likely located (i.e., we would search for a bottle not on the wall or on the ceiling but perhaps on a table or on a shelf).

When participants are asked to perform a visual search in the laboratory, they typically have to search for one target object among a varying number of distractor objects (e.g., to search for a T among Ls) on a computer display, and have to decide whether this target is absent or present. Typically, a new search display is presented in each trial, and response times are measured in order to investigate search performance. The standard (and not very surprising) result of such searches is that the search time increases with the number of distractors in the display and that it takes longer to complete a search when the target is absent as compared to when it is present (e.g., Wolfe, 1998). The latter finding is due to the fact that, when the target is absent, participants are required to search through all objects in the display in order to come to a definite conclusion. However, if there is only one target in the display (and participants are aware of this fact), the search can be terminated once this target has been found. In dual- or multiple-target searches, the search process becomes more complex. When participants are required to decide whether there is one or two target(s) in the display, the search does not terminate when one target is found but continues until either the second target is found or all other objects in the display have been inspected. In this case, the search can be completed faster if two targets are present in the display as compared when only one target is present (e.g., Gibson, Li, Skow, Brown, & Cooke, 2000; Körner & Gilchrist, 2008); this is due to the fact that participants can stop searching immediately after they have found the second target whereas they have to continue searching through all remaining objects if the second target is absent.

In addition to response times, search accuracy is also an important measure of search efficiency. The most frequent errors are missed targets. These errors can have serious consequences. For instance, there can be severe implications if medical personnel miss an abnormality in a scan or airport security staff misses a dangerous object in a passenger's hand luggage. In spite of the consequences, these types of search errors occur quite frequently. Drew, Võ, and Wolfe (2013) had radiologists and novices search for lung nodules on a scan and found that most of the radiologists (and all 25 non-expert observers) missed a small picture of an unexpected object (a gorilla) that was pasted into the scan. This was in spite of the fact that the size of picture was about four times larger than a lung nodule. Furthermore, Potchen (2006) found that about 60% of the radiologists did not notice that the collarbone had been removed from chest x-rays. Finally, and of crucial importance for the current experiment, Tuddenham (1962) had three radiologists scan more than 200 x-rays and found that these experts often missed additional anomalies in x-rays, after one anomaly had already been detected. Tuddenham (1962) suggested that the experts may have stopped searching the x-ray after finding one anomaly, because they may have been "satisfied" with the search result. Smith (1967) named this phenomenon of missing a further target after one target had been found, the "satisfaction of search" effect (SOS-effect).

This SOS-effect has also been demonstrated in other areas, such as in airport security (i.e., a dangerous object is missed after one dangerous object had been found; Biggs, Adamo, Dowd, & Mitroff, 2015) or in the laboratory, using abstract stimuli (e.g., Ts and, Ls; Fleck, et al. 2010; Höfler, Faßbender, & Ischebeck, 2016). However, it has also been repeatedly demonstrated that it is not simply the case that a further target is missed only because a search was already successful (see Cain, et al. 2013, for an overview): if one is satisfied with his or her search, this does not necessarily imply that a search is stopped immediately afterwards. Rather, the search is usually continued, but there is just a higher probability that a further target will be missed. This finding also led to a change in the terminology from the "satisfaction of search"-effect to the more neutral term "subsequent search misses" (SSMs; see Cain et al. 2013).

Berbaum, Franklin, Caldwell and Schartz (2010) suggested that a second target is detected more easily if it looks similar to the initial target (perceptual-set bias; see also Cain et al., 2013). Furthermore, it has been indicated that SSMs are dependent upon the type of the conceptual (or semantic) category of the second target (semantic set bias). This is illustrated in the study by Biggs et al. (2015) who asked online gamers to play a mobile "Airport Scanner App" (KedlinCo, https://www.airportscannergame.com), in which airport luggage inspection was simulated. The gamers' task was to search for (zero, one, two or three) dangerous objects in a bag. The dangerous objects were divided into two categories: gun-related objects or explosives-related objects. It was shown that the second target was found less often when it was drawn from a different category than the first object which had already been found; in other words, once an explosives-related target was detected, a further explosives-related target was found with a higher probability than a gun-related target (and vice versa).

In the present experiment we wanted to replicate and extend the findings of Biggs et al. (2015), while examining the semantic set bias in a more controlled setting. Our participants were required to search in a display that consisted of 20 drawings of everyday objects. The displays could contain 0, 1, or 2 "dangerous" target objects. Participants were asked to find all dangerous target objects and to mark them via a mouse click. Critically, when two target objects were present in the display, these targets were either two guns or two thrust weapons (i.e., were from the same category of dangerous weapons), or one gun and one thrust weapon (i.e., from different categories). We expected longer search times when only one target was present, as compared to when two or no targets were present. However, we did not expect that the search times would differ for the types of targets (i.e., thrust weapons should be found as fast as guns). Furthermore, we expected to find an effect of SSMs such that a second target should be missed more often after a first target had already been found, as compared to when only one target was present. Most critically, if a semantic set bias exists, we expected that SSMs would depend upon the semantic relationship between the two targets. We expected that a second target would be found with higher probability when it was from the same category as the first target, and with lower probability when it was from the other category.

3. METHODS

3.1. Participants

In total, 26 participants (students of the University of Graz, five male, 21 female; M = 22.3 years, SD = 4.3 years) with normal or corrected-to-normal vision took part in this experiment. Most of the participants received class-credit for their participation. The experiment was approved by the ethics committee of the University of Graz. All of the participants gave informed consent.

3.2. Design & material

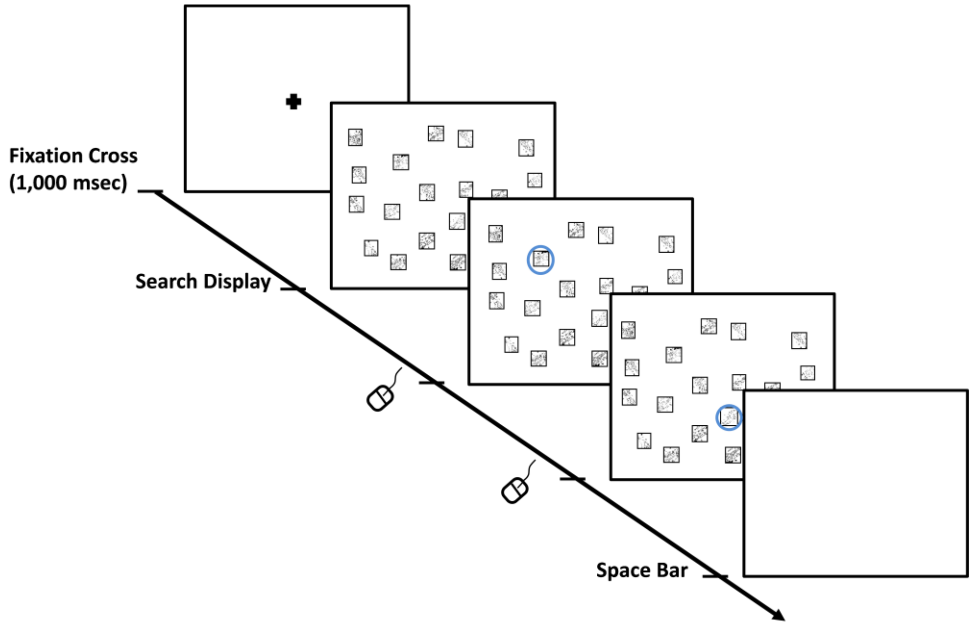
Participants searched in different search displays for dangerous objects from two different categories (guns or thrust weapons) within other everyday objects (see Figure 1). All items were simplified black and white line drawings of everyday objects taken from the database thenounproject.com. Each display consisted of 20 objects in total. From these 20 objects, 0, 1, or 2 objects could be targets. All objects were randomly selected from the total of 50 everyday distractor objects and 20 target objects (guns or thrust weapons), respectively. To familiarize the participants with the objects (particularly with the target objects) they received a preview of all objects before the experiment started. In 50% of the trials, no target was presented (absent search). In the remaining 50% of trials, either one target (single-target search) or two targets (dual-target search) were presented. In single-target searches, this target was either a gun or a thrust weapon on respectively half of the trials. Accordingly, in dual-target searches, both targets were, on half of the trials, from the same category (i.e., either were both guns or both thrust weapons), whereas on the other half, they were from different categories (i.e., one target was a gun and the other a thrust weapon). The combination of target number (0, 1, 2) and target conditions/categories (type of weapons and same/different category) resulted in four search conditions which were randomized within the block: 60 single-target searches (gun or thrust weapon), 60 two-targets/same-category searches (two guns or two thrust weapons), 60 two-target/different-category searches (one gun, one thrust weapon) and 180 absent searches. We measured the manual response times (i.e., the time from display onset to the time of the manual mouse click on the target) and the search accuracy (i.e., the detection rate for the targets depending on the condition).

The stimuli were presented in black on a white background on a 21´´ monitor with a resolution of 1,280 × 1,024 px and a refresh rate of 85 Hz. All items were surrounded by a square that extended 0.9° × 0.9° of visual angle. In each trial, the 20 items were randomly arranged on the display within an invisible 7 × 7 grid, encompassing an area of about 20.3° × 20.3° of visual angle. The orientation of each item in the display was rotated randomly, either 90°, 180°, 270° or 360°. Stimuli were presented using SR Research Experiment Builder (version 1.10.1241). A chin rest was used to prevent head movements.

3.3. Procedure

Each trial started with the presentation of a fixation cross at the center of the screen for 1,000 msec (see Figure 1). After that, the search display was presented. The participants sat at a distance of about 63 cm in front of the computer monitor and were instructed to search for all dangerous weapons in the display and to select these targets via a mouse click. With the mouse click, the selected item became marked with a blue-colored circle. Participants were told that there were up to two targets in the display. They could end the search by pressing the space bar with their left hand, after which the display was cleared and a new trial started. The display was also cleared when the search was not terminated within 15 seconds. Each participant completed two blocks of 180 searches each in a single session that lasted about 90 minutes.

Figure 1.
Schematic example of a dual-target trial (Stimuli are not drawn to scale).



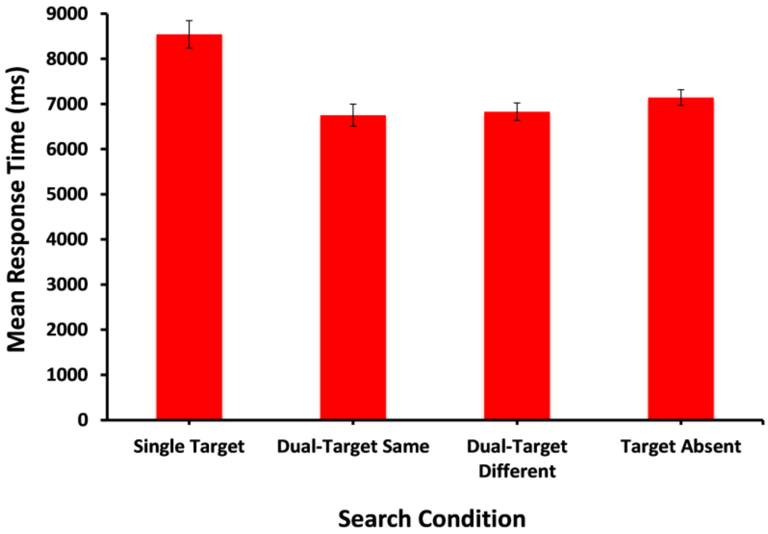
4. RESULTS

We defined a target as being correctly selected when the mouse click was detected within a ± 30 pixel area around the target's center. All trials in which this criterion was not met and all trials in which participants did not complete the search within the time limit of 15 sec were excluded from the analysis. Using these criteria, 3.2 % of the trials were excluded.

4.1. Response times

Averaged across participants, the search lasted 8,544 ms (*SD* = 1,467 ms) when one target was present (see Figure 2). If two targets were present, the search time was 6,751 ms (*SD* = 975 ms) when they were from the same category, and 6,830 ms (*SD* = 864 ms) when the two targets were from different categories. Finally, target-absent searches lasted 7,143 ms (*SD* = 1,161 ms). In order to test for differences in the search times across the search conditions, we conducted a one-way ANOVA for repeated measures. The ANOVA revealed a statistically significant effect of search condition, $F(1.34, 33.47) = 36.75$, $p < .001$, $\eta^2_p = 0.595$ (Greenhouse-Geisser corrected). Post-hoc comparisons (with Bonferroni corrected alphas) showed that single-target searches took reliably longer than dual-target searches (independent of whether the targets were from the same category or from different categories) and absent searches (all *p*s < .001). No other differences were found (all *p*s > .05). That is, participants needed longer to complete a search when only one target was present as compared to searches in which two or no targets were present. This result is in line with previous findings on multiple-target searches (e.g., Gibson et al., 2000; Körner & Gilchrist, 2008).

Figure 2.
Mean response times for the target conditions. Error bars represent the 95% confidence intervals (Cosineau, 2005; Morey, 2008).



4.2. Overall search accuracy

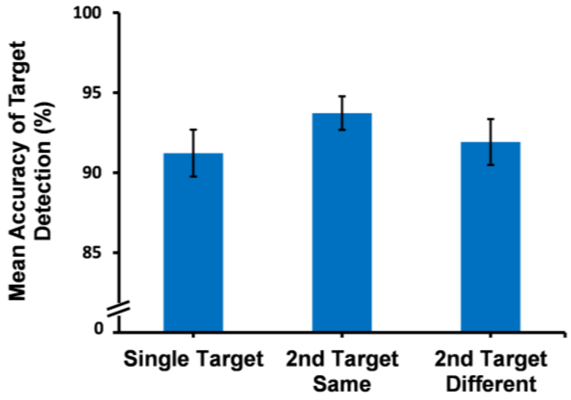
On average, in single-target searches, participants correctly identified the target on 91.2 % of the trials (*SD* = 8.1 %). There was no difference in the search accuracy depending on whether the target was a gun (91.4 %, *SD* = 8.6 %) or a thrust weapon (91.0 %, *SD* = 9.3), $t(25) = 0.25$, $p = .805$. In dual-target/same category searches, participants found both targets correctly on 91.2 % of the trials (*SD* = 6.1 %). Again, there was also no difference with regard to the type of category (two guns: 91.5 %, *SD* = 8.7%; two thrust weapons: 90.8 %, *SD* = 5.5, $t(25) = 0.49$, $p = .627$). Finally, in dual-target/different category searches, participants correctly found both targets on 89.6 % of the trials (*SD* = 9.1 %). Together, the findings suggest that the search accuracy did not differ for guns and thrust weapons in both single- and dual-target searches (all *p*s > .05). Hence, possible SSMs and a semantic set bias were not driven by the category of the target (i.e., gun or thrust weapon).

4.3. SSMs and semantic set bias

We first investigated the presence of SSMs and then whether they depended on the category of the second target (i.e., same or different category). In particular, we compared the probability to detect the target in single-target trials with the probability to detect a second target in dual-target trials (see Biggs et al., 2015). If there was an overall effect of SSMs, the probability of finding a single target would be higher than the probability of detecting a second target in a dual-target search (given the first target is found successfully). Furthermore, we expected that the probability of finding the second target in the dual-target/same-category searches would be higher than the probability of finding the second target in the dual-target/different-category searches (semantic set bias).

As stated above, participants correctly identified a single-target on 91.2% of the trials. Furthermore, they found the second target in a dual-target search with slightly higher probability when it was from the same category (*M* = 93.7%, *SD* = 1.1 %) than when it was from the other category (*M* = 91.9%, *SD* = 1.1 %; see Figure 3). A one-way repeated measures ANOVA with target condition (single target, second-target same category, second-target different category) revealed that the difference was statistically not reliable, $F(2, 50) = 2.32$, $p = .11$. This finding suggests that participants neither showed SSMs nor a semantic set bias while searching for the second target.

Figure 3.
Percentage of targets found for single-target searches and for correctly identified second targets in dual-target searches. Error bars represent the 95% confidence intervals (Cosineau, 2005; Morey, 2008).



5. DISCUSSION

Previous research has repeatedly demonstrated that subsequent-search misses (SSMs) affect search accuracy when searching for multiple targets (e.g., Fleck et al., 2010). SSMs refer to a situation in which a further target is missed with a higher probability after a first target has already been found in a display. In this study, we were interested in whether SSMs were also modulated by a semantic set bias. That is, we tested whether a further target in a display was missed more often when it was from a different category than the first target. To this end, we had participants search a computer display of everyday objects in order to find one or two dangerous objects (a gun and/or a thrust weapon). If two dangerous objects were present in the display, they were either from the same category (i.e., two guns or two thrust weapons) or from different categories (one gun, one thrust weapon).

Our findings with regard to the search performance (i.e., the time needed to complete the search) are in line with previous research on multiple-target search (e.g., Gibson et al., 2000; Körner & Gilchrist, 2008). Search times were significantly longer when there was only one target in the display, as compared to displays with no or two targets. This finding was independent of the type of target object (gun or thrust weapon); however, there was no evidence for SSMs or a semantic set bias in our data. Participants did not find a second target less often when there were two targets in the display and they had already found one target, as compared to trials with only one target. Furthermore, the probability of finding the second target did not depend on the category of the second target (same or different as the first target).

One reason for this apparent lack of SSMs could be an expectation bias such that, as there were two targets in the display on most of the trials, participants might have expected the presence of the second target and, thus, continued to search. Such an expectation bias was reported by Fleck et al. (2010, Exp. 9 and 10) when the ratio between trials with one target and trials with two targets was varied. Fleck et al. (2010) only found SSMs when trials with one target were four times more likely than trials with two targets. This suggests that SSMs are affected by the expectation of how many targets will be present in a search display. One reason for the absence of a semantic set bias could be the stimuli we used. We used two categories of dangerous objects: guns and thrust weapons. It is possible that this distinction was insufficient. Participants might have seen both "types" of targets as belonging to a single category (i.e., dangerous weapons). If this were the case, one would not expect any difference in finding a second target from either the same, or a different, category. We therefore cannot reject a possible semantic set bias per se in multiple-target search.

6. FUTURE RESEARCH DIRECTIONS

A promising starting point for future research could be to investigate how expecting the presence of a target influences the search behavior. For instance, Wolfe, Horowitz and Kenner (2005) used a baggage screening task in which the prevalence of the (single) target was either 1%, 10% or 50%. (That is for instance, in the 1%-prevalence condition, the target was present in only 20 out of 2,000 trials.) Whereas in the 50%-prevalence condition the error rate was about 7%, the error rate drastically increased to 16% in the 10%-prevalence condition and to about 30% in the 1%-prevalence condition. That is, even in single–target trials, the target is missed more often as prevalence decreases. When transferring this finding to the fields of radiology or airport security, in which the prevalence of a target (e.g., a lung nodule or a dangerous object) is typically also very low, the detection rate of a single target may actually be exceedingly low. Hence it is unclear, how this prevalence of a single target might affect the detection of a further target. Another aspect to consider in our experiment is that we measured response times only in order to investigate the search behavior. Tracking eye movements during the search would also be a valuable measurement, in order to test which strategy participants pursue during search and how such a strategy might differ with regard to the prevalence of the targets.

7. CONCLUSION

Our findings revealed that, at least with the current stimuli, there were neither SSMs nor a semantic set bias when searching for multiple targets from the same or different categories in a display. We have addressed some points that might have influenced the current findings. These points might provide a starting point for future research on the factors influencing the prevalence of SSMs and on how they can be avoided.

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