Is the Suppression of Singleton Color Distractors Context Dependent?

Undergraduate Research Thesis

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by

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Abstract

The mechanism of distractor suppression enables individuals to ignore salient, task-irrelevant stimuli. Suppression appears to accumulate via statistical learning, in which singleton distractors appear with greater probability in specific color or at specific locations. Recently, Allon & Leber (2019) presented evidence that spatially learned suppression can be implemented in a context-dependent fashion. Here we question whether context-dependent suppression extends to nonspatial features (specifically, color). To investigate this, we modified the learned suppression paradigm of Wang and Theeuwes (2018), along with the context dependency manipulation of Allon and Leber. Our manipulation paired background scenes (city and forest) with highly probable distractor colors (red and green), such that a specific background scene predicted the salient, irrelevant distractor color on each trial (when present), with 80% validity. Trials began with a background scene and were followed by search displays containing six items, including one shape target; additionally, color singletons were presented on 75% of trials at a nontarget location. We compared three critical conditions: current high-probable distractor (salient distractor is associated with the present background scene category), other distractor (salient distractor is associated with the other background scene category), and distractor absent. Results showed that both the current high-probable and other distractors interfered in equivalent amounts, thus failing to produce the same context-dependent suppression effect previously observed in the spatial domain. These results may reveal an important distinction between location-based and feature-based mechanisms of attentional suppression.
Introduction

Imagine you are walking through a grocery store getting supplies for a picnic. As you walk down the aisle, you may be so distracted by the bright colored packaging of your favorite kind of cookies that you cannot seem to find the bread. Fortunately, most of the time we can overcome – or even completely avoid – such distractions allowing us to find the bread we are looking for. The process by which the focus of your attention is drawn to the distracting package of cookies is called attentional capture, and your ability to ignore certain distracting (e.g., salient) items in your visual field to achieve your goal is called distractor suppression.

Researchers have long been interested in the processes of attentional capture and distractor suppression by which an individual is able to suppress the attentional capture of a salient item in their visual field. This concept was originally suggested by Theeuwes in 1992, who developed the additional singleton paradigm (see Figure 1). The original study presented participants with a display (like that of Figure 1) in which there was a set of 6 objects: the target that had an odd shape, four non-singleton distractors, and one salient singleton distractor – meaning it had an odd color and was only present on a certain subset of trials. Although this original study used only 6 items in the display, set sizes can vary in the display to assess an increase in salience, among other things (Allenmark et al., 2019; Theeuwes, 2004). During the task, participants were instructed to first, find the target, and then respond to a feature of the target in the display (line orientation). Subsequent studies have used different target feature such as gap or dot location on the target. A typical finding for this type of study shows that responses are slower when an odd colored distractor is present than when an odd colored distractor is absent, indicating that the singleton distractor captured attention. Many questions arose concerning the manner in which people learn to suppress this salient distractor. It was claimed
that top-down exertion of control on attentional selectivity is impossible even after practice, indicating that bottom-up processes are the dominant force in attentional allocation (Theeuwes, 1992). This would indicate that suppression of salient objects in a visual display is not always possible, and a salient item in the display will always result in slower reaction times (RTs) due to attentional capture.

The basis of distractor suppression was originally inspired by visual search tasks in which a participant completes a task to find a target in an array of shapes. The difficulty of this task varies as many different factors are changed, but it has been shown that strategic, learned, and passive information are all key factors that contribute to what we now know as the field of distractor suppression (Chun et al, 2011; Geng et al., 2019). After Theeuwes published his paper in 1992, there was some debate in the field as to whether people could ignore salient distractors. Theeuwes argued that people were incapable of doing so, and that bottom-up processes were the driving force of attentional allocation (Theeuwes, 1992). This however was met with opposition by Bacon & Egeth in which they published a paper demonstrating that a singleton color distractor, showing that participants are indeed capable of implementing top-down selectivity in visual search (Bacon & Egeth, 1994). The idea that top-down selectivity could drive visual search and help avoid distraction was further shown by Leber and Egeth. They concluded that these top-down behaviors are influenced by learned associations between tasks and environments, further showing that the ability to avoid distraction with the correct amount of strategy, learned, and passive information (Leber & Egeth, 2006). Ultimately, some consensus did emerge in the field that people can minimize the effects of distraction, at least to some degree (Theeuwes, 2010; Luck, et al., 2021). More recently, debate has been centered on how
distraction can be minimized. One possibility is that people suppress known distractor properties such as locations and/or features.

In more recent literature, a probe task (a secondary identification task randomly inserted into the suppression task) was used to support a new hypothesis which blended the bottom-up and top-down views of suppression. This new hypothesis, the \textit{signal-suppression hypothesis}, is a reconciliation of stimulus-driven and goal-driven attentional capture. The hypothesis states that salient stimuli produce a salience signal due to their distracting characteristics, but based on an individual’s goals and learned patterns of behavior, they are able to suppress distractors after practice or after obtaining crucial knowledge about distractor location or features (Sawaki & Luck, 2010). This hypothesis has gained lots of traction in the field and has informed many further studies concerning distractor suppression. Now that researchers had obtained a working theory of how attentional allocation occurs, research groups began to examine the mechanisms by which participants are able to suppress different salient stimuli, and the extent to which they could implicitly learn to evoke the mechanism of suppression. One prominent idea in the field was that if subjects could learn that a salient distractor was more likely to appear in one location (a statistically reliable and relevant location) that subjects could learn to suppress that location more than others (Wang & Theeuwes, 2018). Leber et al. (2016) tested this hypothesis and found that subjects could in fact suppress salient items based on learning of location in the visual field. Wang and Theeuwes along with several other research groups have recently also shown that suppression may indeed be possible under certain conditions. For instance, researchers have shown that suppression of salient colored distractors is possible when the singleton distractor appears in a high-probability location, meaning that it appears in one location much more often than it appears in other locations (Failing, Feldmann-Wustefeld, Wang, Olivers, & Theeuwes,
This research suggests that individuals implicitly learn where the distractor is likely to appear, and then preemptively suppress that location. This finding agrees with that of Leber in 2016, and further supports the signal-suppression hypothesis articulated by Gaspelin and colleagues (Gaspelin, et al, 2015).

While Wang and Theeuwes’s (along with many other’s) work has advanced our knowledge of distractor suppression in a fundamental way, much of the work done only applies to location-based suppression. Think back to the grocery store; this would mean that you could only learn to ignore those delicious cookies if they appeared on the same shelf every time – and past research has shown that you could get good at doing so. But how does this finding scale up to the real world? For one, spatial location does not define all properties that we may wish to ignore in the world around us. For instance, if the manager of this grocery store frequently moves the cookie display, can we learn to ignore them based on other properties, such as their color? Previous studies have shown that, yes, we could easily learn to ignore them based on colors (Geyer, Muller, & Krummenacher, 2008). In an experiment conducted by Vatterott & Vecera, it was shown that color singletons have a large amount of attentional capture early on during experimental trials, but after enough experience with these color singletons, resist to capture is possible and these singletons are capable of being completely ignored (Vatterott & Vecera, 2012). Furthermore, it has been shown that increasing probabilistic expectations about distractor appearance can allow more effective suppression (Won, et al., 2019). While this shows that learning based off of critical or repeated information is possible, it provides little insight into the level of flexibility that accompanies learned suppression.
There are many more questions which accompany the intricate process which is distractor suppression. Once again, return to the grocery store: cookies might be distracting in the snack aisle, and we may be able to learn to suppress them there, but are we flexible enough to ignore the same distracting stimulus in the beverage aisle? This question addresses a major theme in cognitive psychology literature: contextually dependent attentional control – and this specific question has yet to be answered. This is the major question which drives this study.

Figure 1: Variant of the additional singleton paradigm. Such a display would be presented to a participant with the goal to find the target (diamond in this example) and then quickly key in an appropriate response for the location of the gap or the orientation of the line. Note the singleton distractor presented in this image is red. This object is considered highly salient and would thus draw attention. However, when the singleton distractor is presented at a consistent spatial location, participants, over time, learn to suppress the singleton distractor to find the target faster (Wang & Theeuwes, 2018).

One factor that can influence the impact of a singleton distractor on visual search is color salience and color frequency (Theeuwes, 1992). Previous findings demonstrate that colors which appear less frequently in a visual search paradigm have shown to be more disruptive to visual search. This means that these less frequent colors have greater attentional pull and are harder to suppress, causing a delayed response time from the participant (Geyer, Muller, & Krummenacher, 2008). This is likely due to the mechanism of learned suppression through practice of numerous trials, allowing an individual to more effectively suppress the colors that they have more practice at suppressing. For example, if in an experiment containing displays
such as those in Figure 1 the singleton distractor is red on 80% of trials and green on 20%, then the trials with a green singleton distractor would be more disruptive and likely lead to longer reaction times compared to those with red. This is a necessary and important finding for the implications of the study we conducted.

Another factor which can heavily impact the level of attentional capture from a salient distractor is context (i.e. what aisle of the grocery store are you on?). This is possible via the implicit learning process by which people can learn to associate two unrelated stimuli when they repeatedly occur together. For example, visual cues associated with the presence of a distractor, such as a background image (see Figure 2), can lead observers to form an implicit association between the background and distractor feature (Wang & Theeuwes, 2018). A study conducted by Cosman & Vecera (2013) examining the effect of implicit visual cues on search strategy (the approach taken to allocating visual attention to complete a certain task) found that participants used the appropriate search strategy that was paired with a specific background during training when presented with that same background during testing. This shows that attentional strategy can in fact be associated with contextual cues, and laid important ground work for the world of distractor suppression, and the possibilities of implicit learning associated with such.

Figure 2: Context-enriched additional singleton paradigm. Above is an example of the additional singleton paradigm with contextual cues present (the background pictures of either of a city or a forest). In such experiments, the background cue would be linked to some sort of statistical regularity (i.e. location, color, etc) such that the participant could implicitly learn to suppress certain features when certain contexts are present.
These previous findings encouraged us to examine contextually dependent, feature-based suppression. Allon & Leber (2019) have previously demonstrated that participants can associate different backgrounds with different high-probable distractor locations. This means that when a participant is presented with two backgrounds (i.e. city and forest), each of which have a different location which is more likely to hold a distractor, they are capable of using the background image to inform their attentional suppression, and suppress different high probable locations. This is a novel finding in the field: taking the findings of Wang & Theeuwes using them to combine learned suppression and contextual cuing (Leber & Allon, 2019; Wang & Theeuwes, 2018). We sought to combine this finding with that of Geyer, Muller, & Krummenacher to investigate the role that contextual cues play in implicit learning of distractor suppression based on singleton distractor features.

In this experiment, we investigated whether contextual cues that indicate the probability of a salient distractor’s color on an upcoming trial can influence the impact of that distractor on visual search and attentional allocation. We paired different types of background scenes with either a high or low probability of a specific color singleton distractor occurring. We were specifically interested in whether background scenes cueing high probability distractor colors reduce the impact of those distractors on search, presumably by allowing the participant to anticipate and thus suppress the salient distractor.

**Methods**

**Participants**

Fifty-six participants were recruited from either the research experience program (REP) through The Ohio State University’s Psychology Department or from the local community.
Participants were compensated with course credit or cash payment respectively, with those who were paid being paid $15 per hour. All participants reported normal or corrected-to-normal visual acuity and normal color vision. All procedures followed during the data collection process were approved by The Ohio State University’s Institutional Review Board.

Each session took approximately 1.5 hours. Participants gave their informed consent to the protocol approved by the IRB at The Ohio State University. Participants were then walked through a series of instruction slides and given practice trials on a series of tasks, preparing them for the main experiment.

Apparatus

An Apple Mac Mini equipped with MATLAB software and Psychophysics Toolbox extensions (Pelli, 1997; Kleiner, et al., 2007) was used to present the stimuli in a small testing room on a 21-inch monitor with a 120 Hz refresh rate using 1920 x 1080 resolution. The participants viewed the monitor from a distance of approximately 55 cm in a dimly lit room. They were instructed to sit in the center of the monitor and were asked to not move during the study. Manual button press responses were entered using a standard QWERTY keyboard using the “F” and “J” keys as directed via experimental instructions.

Experimental Task

This experiment used a modified version of Wang and Theeuwes’s (2018) and Allon & Leber’s (2019) paradigm. Participants performed a visual search task, searching for an odd-shaped target while ignoring a task-irrelevant colored singleton distractor. They were not informed of any probability manipulations present throughout the study. In this task, participants were first presented with either a city or a forest background for 1000ms, cueing them to a specific feature of the target that they will attend to (gap location or bar orientation). This feature
of importance was tied to a specific background scene, and each scene always cued a different feature (i.e. city scenes indicated the participant must report a gap location; forest scenes indicated the participant must report a bar orientation). After the cue, a fixation cross appeared for a variable duration between 400-600 milliseconds. Finally, a search display containing 6 shapes appeared in a circular formation around the fixation cross. The search display always contained an odd-ball shaped item and on 75% percent of trials, it contained a singleton color distractor which was never the same item as the odd-ball shape item. The participant then identified the target (the odd-shaped item) and keyed in the appropriate response (either the “F” key or “J” key) depending on the features of the target. They had 3000 ms to do so, or else the screen reported that they were “Too Slow”. If the target had a left gap or line tilted to the left, the participant pressed the “F” key. If the target had a right gap or the line tilted to the right, the participant pressed the “J” key. After the participant keyed in a response, a black screen would appear from 1000 ms after the trial. If the participant answered correctly based on the stimuli provided, the screen would read “Correct!” . If the participant answered incorrectly based on the stimuli provided, the screen would read “Incorrect!” . Figure 3 below describes the time course of one trial as described above.

Six different scene images were presented to the participant to cue them to the correct feature of the target item, three images of city scenes and three images of forest scene (see figure 4 below). The number of city and forest scenes were predetermined (with each of them showing up 360 times during the experiment), but the specific images within these categories which showed up on each trial were randomly sampled from the set of images in each category.

We manipulated three subject-level variables to determine stimulus-task contingencies. 1) **Background.** For half of the participants, city scenes were tied to high-probable red distractors
and forest scenes were tied to high-probable green distractors. For the remaining participants, this mapping was reversed. 2) Target task. For half of the participants, city scene were associated with the line task and forests scenes with the gap task; for the remaining participants, this mapping was reversed. 3) Shapes. For half of the participants, city scenes held displays of circles and diamonds and forest scenes held displays of squares and pentagons. For the remaining participants, this mapping was reversed. Background, Task, and shapes variables were factorially crossed, and we collected data in multiples of eight to achieve complete counterbalancing.

The location of target and singleton distractor item were manipulated in a within-subject manner. The target and the distractor were set to appear equally often at each of the six locations, seeking to remove any bias that may have occurred due to location-based suppression learning.

![Figure 3: Trial sequence: Background scene appears for 1000 ms. After fixation period of 400-600 ms, a target display appears. Participant begins to search for the target among distractors. Once the target is found, either the orientation of the bar or the gap location is reported through a keyboard button press. The specific reported feature will be tied to the background and counterbalanced. The target display remains on-screen for 3000 ms or until the participant gives a response there is then a black screen for 1000 ms after the trial, providing feedback on if the participant answered correctly or incorrectly.](image-url)
The breakdown of the 6 total trial types that each participant encountered can be seen below in Figure 5. These trial types were counterbalanced across participants to eliminate any biases in the final data set. Note that in this example, for city scenes red is the high-probability (HP) color, and for forest scenes green is the high-probability (HP) color. Each participant experienced 360 trials with background scenes as cities, and 360 trials with background scenes as forests. Within each of these two groups, on 90 trials there was no singleton distractor present and on 270 trials there was a singleton distractor present. Of these distractor present trials, 20% of trials (n = 54) contained a low probability color distractor and 80% (n = 216) contained a high probability color distractor. All of these trials were evenly spaced throughout the nine blocks of the study, allowing for an equal opportunity for implicit learning to occur in each block.
Figure 5: Breakdown of trial types to take place during the study. Trial types were counterbalanced across participants to ensure that results are indeed a result of the intended manipulation.

Each subject completed a total of 720 trials divided into 9 blocks (80 trials per block). To analyze potential changes in performance over time due to learning, we grouped every set of 3 blocks into an epoch, for a total of 3 epochs in the study.

After each participant completed all the main experiment trials, they were asked to complete a short survey. During this survey, the participants were first asked explicitly if they noticed a statistical pairing between distractor color and background scene. After this answer was recorded, they were then asked to complete a short task in which they attempted to pair shape displays with backgrounds upon which they are more likely to appear, as they were statistically regulated during the study. Each participant completed 20 trials of the survey task, with 10 city background scenes and 10 forest background scenes. They were asked to pick between two shape displays which were identical in every way except for the color of the singleton distractor.
Responses were once again given via keyboard button press with the “F” key indicating the shape display on the left, and the “J” key indicating the shape display on the right. Participants were then given the opportunity to ask any questions about the study.

Data Analysis

During the main experiment, reaction times (RT) and accuracy for the button press on each trial were recorded. Participants with mean accuracy scores of below 80% were excluded and their data set was replaced with a new participant. Additionally, any individual trials with reaction times above 3 SD of the mean of their respective condition or faster than 150 ms were trimmed.

Results

Four participants were excluded for low accuracy in the task (78.6%, 76.5%, 62.7%, and 72.3%) which fell below the predetermined 80% accuracy cutoff for the experimental design. The final four participants were run as replacements, matching the excluded participants’ variables to account for counterbalancing. For reaction time trimming, we excluded inaccurate trials and trials with RTs exceeding 3 SD above the participants’ means (7.06% and 1.98% of correct trials, respectively).
We computed a two-factor (distractor condition [3 levels] x epoch [3 levels]), repeated measures ANOVA. A Greenhouse-Geisser correction was applied when Mauchly’s test showed a violation of the sphericity assumption. The ANOVA yielded a significant main effect of distractor condition $F(1.614, 88.768) = 52.041, p < 0.00001, \eta^2_p = 0.468$. There was also a significant main effect of epoch $F(1.521, 83.681) = 12.839, p = 0.00008, \eta^2_p = 0.189$, likely showing practice-related improvements in speed. The two-way interaction was also significant $F(3.379, 185.863) = 4.632, p = 0.002563, \eta^2_p = 0.078$, showing that the effect of distractor condition changed as a function of epoch.

To follow up on the initial ANOVA, we conducted three additional two-factor repeated measures ANOVAs examining each pair of distractor conditions across the three epochs. These subsequent analyses would enable us to 1) better understand the nature of the interaction and 2) better characterize the main effect of distractor condition.

The first follow up ANOVA compared the high probability and the low probability distractor conditions across epoch. We found a significant main effect of epoch $F(1.460, 80.318)$...
= 14.759, \( P = 0.000031, \eta^2_p = 0.212 \), much like the effect seen in the full 3x3 model. However, critically, we did not find a significant main effect of distractor condition, \( P = 0.414 \), indicating that the processing of salient distractors did not vary with context. The interaction between epoch and distractor condition was nonsignificant, \( F(2,110) = 2.832, p = 0.063, \eta^2_p = 0.049 \). We can see that the low probability condition has a greater numerical reduction of capture from epoch 2 to 3 than the high probability condition. It is not clear what would account for or predict this interaction, and again, it was not significant.

The second follow up ANOVA compared the high probability and singleton absent conditions and found a significant main effect of epoch and distractor condition, \( F(1.554, 85.459) = 11.759, p = 0.000133, \eta^2_p = 0.176 \) and \( F(1, 55) = 80.195, p < 0.00001, \eta^2_p = 0.593 \), respectively. The ANOVA also yielded a significant two-way interaction between epoch and distractor condition, \( F(2, 110) = 3.201, p = 0.044546, \eta^2_p = 0.055 \).

The third ANOVA compared the low probability and singleton absent conditions and found a significant main effect of epoch and distractor probability, \( F(1.605, 88.264) = 11.322, p = 0.000146, \eta^2_p = 0.171 \), and \( F(1, 55) = 56.478, p < 0.00001, \eta^2_p = 0.507 \), respectively. The ANOVA also yielded a significant two-way interaction between epoch and distractor condition as well, \( F(2, 110) = 7.056, p = 0.001308, \eta^2_p = 0.114 \). In both the second and third ANOVAs, we see a significant reduction in capture over time from the significant effects of epoch, probability, and the interaction between epoch and probability. This indicates a general, gradual reduction of distracter interference over time, a common finding originally reported by Theeuwes (1992).
Discussion

The goal of this study was to examine the question of how context-dependent feature-based suppression compared to that of context-dependent location-based suppression. Previous studies have demonstrated that participants are capable of pairing strategy usage with context (Cosman & Vecera, 2013) as well as location-based suppression with context (Allon & Leber, 2019).

In this study, we modified the learned suppression paradigm of Wang & Theeuwes (2018) along with the context dependency manipulation of Allon & Leber (2019). Our manipulation paired background scenes (city and forest) with highly probable distractor colors.
(red and green), such that a specific background scene predicted the salient but irrelevant distractor color on each trial (when present), with 80% validity. Trials began with a background scene and were followed by search displays containing six items, including one shape target; additionally, color singletons were presented on 75% of trials at a nontarget location. Results of this study indicate that individuals did not implicitly learn to suppress specific features of singleton distractors based on contextual cues. Additionally, any suppression that was learned over the course of the study was not context specific and could not be implemented flexibly on a trial-by-trial basis.

Despite finding a significant interaction in the ANOVA comparing all three epochs by all three distractor conditions, upon further analysis, we can see that this was not due to differences between the high probability and low probability distractor conditions (the critical comparison of the study). This would indicate that while attentional capture is happening on trials with a singleton present, this capture is not significantly different between the high probability and low probability conditions, showing that participants did not learn to associate singleton distractor features with the contextual cue presented. This kind of pairing has been seen multiple times throughout past literature, both in strategy usage and in location-based suppression (Cosman & Vecera, 2013; Allon & Leber, 2019). Thus, these past context-based findings do not seem to apply to the feature-based manipulation presented in this paradigm. This could be an important first step towards revealing an important distinction between location-based and feature-based mechanisms of attentional suppression.

Why did we not see the principles of location-based suppression generalize to feature-based suppression? One hypothesis might be that location-based suppression and feature-based suppression are two very different mechanisms which have little overlap. This could be further
explained by the idea of the spatial priority map, a map of attentional priority as it is spatially represented in the visual field. Suppression that is location-based has been shown to utilize such a map, allowing individuals to place more or less attentional focus on different areas of their visual space (Britton & Anderson, 2020). This idea, while largely helpful for explaining location-based suppression, has no counterpart for feature-based suppression. While attentional criteria can be set for certain tasks, it is not as clearly represented for feature-based accounts as it is for location-based accounts. Additionally, due to the fact that location-based suppression involves a percentage of physical movements occurring in one direction or another, location-based suppression contains a motor component which could help to explain the lack of generalizability between location-based and feature-based suppression mechanisms.

Another hypothesis to explain the lack of similarity between location-based and feature-based suppression might be that strategy of attentional allocation came into play, due to the specific design of our paradigm. In our experimental design, all non-singleton items in the display were gray in color. Thus, a red or green item in the display never held attentional significance, and participants had no reason to pay attention to such an item selectively. It is possible that through repeated exposure to irrelevant salient items, participants learned to simply ignore all colorful items in the display, and not ignore them based specifically on background scene. In order to interrupt this process, we propose an additional change to the paradigm. Specifically, we would replace all of the gray non-singleton distractors with colored items. These items’ color will be randomly sampled from a color wheel on each trial, keeping the rest of the manipulation the same. By making this change, we seek to interrupt the strategic process of ignoring all color information, forcing the participants to selectively suppress different colors dependent on different backgrounds. If this manipulation to the paradigm allows us to find
evidence for context-dependent feature-based suppression, then this would lead us to conclude that feature-based suppression is possible in a context dependent manner.

**Conclusion**

Is the suppression of singleton color distractors context dependent? Current results found no evidence for feature-based suppression of singleton color distractors in a context dependent manner. This finding is inconsistent with the previous findings from studies on context-dependent location-based suppression. This may indicate that location-based and feature-based suppression have key differences that have yet to be revealed by the literature. While this experiment found no such effect, follow up work will be needed before drawing firm conclusions about this potential form of distractor suppression.
References


