# Awareness yet Underestimation of Distractors in Feature Searches

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**Abstract**

Feature search studies typically address the speed and accuracy of identifying a target item while dismissing attention focused on distractors. In the studies presented here, the level of attention focused on distractors is measured in a feature search task by occasionally asking participants how many items appeared in the search display. Results show some awareness for number of distractors; however, participants tended to underestimate the number of items. Results from two of the studies suggest that individuating distractors from one another and not viewing the entire display contribute to the underestimation effect.

**Keywords:** Perception; Visual Search; Attention; Memory; Psychology.

## Visual Search Studies

A large body of research addressing visual search (see Wolfe, 1998, for a review) has established an impressive catalog of data on target searching and target finding. When people engage in a feature search, they do not need to check every distractor and have equally fast response times regardless of number of distractors. Treisman and Gelade (1980) refer to this phenomenon as the pop-out effect because the results imply that the target "pops-out" of the display and is immediately found. Alternatively, conjunctive searches (i.e., trying to discover a target that has two properties common to the distractors) are typically slower and are slowed further by an increase in the number of distractors. Researchers (e.g., Treisman & Gelade, 1980) attribute this slowed processing to checking each distractor until the target is found. Each check on a distractor is fast, but as more checks accumulate, the overall response time increases.

Using the visual search paradigm, Wolfe and colleagues (1999) have developed the "inattentional amnesia hypothesis," which purports that "unattended visual stimuli may be seen, but will be instantly forgotten." In contrast, other researchers have found support for the conclusion that there is memory during a visual search. (Kristjansson, 2000; Peterson, Kramer, Wang, Irwin, & McCarly, 2001; Shore & Klein, 2000). In these studies, the dependent measure was the number of distractors revisited during a visual search task. In all of these studies, researchers have found that participants do revisit distractors during a search task, but this has been interpreted differently depending on the theoretical stance of the researcher. While Peterson et al. (2001) noted that "the pattern of revisitation did not fit the predictions of the memoryless search model," Horowitz and Wolfe (2003) have claimed that revisitation provides evidence for the claim that, "visual search has no memory."

Theoretical viewpoint notwithstanding, it does seem doubtful that participants would not notice distractors at all, even in a feature search. We questioned the connection between no difference in response time with additional distractors and a supposed lack of awareness for distractors. We presented participants with feature searches and occasionally asked follow-up questions about the display to probe the nature of memory for distractors. Most important of these questions was asking for an estimate of the number of the distractor items.

Assuming that participants would say there were more than zero distractors, these estimates of quantity were tested for whether or not participants simply guessed or whether they drew their estimates from a particular sort of representation. If participants tended to guess the number of distractors then this suggests that they had virtually no awareness of the distractors. We predicted that participants would not guess the number of distractors.

The numerosity question was designed to provide a good measure of the degree of awareness for the distractors and according to Weber's Law (see Falmagne, 1985), people's estimates of quantity or time should approximate a normal distribution centered around zero and therefore will be equally likely to respond with underestimates as overestimates. If participants tend to lean toward underestimation or overestimation then they would violate Weber's Law and additional factors would be necessary to explain the inequity in under and overestimates.

# Experiment 1

Experiment 1 tested the hypothesis that distractors in a feature search receive no attention. Experiment 1 also checked the type of error made when judging item quantity.

## Method

Twenty participants engaged in a series of feature (color) searches with between 3 and 50 items in each condition. Figure 1 displays the feature search screenshot from Experiment 1. The target differed from the distractors in two dimensions – color (blue target and red distractors) and shape (X in the center of targets and circle in center of distractors). Though only color was emphasized, two dimensional differences is traditional for feature searches to ensure that the target and distractors are distinct from one another. Pretests confirmed that these target-distractor differences produced the traditional pop-out search effects.

Participants viewed the computer screen with 14.5 inch width and 11 inch height from a chin rest which was 16.5 inches from the screen. Targets and distractors could appear in any position on the screen and the screen subtended an 18.4$^{o}$ angle from the chin rest.

The participants were instructed to fix their eyes on a cross in the center of the screen. After the fixation, a display of Army symbols was presented and the participants were instructed to press the "1" button if the target was present and the "5" button if the target was absent. They used an E-Prime Serial Response Box to input all responses. They were also instructed that a question about the display may or may not appear after this task.

There were a total of 1200 trials per participant and the entire experiment was divided into four sessions with 300 trials per participant. Overall, there were 300 trials in which a question was displayed and 900 trials with no question.

Every trial began with a black Courier New font 18 point plus sign on a white background as a fixation point. The fixation point was displayed for 2000 milliseconds (ms) and was replaced by a scatter of three to forty-nine non-overlapping red Army symbols, in a frame with a width and height of 27 pixels (though the height of each item was somewhat smaller than the frame). They were also instructed to make their visual search response both quickly and accurately. If responses took more than 2000 ms, participants were told to work more quickly on future trials. Accuracy and response time feedback immediately followed the response and was displayed for 100 ms. Participants were instructed to answer the questions as accurately as possible, but were given no specific response time instructions and were given no feedback on their responses to questions.

All participants received thirty practice trials in their first session and one practice trial for each of the remaining three sessions. Type of trial (target-present or target-absent) was initially selected randomly with the condition that each type represented half of all trials (and when a question referred to a target, it was also a target-present condition). The order of trials was randomized and then remained the same for each participant.

Question responses were in multiple choice format. For the number question, the five options were 1-10, 11-20, 21-30, 31-40, and 41-50. The search screens before the quantity question had 5, 15, 25, 35, or 45 total distractors and had fifteen trials each.

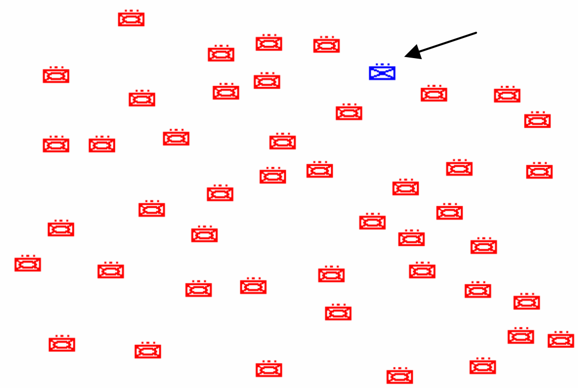

Figure 1. A typical visual search display in Experiment 1. Arrow points to target that was a different color and internal shape than the distractors.

## Results

After removing all practice trials, all inaccurate visual search responses (1.9% of trials), and responses that took longer than 2000 ms (1.0% of trials, used because feature searches are typically much faster than two seconds), 97.2% of all trials remained. The data showed the typical pop-out effect. The average search response time was 642 ms which did not increase with more distractors (a characteristic property of feature searches).

After determining that participants were indeed performing a true feature search, the first test was to determine if participants were merely guessing the number of distractors. In order to make a guess, the participants could choose any one of five options. The midpoint of each option was used to compute the absolute value of the difference from correct (e.g., selecting "11 to 20," when the number of items is 5 would be 10 away from correct). A probability value was derived for each difference value given the number of items that actually appeared. The probability of answering correctly was multiplied by its corresponding difference score and resulted in an average guess difference of 16. A one-sample t-test of average difference from correct (mean of 10.44) found a significant difference from 16, $t(19) = 10.05$, $p < .001$, indicating that participants did not merely guess the number of items in the display.

Chi-square tests were run to check whether participants showed a tendancy to under or overestimate the number of distractors. In all but the 5 and 45 distractor conditions, there were chances to both underestimate and overestimate when making an error. When there were 15 distractors, there was one option that would result in underestimation and three options that would result in overestimation, leaving the probability to underestimate at 0.25 and overestimate at 0.75. The reverse was true for 35 distractors and with 25 distractors; the chance for either error was 0.50. More frequent underestimating than expected was found with 15, 25, and 35 distractors with a p-value of 0.001: $\chi^2(1) = 105.6$, $\chi^2(1) = 138.6$, and $\chi^2(1) = 71.5$, respectively. These tests provided evidence that participants tend to underestimate the number of distractors during a feature search.

### Discussion

The results indicate that, as a by-product of feature search, some attention is devoted to distractors. However, participants tended to underestimate the number of distractors in the feature search. We pursued three possible causes of the underestimation effect. First, perhaps participants judge the quantity of distractors based on how much colored area is created by the distractors compared to the white space background. Second, perhaps participants judge the quantity of items based on how much background color separates the items. Evidence for this hypothesis materialized in Experiment 1 - when the display became more crowded with distractors, underestimates increased. Third, the target's pop-out effect caused the fovea to take the shortest path from fixation to target (Findlay, 1997), thereby allowing attention to focus on only a small portion of the screen. [1]

## Experiment 2

Experiments 2 and 3 were devoted to understanding the underestimation effect from Experiment 1. Weber's law (see Falmagne, 1985) suggests that when estimating frequencies, people and animals approximate with errors that reflect an equal distribution of underestimations and overestimations.

One explanation for the underestimation in Experiment 1 is that the estimation is based on the amount of colored area from the distractors versus the amount of white spaced background color. If the distractors are bigger than in Experiment 1 and therefore cover more of the screen, perhaps participants would estimate that there were more distractors; this would result in less underestimation or possibly overestimation. According to this hypothesis, overestimation would increase when the size of the distractors decreased from Experiment 1.

The reverse situation may also be true. Participants may rely more on the amount of whitespace background area between items than the amount of color-filled area of the distractors. In order to individuate items, the background space may be a better indicator of quantity. Therefore, smaller items may show less underestimation and larger items may show more because the small distractors are more readily distinguished, or individuated, from each other that the large distractors. Figure 2 shows the relative differences in background color between the smallest and largest sizes.

### Method

Twenty participants participated in a visual search much like in Experiment 1. In Experiment 2, the number or trials was reduced to 400 and there was an added size variable with three levels. Small items were 14 pixels (long and wide), medium items were 27 pixels, and large items were 40 pixels. There were 75 total trials which asked for an estimate of item quanity, including 25 trials for each level of size and among sizes, 5 trials for each of 5, 15, 25, 35, and 45 distractor conditions. Figure 2 displays a small and large search display (medium is represented in Figure 1).

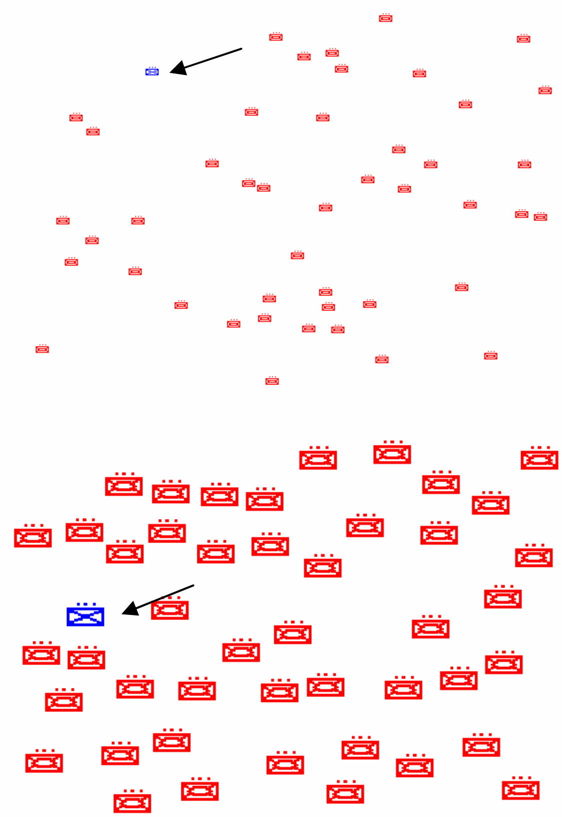

Figure 2. Example displays with the same number of distractors for small items (top) and large items (bottom). The arrows point to the target in each example.

### Results

All practice trials were excluded from all analyses. Also, all trials in which the search task took longer than

[1] A fourth possible explanation is that because search time was high for small items, more search time reduced underestimates. However, an experiment not reported here opposes this theory.

2000 ms were removed from all analyses. These trials comprised 0.8% of all trials. All incorrect search trials were also removed from all further analyses, which was an additional 2.4% of trials.

Just as in Experiment 1, response time did not change with the number of distractors. However, a one-way ANOVA showed a significant difference among the size conditions, $F(2, 38) = 41.38$, $MS_E = 272.7$, $p < 0.001$. Follow-up t-tests showed that small (720 ms) was slower than both medium (690 ms), $t(19) = 6.63$, $SE_M = 4.58$, $p < 0.001$, and large, $t(19) = 8.01$, $SE_M = 5.85$, $p < 0.001$, and that medium was slower than large (673 ms), $t(19) = 3.19$, $SE_M = 5.16$, $p = 0.005$.

Signed error was used to determine varying degrees of underestimation among the levels of the size variable. Signed error was calculated by subtracting the correct answer from the participant's response (e.g., estimating 25 distractors when there are 45 distractors presented is a -20 signed error). The ANOVA for signed error revealed a significant difference in size, $F(2, 38) = 29.51$, $MS_E = 3.52$, $p < 0.001$. Follow-up t-tests revealed differences between small (-3.22) and medium (-5.46) and between medium and large (-7.78). Chi-square tests also revealed that the medium and large sizes tended towards more underestimates than overestimates (identical procedure to the chi-square test of Experiment 1), in all but the 15 distractor case of the medium distractors at a minimum of $p < 0.05$ ($\chi^2(1) = 3.51$, $\chi^2(1) = 7.69$, and $\chi^2(1) = 18.30$, for 15, 25, and 35 distractors of the medium size, respectively and $\chi^2(1) = 19.20$, $\chi^2(1) = 53.93$, and $\chi^2(1) = 24.73$ for 15, 25, and 35 distractors of the large size, respectively. The small size did not pass the critical chi-square value of 3.84 with any of the interpretable number conditions, $\chi^2(1) = 0.027$, $\chi^2(1) = 0.087$, and $\chi^2(1) = 2.48$ for 15, 25, and 35 distractors, respectively.

### Discussion

Results of Experiment 2 showed a greater response time when items were small and fewer underestimates when items were small. Together these results point to two explanations of the underestimation effect. One is that smaller items are more readily individuated based on the amount of whitespace background area separating items from one another and the second is that higher search response times for smaller items allow more time for viewing more of the display and hence perception of more items that can later be included in an estimate of numerosity.

## Experiment 3

Experiment 2 showed that the size of the items is a factor in the underestimation effect: The larger the distractors and the less blank space, the less well initial distractors can be individuated, which leads to less accurate estimations and greater underestimation. Experiment 3 goes on to address the question of whether underestimation might also be caused by not viewing the entire display (e.g., more time to view the display may allow perception of more distractors).

In a feature search, the participant's task is to determine whether the target item is or is not in the display. Participants find the target in a feature search so quickly that they may press the button before allowing enough time for the visual system to see the entire display. If the participant views only a portion of the display, then they will also not include the unviewed distractors as part of their number estimate and will tend to underestimate.

This hypothesis was the basis of Experiment 3. If participants move their eyes directly from fixation to target as suggested by Findlay (1997), then people should view less of the display when the target is closer to the starting fixation point and the eye traverses over a smaller portion of the screen. We therefore manipulated the radius of the position of the target in Experiment 3 to include near, middle, and far distances.

### Method

Nineteen participants participated in Experiment 3, which was a variation of Experiment 2. Instead of multiple sizes, all items were the medium size of Experiment 2, but there were three distances of the target from fixation. Targets in the near condition were 0 to 30 pixels away from the position that a fixation point was in prior to presentation of the search display. Targets in the middle condition were 90 to 105 pixels from fixation and in the far condition they were 180 to 195 pixels from fixation.

### Results

First, all practice trials were excluded from all analyses. Also, all trials in which the search task took longer than 2000 ms were removed from all analyses and comprised 3.2% of all trials. Inaccurate search trials were also removed from all trials and comprised 5.4% of trials.

As in Experiments 1 and 2, there was no trend for slowing of response time with more distractors. Unlike the size variable in Experiment 2, search response time did not alter due to distance condition.

The ANOVA for signed error revealed a significant difference in distance, $F(2, 34) = 4.20$, $MS_E = 1.75$, $p = 0.023$. Follow-up t-tests revealed differences between near (-4.79) and far (-3.70) and between middle (-4.83) and far. Chi-square tests also revealed that all three distances with 25 and 35 distractors showed significantly more underestimations than expected (though not in any distance condition for 15 distractors).

### Discussion

Results of Experiment 3 showed no difference in search accuracy or response time. However, a greater underestimation effect when the target is close to fixation suggest that when search can be completed without scanning the entire display, underestimation results from not perceiving or not focusing on the entire display.

## General Discussion

Traditional accounts of feature search, in which people attempt to find an object within an array of objects that do not share the target's one critical property (though the targets and distractors differed in both color and shape in these experiments, participants were only told to look for a different color) suggest that distractors are not attended and thus fall into the dubious category of "unattended" items. The preceding experiments show that participants do attend to distractors in a feature search with enough attention to estimate the number of distractors. Of interest, the estimates of distractors do not follow Weber's Law, instead of a normal distribution around a mean as Weber's Law would predict, participants estimates are skewed toward underestimation.

Experiment 1 revealed that participants were not guessing the number of distractors and the numerosity aspect of the distractors was attended to in some fashion and contributed to a memory representation. Further, it also revealed that participants tended to underestimate the number of distractors. Three hypotheses emerged to explain this underestimation effect. First, participants might judge the relative proportion of background to item color and judge there to be fewer items because of the greater proportion of background color. Second, the amount of background may conversely help participants by more definitively individuating distractors from one another. Third, participants may view only a portion of the screen and therefore do not include all distractors in their estimate of quantity. Feature searches are typically quick, allowing minimal time to view the entire screen and Findlay (1997) found that participants' eyes move directly from the fixation point to the target.

Experiment 2 tested the first two hypotheses. Targets and distractors appeared in three different sizes: small, medium, and large. If frequency of underestimates was higher for small items this would have favored the hypothesis that people judge quantity based on the relative proportion of foreground to background (the first hypothesis, above). The results favored the second hypothesis: The frequency of underestimates increased when the items were large suggesting that judgments of quantity were based on the ability to individuate items because there is less background between larger items.

Experiment 3 shifted the focus to the third hypothesis: participants might underestimate because they do not view the entire display. Feature searches are typically quick and accurate giving the illusion that targets pop-out at viewers. This suggests that feature searches may be over too quickly and do not allow viewing of the entire display. If participants do not view the entire display, then they would also not include unviewed distractors in memories through which they judge item quantity. Experiment 3 showed that participants were less likely to underestimate quantity when the target was further from initial fixation, thus allowing participants to view more of the screen and include more distractors in their estimate of quantity.

Together, the three experiments establish the phenomena of not guessing distractor number in feature searches, but still underestimating the quantity. The two explanations of underestimation with evidence were that participants have difficulty individuating items and that they may not have viewed the entire display (because of target distance or too little time). However, these two hypotheses essentially reduce to one: underestimation is reduced to the extent that individuals have the opportunity and do view separate distractors. If the perceptual system naturally groups proximal items together, then the individual does not view separate distractors. If the target is found without scanning the entire display, then some of the items are not viewed and will not be included in an estimate of quantity.

We view the feature search process as being heavily influenced by the goals of the search, and that attention can be distributed across a wide area depending on the task. We also agree with Most, Scholl, Clifford, and Simons (2005) that results from previous pop out searches are "insufficient to infer automatic attention capture." Most et al. (2005) go on to note that "because the observer is actively looking for the target, his or her attention is presumably broadly and purposefully distributed throughout the display." Our research supports this assertion.

Perhaps the terms *unattended* and *inattention* are misleading. Indeed, even the definition of attention has sometimes been an area of debate (see Fernandez-Duque & Johnson, 1999). Furthermore, the definition of *inattention* has also been a matter of debate and, "establishing an operationally defined domain of 'unattended' would be liberating" (Moore Grosjean, & Lleras, 2003). Our research indicates that any operational definition of attention should include the postulate that attention is not an absolute binary value, but rather attention is a diffuse construct that can be distributed across a wide area of stimuli. Wolfe's original Visual Search model, included aspects of parallel processing in visual search (Wolfe, 1989) and if one accepts the idea of limited attention during parallel processing, then Wolfe's Visual Search model would accommodate our data. However, in later versions of the Visual Search model (Wolfe, 1999), Wolfe replaced "parallel and series" terms describing the search with "efficient and inefficient"; and it is unclear whether an "inefficient" search can still include limited attention. Our data indicates that an inefficient search can still include limited attention.

The tendency to underestimate also presents a challenge to Weber's Law (Falmagne, 1985) which suggests that when estimating quantity, people and animals are equally likely to under and overestimate. However, this challenge is short-lived when one considers that the variables that affected the frequency of underestimates did not generally affect accuracy. If participants individuated or perceived more distractors, they may have shifted their responses closer to the correct quantity, but they did not reduce the variability in their estimates that determined the number of errors, they simply shifted the mean of the number of distractors to a lower criterion.

## Conclusions

The study was originally designed to test whether a degree of awareness exists for distractors in the context of a feature search. This test confirmed out suspicions of the misuse of inattention, but a tendency to underestimate quantity was also discovered. Further experimentation showed that participants judged quantity based on their ability to individuate items from one another and the opportunity to view the entire display. As a whole, these results could bring research focus back to a previously established hypothesis that distractors in a feature search receive no attention.


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