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RESEARCH ARTICLE

REVISED Can enhancement and suppression concurrently guide attention? An assessment at the individual level [version 2; peer review: 3 approved]

Tomoya Kawashima[1,2], Kaoru Amano[2,3]

[1]Graduate School of Human Sciences, Osaka University, 1-2 Yamadaoka, Suita City, Osaka, 565-0871, Japan
[2]Center for Information and Neural Networks (CiNet), Advanced ICT Research Institute, National Institute of Information and Communications Technology (NICT), 1-4 Yamadaoka, Suita City, Osaka, 565-0871, Japan
[3]Graduate School of Information Science and Technology, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan

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Abstract
Background: Although people can pay attention to targets while ignoring distractors, previous research suggests that target enhancement and distractor suppression work separately and independently. Here, we sought to replicate previous findings and re-establish their independence. Methods: We employed an internet-based psychological experiment. We presented participants with a visual search task in which they searched for a specified shape with or without a singleton. We replicated the singleton-presence benefit in search performance, but this effect was limited to cases where the target color was fixed across all trials. In a randomly intermixed probe task (30% of all trials), the participants searched for a letter among colored probes; we used this task to assess how far attention was separately allocated toward the target or distractor dimensions. Results: We found a negative correlation between target enhancement and distractor suppression, indicating that the participants who paid closer attention to target features ignored distractor features less effectively and vice versa. Averaged data showed no benefit from target color or cost from distractor color, possibly because of the substantial differences in strategy across participants. Conclusions: These results suggest that target enhancement and distractor suppression guide attention in mutually dependent ways and that the relative contribution of these components depends on the participants' search strategy.

Keywords
Attention, Enhancement, Suppression, Visual search

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1. **Li Jingling**, China Medical University, Taichung, Taiwan
2. **Xiangyong Yuan**, Institute of Psychology, Chinese Academy of Sciences, Beijing, China
3. **Ru-Yuan Zhang**, Shanghai Jiao Tong University, Shanghai, China

Any reports and responses or comments on the article can be found at the end of the article.

Corresponding author: Tomoya Kawashima (kawashima-t@hus.osaka-u.ac.jp)

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REVISED **Amendments from Version 1**

In this new version (Version 2), we have corrected several concerns throughout the manuscript based on the reviewers' suggestions. We have revised the figure for the experimental procedures. We also provided additional analysis and further discussion.

Any further responses from the reviewers can be found at the end of the article

Introduction

Owing to limitations in attentional capacity, we must attend selectively to goal-related items and ignore ones that are unrelated to our goals. Directing our visual attention toward an object with a specific feature dimension can help improve the detection of task-relevant items. The possession of prior information regarding the properties of a target is known to expedite visual search by enhancing the attention paid to target stimuli (Vickery, King, & Jiang, 2005; Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004). Another means of accelerating visual search is to guide attention away from task-irrelevant items (Arita, Carlisle, & Woodman, 2012; Woodman & Luck, 2007). For example, Arita *et al.* (2012) found that presenting prior information on a color to be ignored sped up the perceiver's visual search. The participants in their study performed a visual search after providing a distractor color as a negative cue; target detection was found to be faster than in neutral trials, and the authors argued that observers can use their prior knowledge of distractor features to guide visual attention.

This distractor suppression has been reportedly achieved through extensive practice or learning (Cunningham & Egeth, 2016; Zehetleitner, Goschy, & Müller, 2012; Geng, Won, & Carlisle, 2019). Cunningham and Egeth (2016) asked participants to perform a visual search task with negative or neutral cues (such as the words "Ignore Red" or "Neutral") and found that the reaction time (RT) to the target was increased by negative cues in the first block of 72 trials; however, this difference decreased in subsequent blocks. These results suggest that observers can learn to suppress specific to-be-ignored features through considerable practice.

Further studies have shown that even a salient distractor can be suppressed (Chang & Egeth, 2019, 2021; Gaspelin, Leonard, & Luck, 2015, Gaspelin & Luck, 2018a). Gaspelin *et al.* (2015) embedded probe tasks into visual search tasks to examine the distractor suppression effect. In the visual search task (70% of all trials), the target was defined by a shape (e.g., a diamond), and a singleton distractor was presented for half of the search trials. In the probe task (30% of all trials), alphabet letters were briefly presented (100 ms) among the search shapes, and the participants were asked to report as many letters as they could recall. The authors found that the RTs in the search task were faster when the singleton was presented (*singleton-presence benefit*). In the probe task, the recall accuracy for probes at the singleton location was lower, suggesting that the benefit was not due to the rapid disengagement from the singleton. From these results, Gaspelin *et al.* (2015) proposed that a physically salient item can be actively suppressed before attentional capture (signal-suppression hypothesis (Sawaki & Luck, 2010, 2013)).

This distractor suppression can be explained by two mechanisms: secondary inhibition or active suppression (Chelazzi, Marini, Pascucci, & Turatto, 2019; Gaspelin & Luck, 2018b; van Moorselaa & Slagter, 2020). In the first, ignoring task-unrelated stimuli is performed by focusing attention onto the target representation. Even where the distractor is salient, distractor interference can be diminished through a top-down attentional setting that focuses on target features (feature-search mode) relative to the set focusing on salient items (singleton-detection mode (Bacon & Egeth, 1994; Leber & Egeth, 2006)). Thus, target enhancement can indirectly suppress distractor representation simply because the distractors are not attended to (i.e., the attention is directed away or secondary inhibition). The second involves direct distractor suppression. Several studies that incorporate electroencephalography (EEG) have observed the distractor-suppression related distractor positivity (Pd) component in response to salient distractors without the N2pc (N2-posterior-contralateral) component, which represents attentional selection (Luck, 2012; Luck & Hillyard, 1994), suggesting that the distractor can be suppressed without attentional selection (Gaspelin & Luck, 2018a, b; Sawaki & Luck, 2010; Burra & Kerzel, 2013).

Chang and Egeth (2019, 2021) sought to determine whether singleton-presence benefit in visual search could be explained by target enhancement, distractor suppression, or both. Instead of using a memory-based probe task, as Gaspelin *et al.* (2015) did, Chang and Egeth (2019) asked participants to detect a probe target ("A" or "B") presented in a probe in a forced-choice manner and found 9 milliseconds (ms) singleton-presence benefit in visual search. Critically, the probe target appeared in the target or distractor feature that had been presented in search trials such that target enhancement and distractor suppression could be assessed separately. Moreover, these authors revealed that the RT was faster when the probe target was in the target color (34 ms target-color benefit) and slower when it was in the distractor color (43 ms distractor-color cost), arguing that target enhancement and distractor suppression guide attention in separate and independent ways (*enhancement-plus-suppression*: Chang & Egeth, 2019). Thus, target enhancement and distractor suppression work in parallel (Andersen & Müller, 2010).

Although Chang and Egeth (2019) concluded that "observers can concurrently maintain two different attentional control processes and use either one of them as the occasion demands" (p. 1731), this concurrent enhancement and suppression are cognitively demanding. Although such attentional templates can be created implicitly through successive practice, attention should be allocated at the beginning of the experimental session to a specific feature, particularly to the to-be-suppressed items (Cunningham & Egeth, 2016). Furthermore, several studies have shown that visual attention can be guided by only a single item in working memory (Olivers, Peters, Houtkamp, & Roelfsema, 2011; van Moorselaar, Theeuwes, & Olivers, 2014). van Moorselaar *et al.* (2014) required participants to conduct a visual search while holding a variable number of colors in working memory and found that attentional guidance through working memory representation was obtained only when a single color appeared. First, these results suggest that it is difficult to guide attention simultaneously by more than two representations, indicating a possible cognitive demand for maintaining representations for both enhancement and suppression (but see Bahle, Beck, & Hollingworth, 2018; Bahle, Thayer, Mordkoff, & Hollingworth, 2020). Second, attending to target information may be preferable to ignoring distractor features because enhancement and suppression do not have the same efficiency in attentional guidance. The effects of negative cues have been widely reported to be smaller than those for positive cues (Arita *et al.*, 2012; Beck & Hollingworth, 2015; Becker, Hemsteger, & Peltier, 2016). Even within the same search settings, distractor inhibition mediated by negative cues has been shown to be inefficient relative to target enhancement mediated by positive cues (Kawashima & Matsumoto, 2018). When both positive and negative cues are provided, participants selectively encode positive information for visual search (Rajsic, Carlisle, & Woodman, 2020), although some studies suggest simultaneous guidance of target enhancement and distractor rejection (Stiwell & Vecera, 2020; Beck, Luck, & Hollingworth, 2018). Based on the reported individual differences in selecting a search strategy (Boot, Becic, & Kramer, 2009) and the tendency to avoid cognitive demands (Kool, McGuire, Rosen, & Botvinick, 2010), observers may rely on a single attentional control process instead of maintaining two simultaneous processes, as suggested by Chang and Egeth (2019), in the performance of visual search. Thus, it would be valuable to gain further insights into the mechanisms of attentional enhancement and distractor inhibition.

In the present study, we first repeated the work of Chang and Egeth (2019) with the intention of replicating their findings. We then modified their paradigm to re-investigate whether target enhancement and distractor suppression can guide attention independently. Experiment 1 was drawn from Chang and Egeth (2019) and was performed as an online experiment. In addition to group-level analyses, as performed in their work, we explored differences in behavior among individuals. Specifically, we investigated a correlation between target enhancement and the effects of distractor suppression. We obtained the raw data of Chang and Egeth (2019) and applied the same analysis, hypothesizing that if target enhancement and distractor suppression could guide attention independently, as Chang and Egeth (2019) argued, no negative correlation would be observed. Furthermore, Experiments 2 and 3 were intended to quantify the effects of target enhancement and distractor suppression separately by manipulating color combinations of the target and the distractor. In particular, unlike the use of fixed colors for the search target and distractor in Experiment 1, we altered the search target and distractor colors on a trial-by-trial basis in Experiments 2 and 3, respectively. Thus, the participants could expect only a target or a distractor color. Accordingly, we calculated the magnitude of the enhancement and suppression for each participant and compared the effect across experiments. We hypothesized that if two attentional-guidance elements, enhancement and suppression, competed for common processing resources, the magnitude of the effect in Experiment 1 would be smaller than those in Experiments 2 and 3 because Experiment 1 required both of these attentional controls.

Methods

Study design

Schematic illustrations of experimental trials are shown in Figure 1. Search trials (70% of all trials) and probe trials (30%) were randomly presented to participants. In the search trials, participants were asked to report whether a dot inside the search target (diamond) was presented on the left or right. In the probe trials, participants were required to detect a probe target (A or B). The probe target appeared in a critical color (either of the target or distractor color in search trials) or in a neutral color (a color that had not been presented in search trials). Experimental codes can be found at https://doi.org/10.5281/zenodo.5944534 (Kawashima & Amano, 2022a).

Participants

The research subjects were healthy adults between the ages of 20 and 35 living in Japan from the Center for Information and Neural Networks (CiNet)'s research participation pool. In total, 150 participants were enrolled in this study via

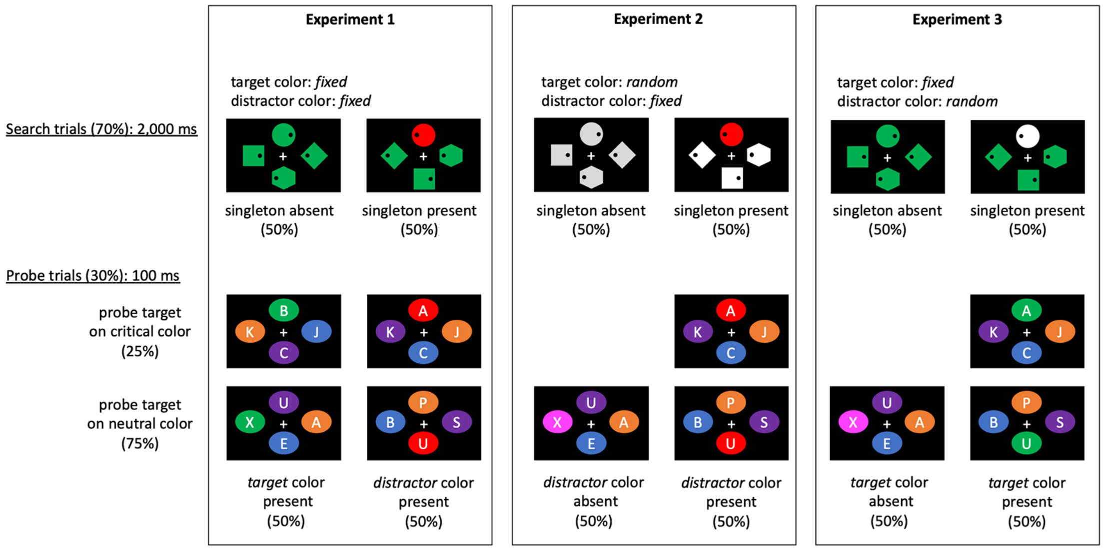

Figure 1. Schematic illustration of experimental trials. The search (70% of trials) and probe trials (30% of trials) were presented to the participants randomly. In the search trials (top panel), participants were asked to report whether a dot inside the search target (diamond) was presented on the left or right. The four stimuli had the same color in half of the trials (singleton absent), whereas one of the four stimuli had a different color (singleton present) in the other half of the trials. The singleton was never the search target; thus, it functioned as a distractor. The color of the target stimulus was fixed (Experiments 1 and 3) or random (Experiment 2); the color of the distractor (singleton) was also fixed (Experiments 1 and 2) or random (Experiment 3). Notably, the task was just to identify the location of a dot inside the target (diamond), and the assigned color was irrelevant to the task. We examined whether or not the singleton-presence benefit can be obtained even when the target or distractor color was changed on a trial-by-trial basis. In the probe trials (bottom panel), the task was to detect a probe target letter (A or B). In Experiment 1, in half of the trials, the target color (e.g., green) in the visual search was presented, while in the other half, the distractor color (e.g., red: a singleton color in the visual search) was presented. The probe target letter appeared in a critical color (either of the target or distractor color in search trials) or in a neutral color (a color that had not been presented in search trials). The probe presentation in the target or distractor feature that was presented in the search trials enabled the assessment of the target enhancement and distractor suppression separately. In Experiments 2 and 3, either the distractor or target color appeared in half of the probe trials, respectively, while all items were presented in neutral colors in the other half of the trials. This process enabled the calculation of the distractor suppression and target enhancement effects in Experiments 2 and 3, respectively.

the web-based SONA recruitment system (www.sona-systems.com) and were promised monetary compensation (1,000 Japanese Yen or approximately 10 US dollars). Three experiments were conducted, each with 50 different participants. The color combinations for the target and distractor differed across the three experiments. A minimum sample size of 25 was estimated via a priori power analysis using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009: with settings of power = 0.80, alpha = 0.05, and $\eta_p^2 = .374$) based on a previous report (Chang & Egeth, 2019). We doubled this number because of the possible large variability inherent in data collected through online experimentation.

In Experiment 1, four participants were removed owing to their probe task performance, which was below the level of chance. Ultimately, 46 participants, who were aged between 20 and 30 years (*M* = 22.3, *SD* = 2.04, 17 female participants), were included in the analyses. For the same reason, two and three participants were removed from Experiments 2 and 3, thereby resulting in 48 (*M* = 21.9, *SD* = 1.36, 26 female participants) and 47 (*M* = 22.8, *SD* = 2.63, 22 female participants) total participants, respectively.

Ethics and consent

The study was approved by the ethics and safety committee of the National Institute of Information and Communications Technology in Osaka, Japan (approval number: 20191031). Informed consent was obtained from all participants. The informed consent statement was displayed on the monitor at the beginning of the online experiment, with a full description of the study purpose, authors identification, and that data would be stored privately with authors. Participants expressed their willingness to participate in the experiment by pressing a predetermined key. All methods were performed in accordance with the relevant guidelines and regulations.

Data collection

All experiments were performed online. Participants obtained the link to the online experiment through the SONA Systems recruitment website and, after clicking on the link, the experiment started. Participants were asked to participate in the experiment in a quiet room and not to use cell phones or listen to music during the experiment.

Stimuli and experiment design

Stimuli were generated and presented via Pavlovia.org based on PsychoPy (v2020.1: Peirce *et al.*, 2019). At the beginning of the experiment, we calculated the pixel density (pixel/mm) of the participants' monitors using a card task and then calculated their viewing distance with a blind spot task (Li, Joo, Yeatman, & Reinecke, 2020). The blind spot task featured three practice trials (repeated if needed), followed by five experimental trials. The same five trials of the blind spot task were presented in each half of the main task to obtain a reliable viewing distance throughout the experimental session. These parameters were used to determine the visual angle of the stimuli.

We created search and probe displays similar to those of Chang and Egeth (2019), as shown in Figure 1. The search (70% of trials) and probe trials (30% of trials) were presented to the participants randomly. The search and probe displays contained four geometric shapes presented at each corner of an imaginary diamond with a diagonal of 10.34°. The search displays contained one diamond, one circle, one square, and one hexagon (1.7° × 1.7°). The search target was the diamond. Each shape contained a black dot (0.15°) located 0.3° to the right or left side of the shape. The task was to report the dot location of the target shape by pressing the "F" or "J" keys for the left or right side, respectively, as quickly and accurately as possible. For 50% of the search trials, one randomly chosen distractor item was presented as a singleton (i.e., one shape was drawn in a different color). This point was explicitly mentioned in the instruction. In the remaining trials, no singleton was presented (i.e., all the shapes were drawn in the same color). The location of the target dot, target shape, and singleton varied randomly. The search trials began with a black screen (500 ms) followed by a fixation cross (800 ms) and then a search display (2,000 ms). A feedback display was subsequently presented for 500 ms with the word "correct!" or "error" based on the participants' responses.

The target and distractor colors were fixed in the task in Experiment 1. These colors were assigned to the participants randomly. In Experiment 2, only the distractor color was fixed throughout the trials; the target color was varied randomly on a trial-by-trial basis. In Experiment 3, only the target color was fixed; the distractor color was changed for each trial.

The probe displays contained four different colored ovals (1.5° × 1.2°), inside which a letter (0.75° in height) was presented. The task was to detect the letter A or B in the display and to press F or J keys in response, respectively. The other three letters were randomly selected from other alphabets, with the exception of I and O. The probe trials began with a black screen (500 ms) and the subsequent fixation cross (800 ms) followed by a probe display for 100 ms. The observers had to press a key within 3,000 ms after the presentation of the probe. A feedback display was then presented for 500 ms with the word "correct!" or "error" based on the participant's key press.

The target–distractor color combinations were manipulated in the experiments. For Experiment 1, 50% of the probe trials contained the target color in the search trials, where the target color that appeared in the search trials also appeared in the probe trials (i.e., the target-color-present trials). The probe target was presented on the target-colored items in 25% of this group of trials or on neutral-colored items in 75% of this group. The remaining 50% of probe trials included a distractor color in the search trials (i.e., the distractor-color-present trials) where the probe target appeared on a distractor-colored item in 25% of trials or on a neutral-colored item in 75% of trials. The location of the probe target was varied randomly. For Experiment 2, all the target-color-present trials in Experiment 1 were replaced with neutral trials where all probes were colored in neutral colors. Thus, the rate of distractor-color-present trials was maintained at the same level as that of Experiment 1. Namely, 50% of probe trials included a distractor color (25% featured a probe on a distractor-colored item, and 75% featured a probe on neutral-colored items). Conversely, the remaining 50% of probe trials included neutral-colored items. Similarly, for Experiment 3, 50% of the probe trials included the target color (25% had a probe on the target-colored item, and 75% had a probe on the neutral-colored items), and the remainder included neutral-colored items.

Five distinctive colors (red, medium blue, forest green, dark orange, and magenta) were used as the target, distractor, and neutral colors. Their roles were randomly assigned across participants. Four other unique colors (white, light gray, dark gray, and dim gray) were used as the target color (Experiment 2) and distractor color (Experiment 3), respectively. We used grayscale as random colors to avoid potential confounds in the color space associated with fixed colors; target-to-target and distractor-to-distractor color similarity could affect the formation of the search template (Geng & Witkowski, 2019). The experiment was preceded by 10 practice trials for the search task and 10 practice trials for the probe task. The main experiment comprised 448 search trials and 192 probe trials (640 trials in total) with an opportunity given for a brief rest every 40 trials.

Analysis

All data analysis was carried out using R (version 4.0.3). In the search task, a paired *t*-test was used to compare the reaction times (RTs) between singleton-present and singleton-absent trials. In the probe task, we conducted repeated-measures analysis of variance (ANOVA) with within-subject factor critical color and within-subject factor probe-target location on RTs and accuracy (Experiment 1). For Experiment 2 and 3, a paired *t*-test was used to compare the RTs and accuracy between probe conditions. A Pearson correlation analysis was conducted for evaluating the relationship between target enhancement and distractor suppression. Target enhancement effect was calculated by subtracting the RTs for critical-colored condition (probe on a target color) from those for neutral-colored condition, while distractor suppression effect was calculated by subtracting the RTs for critical-colored condition (probe on a distractor color) from those for neutral-colored condition.

Re-analysis of Chang and Egeth (2019)

We obtained the raw data from Chang and Egeth (2019) and applied the same correlation analyses as those used in Experiment 1. Specifically, to assess the relationship between target enhancement and distractor suppression, we calculated the magnitude of enhancement by subtracting the RTs on target-color trials from those on neutral-color trials and the magnitude of suppression by subtracting the RTs in neutral-color trials from those in distractor-color trials. Furthermore, we combined correlation coefficients of those in Experiment 1 and in Chang and Egeth (2019) to better ascertain whether enhancement and suppression could guide attention independently.

Results

Search task

Trials with RTs faster than 100 ms or slower than 5,000 ms were excluded from the analysis. Further, we removed trials with RTs 3.5 standard deviations above or below the mean for each participant, resulting in the elimination of 0.4%, 0.6%, and 0.5% of all the search trials in Experiments 1, 2, and 3, respectively. Full raw data for all the experiments can be found under *Underlying data* (Kawashima & Amano, 2022b).

All participants performed well on the search task ($n = 46$, 48, and 47 for Experiment 1, 2, and 3, respectively). The mean accuracy was 96.5% (95.5%, 96.2%) and 96.9% (95.3%, 96.5%) for singleton-present and singleton-absent trials in Experiments 1, 2, and 3, respectively. Therefore, we did not examine accuracy owing to possible ceiling effects. A pairwise *t*-test was used to compare the RTs between the trials. Figure 2 shows the mean RTs in the visual search task. In Experiment 1, where target and distractor colors were fixed during the trials, the RTs were faster for singleton-present trials than in singleton-absent trials (−5.8 ms [95% CI, −0.23 to −11.3]; $t(45) = 2.10$, $p = .041$, $d = 0.31$). This singleton-presence benefit fits with earlier findings (Chang & Egeth, 2019; Gaspelin *et al.*, 2015), allowing us to test target enhancement and distractor suppression for probe trials. Unexpectedly, however, in Experiment 2, where the target colors were randomized and the distractor color was fixed, no RT differences were observed between singleton-present and

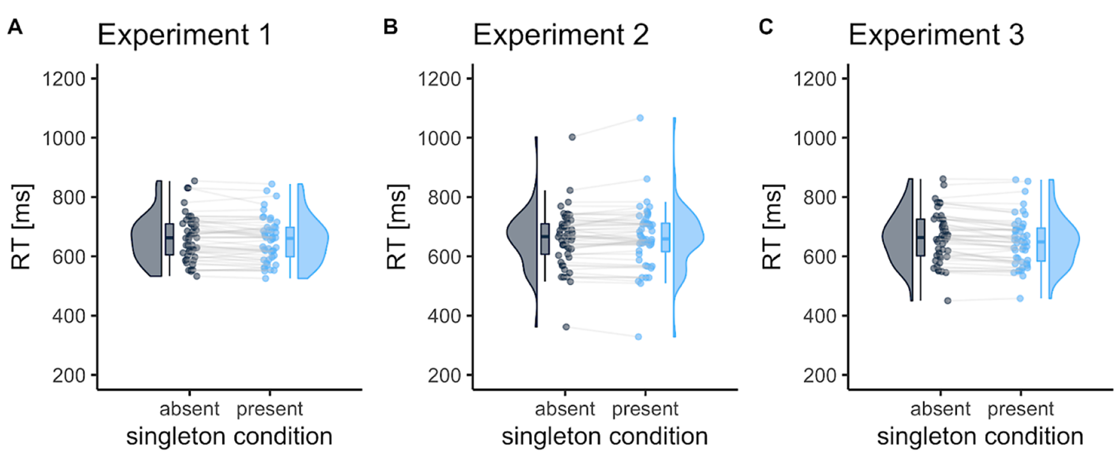

Figure 2. The mean reaction times (RTs) in the visual search task as a function of the singleton condition. Each dot represents the mean RT per participant. The RT was shorter in singleton-present trials than in singleton-absent trials for Experiments 1 and 3. The box represents the interquartile range, which contains 50% of the values (median with midline), and the bottom and top edges of the whiskers represent the 1.5 × interquartile range. Figures were drawn using the “raincloudplots” package in R (Allen *et al.*, 2021).

singleton-absent trials (2.8 ms [95%CI, −3.2 to 8.8]; t (47) = 0.94, p = .354, d = 0.14). However, in Experiment 3, where the target color was fixed and the distractor colors were random, singleton-present benefits were observed in the RTs (−14.0 ms [95% CI, −8.6 to −19.4]; t (46) = 5.20, p < .001, d = 0.76). The same results were obtained using log-transformed RT (Supplementary Analysis).

Probe task

The same criteria were used to exclude trials in search tasks. We removed trials if two or more consecutive preceding trials were probe trials, because successive probe tasks could transiently disrupt the attentional set for target or distractor and thus distort probe responses (Chang & Egeth, 2019; Gaspelin & Luck, 2018a), which resulted in the elimination of 9.8%, 9.7%, and 10.0% of all probe trials in Experiments 1, 2, and 3, respectively. We performed a 2 (critical color: target color or distractor color presented on a probe trial) × 2 (probe-target location: neutral-colored or critical-colored item on which the target was present) repeated-measures analysis of variance for both RT and accuracy. Please note that target enhancement effect is calculated by subtracting the RTs for critical-colored condition (probe on a target color) from those for neutral-colored condition, while distractor suppression effect is calculated by subtracting the RTs for critical-colored condition (probe on a distractor color) from those for neutral-colored condition.

In Experiment 1 (Figure 3A and B), no significant main effect of critical color and probe-target location on RT was found (F (1, 45) = 1.00, p = .321, η_p^2 = .02; F (1, 45) = 0.53, p = .471, η_p^2 = .01), nor was there any significant interaction (F (1, 45) = 2.37, p = .130, η_p^2 = .05). These results indicate no enhancement or suppression effects in the probe task (−13.4 ms [95%

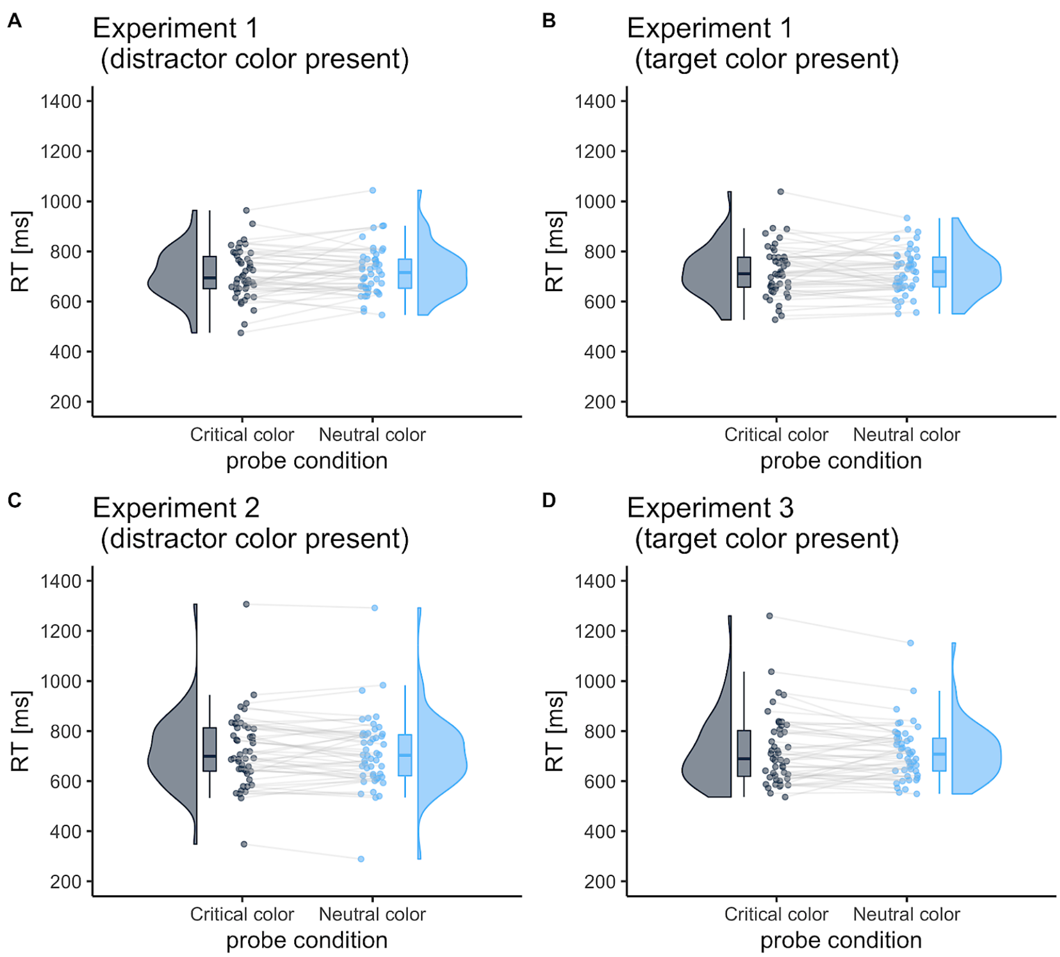

Figure 3. Mean reaction time (RT) in the probe task as a function of probe-target color. The probe-target color was either the critical color or neutral color. The critical color was either the distractor or target color in Experiment 1; it was always the distractor color in Experiment 2 or the target color in Experiment 3. The neutral color was one that had not been presented in search trials. Each dot represents the mean RT per participant. The box represents the interquartile range, which contains 50% of the values (median with midline), and the bottom and top edges of the whiskers represent the 1.5 × interquartile range. Figures were drawn using the "raincloudplots" package in R (Allen *et al.*, 2021).

CI, −6.9 to −33.9]; −1.7 ms [95%CI, −19.4 to 16.0]: the scatter plot in Figure 5B). This remained true even when the target or distractor colors were presented randomly in the visual search task (Experiments 2 and 3): no difference was observed in the probe location for the suppression effect (Figure 3C: 8.5 ms [95%CI, −8.4 to 25.3]; $t\,(47) = 1.01$, $p = .318$, $d = 0.15$: the scatter plot in Figure 5A) and for the enhancement effect (Figure 3D: −8.1 ms [95%CI, −27.4 to 11.1]; $t\,(46) = 0.85$, $p = .400$, $d = 0.12$: the scatter plot in Figure 5C). The same results were obtained using log-transformed RT (Supplementary Analysis).

For accuracy, in Experiment 1 (Figure 4A and B), there was neither a significant main effect of critical color and probe-target location ($F\,(1, 45) = 1.00$, $p = .323$, $\eta_p^2 = .02$; $F\,(1, 45) = 0.0002$, $p = .989$, $\eta_p^2 = .00$) nor a significant interaction ($F\,(1, 45) = 0.06$, $p = .810$, $\eta_p^2 = .00$). These results indicate no enhancement or suppression effects in the probe task (−1.7 % [95% CI, −19.4 to 16.0]; −13.5 % [95%CI, −33.9 to 6.9]). In addition, we found no difference in the probe location in Experiments 2 and 3 (the suppression effect: Figure 4C, −0.008 % [95%CI, −0.04 to 0.02]; $t\,(47) = 0.60$, $p = .551$, $d = 0.09$; the enhancement effect: Figure 4D, 0.01% [95%CI, −0.02 to 0.05]; $t\,(46) = 0.75$, $p = .455$, $d = 0.11$).

We further compared the accuracy of the experiments to verify whether the overall task difficulty differed among the experiments. In the target-color present condition (Figure 4B and D), two-way ANOVA with between-subject factor (experiment) and within-subject factor (probe condition) demonstrated the lack of the main effect of the experiment or probe condition ($F\,(1, 91) = 0.24$, $p = .629$, $\eta_p^2 = .00$; $F\,(1, 91) = 0.16$, $p = .695$, $\eta_p^2 = .00$) or an interaction effect ($F\,(1, 91) =$

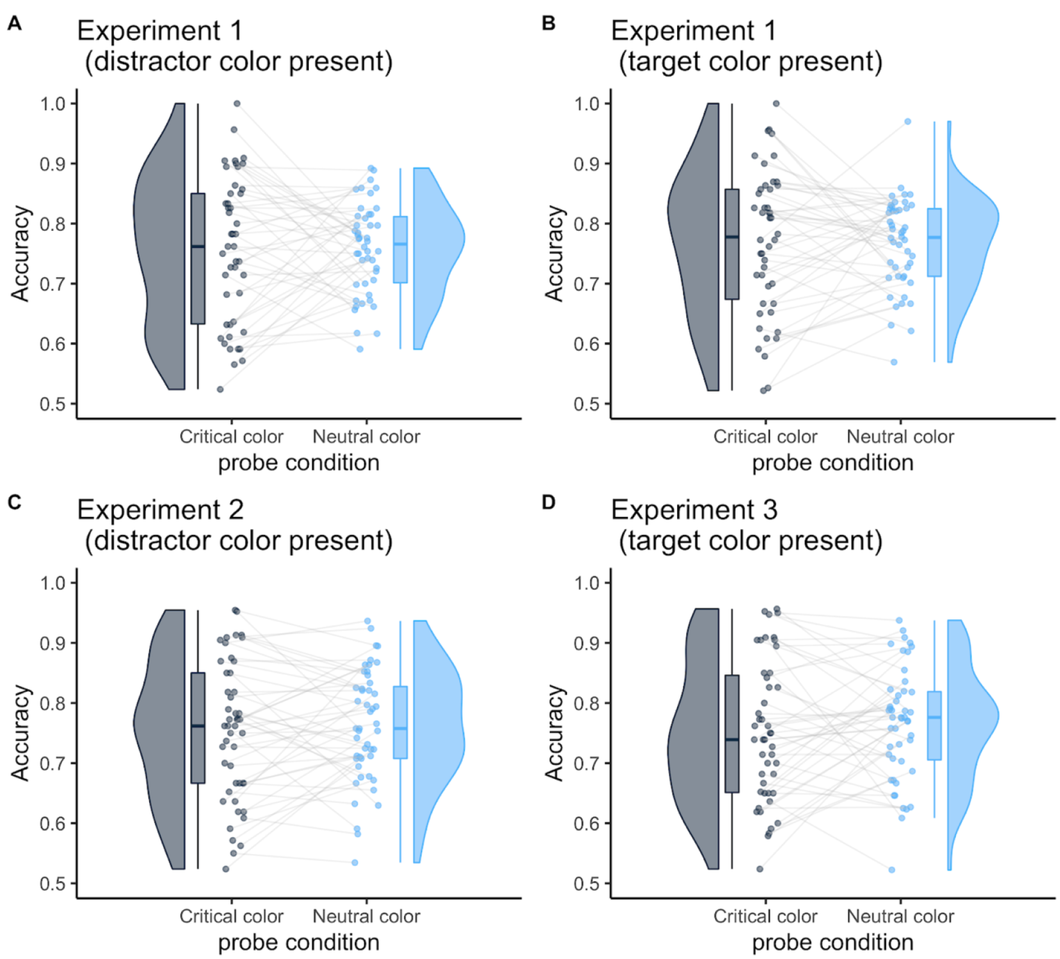

Figure 4. Mean accuracy in the probe task as a function of probe-target color. The probe-target color was either the critical color or neutral color. The critical color was either the distractor or the target color in Experiment 1; it was always the distractor color in Experiment 2 or the target color in Experiment 3. The neutral color was one that had not been presented in search trials. Each dot represents the mean accuracy per participant. The box represents the interquartile range, which contains 50% of the values (median with midline), and the bottom and top edges of the whiskers represent the 1.5 × interquartile range. Figures were drawn using the "raincloudplots" package in R (Allen *et al.*, 2021).

0.43, $p = .512$, $\eta_p^2 = .00$). The same analysis was performed for the distractor-color present condition (Figure 4A and C), which illustrated the absence of the main effect of the experiment or probe condition ($F(1, 92) = 0.005$, $p = .944$, $\eta_p^2 = .00$; $F(1, 92) = 0.22$, $p = .639$, $\eta_p^2 = .00$) or an interaction effect ($F(1, 92) = 0.06$, $p = .809$, $\eta_p^2 = .00$). Thus, randomizing the target or distractor color did not change the overall difficulty of the probe task.

Although the study observed no target enhancement or distractor suppression, we compared these effects across experiments. For the target enhancement effect, no significant difference was observed between Experiments 1 and 3 (Experiment 1: −1.7 ms; Experiment 3: −8.1 ms; $t(91) = 0.49$, $p = .624$, $d = 0.10$). Similarly, no significant difference was observed between Experiments 1 and 2 (Experiment 1: −13.5 ms; Experiment 2: 8.5 ms; $t(92) = 1.68$, $p = .097$, $d = 0.35$) for the distractor effect.

Our results in Experiment 1 showed no enhancement or suppression effects in either RT or accuracy in the probe task, which does not support the findings of Chang and Egeth (2019). This may be due to the larger variability across participants in search performances. Therefore, we assessed the relationship between target enhancement and distractor suppression effects in Experiment 1. The magnitude of enhancement was calculated by subtracting the RTs on target-color trials from those on neutral-color trials. The magnitude of suppression was obtained by subtracting RTs in neutral-color trials from those in distractor-color trials. As shown in Figure 5B, we found a significant negative correlation between them ($r = -.46$, 95% CI [–.66, –.20], $p = .001$, $t(44) = 3.44$). This negative correlation remained significant after Spearman's rank-order correlations, which are less sensitive to outliers than Pearson's product-moment correlation ($rs = -.40$, $p = .006$). This correlation indicates that those with larger RT benefits by target enhancement had less inhibition to the distractor color and vice versa.

To improve the comparison of our findings to those of Chang and Egeth (2019), we obtained their raw data and applied the same correlation analyses. We found a numerically negative but nonsignificant correlation between target enhancement

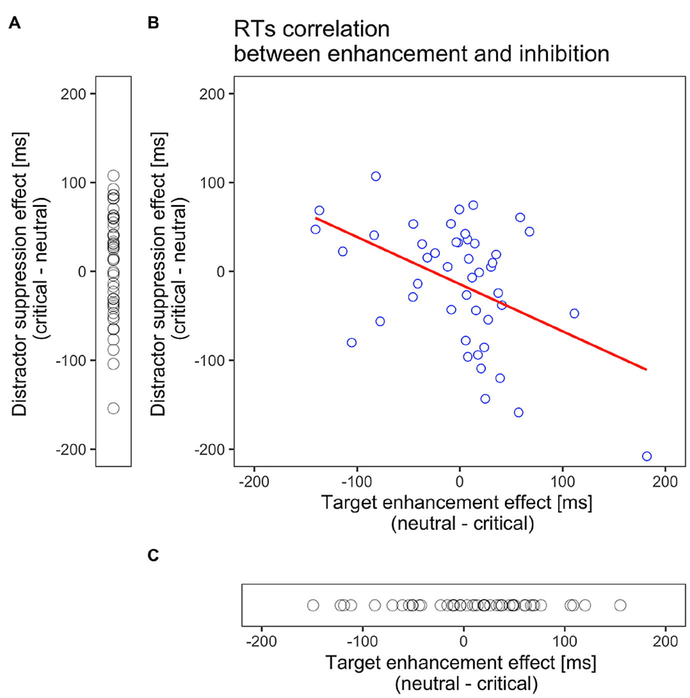

Figure 5. Scatter plots for target enhancement or distractor suppression. (A). Probe effect of all subjects in Experiment 2. Distractor suppression effect varied across subjects, and no group-level effect was observed. (B). Correlations between target enhancement and distractor suppression effects in Experiment 1 for reaction times (RTs). Target enhancement (distractor suppression) indicates a faster RT for the target-colored probe than the neutral probe, while distractor suppression indicates a faster RT for the distractor-colored probe than the neutral probe. The red line indicates the best fit line to the data. The target enhancement and distractor suppression were negatively correlated (Pearson's $r = -.46$, $p = .001$), suggesting that they are not mutually independent. (C) Probe effect of all subjects in Experiment 3. Target enhancement effect varied across subjects, and no group-level effect was observed.

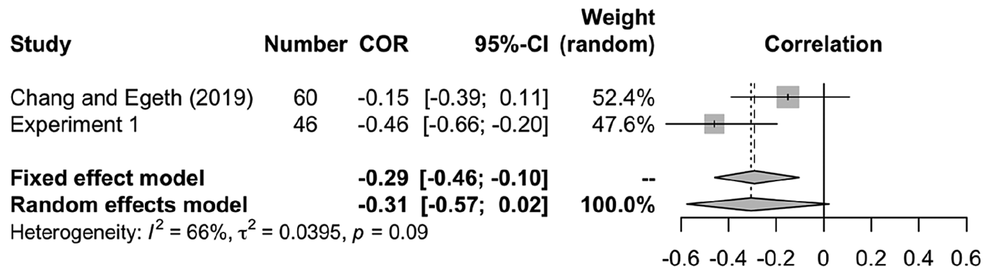

Figure 6. Meta-analysis of studies on the correlation between target enhancement and distractor suppression. Forest plot indicates pooled individual-study Pearson's correlation coefficients with corresponding 95% CIs. Random effect model showed a marginal negative correlation between target enhancement and distractor suppression ($r = -.31$, 95% CI [−.57, .02], $p = .068$), suggesting that they are not mutually independent.

and distractor suppression ($r = -.15$, 95% CI [−.39, .11], $p = .257$, $t\,(58) = 1.15$). Further, we applied a meta-analysis of correlations between Chang and Egeth (2019) and Experiment 1 of the present study using the "meta" package in R (Schwarzer, 2007). As Figure 6 shows, the pooled correlation in this dataset is $r = -.31$ (95% CI [−.57, .02], for the random-effects model), which is marginally significant ($z = -1.83$, $p = .068$).

Although a negative correlation between the magnitude of distractor suppression and attentional enhancement was found for RT, no correlation was found for accuracy in Experiment 1 ($r = -.13$, 95% CI [−.40, .16], $p = .378$, $t\,(44) = 0.89$) and in Chang and Egeth's (2019) data ($r = .16$, 95% CI [−.09, .40], $p = .211$, $t\,(58) = 1.27$). We checked for a possible speed-accuracy trade-off in Experiment 1, analyzing RT and accuracy together by computing inverse efficiency scores (RT/proportion correct: Bruyer & Brysbaert, 2011) for each participant and condition in Experiments 1, 2, and 3. The inverse efficiency score combines both RT and accuracy into a single measure. The ANOVA of the inverse efficiency index in Experiment 1 also revealed a non-significant probe effect reflected in no interaction between critical color and probe-target location ($F\,(1, 45) = 0.12$, $p = .733$, $\eta_p^2 = .003$). Neither was any probe effect observed in Experiments 2 and 3 ($t\,(47) = 1.32$, $p = .194$, $d = 0.19$; $t\,(46) = 1.29$, $p = .204$, $d = 0.19$). This lack of probe effect in inverse efficiency scores indicates that faster RTs were not accompanied by a sharp decrease in accuracy in our task.

Discussion

The present study tested whether target enhancement and distractor suppression can work independently. We observed the singleton-present benefit of RTs in the visual search task, replicating previous findings (Chang & Egeth, 2019, 2021; Gaspelin & Luck, 2018a). This suggests that a salient distractor in a visual display can be excluded from selection, supporting the idea of a signal-suppression hypothesis (Sawaki & Luck, 2010, 2013). However, the RT benefits in visual search unexpectedly disappeared when the target color was varied from trial to trial (Experiment 2; Figure 2B). One possible reason for the lack of RT benefits is that, to some extent, the participants relied on attentional enhancement to target items rather than direct suppression to exclude the salient item. In Experiment 2, the participants could not expect target features due to its randomness, so the contribution of attentional enhancement in the visual display was lower than that in Experiment 1 and 3. This makes it plausible that target enhancement guides visual attention more effectively than distractor suppression.

We found a singleton-presence benefit in Experiment 3, where the distractor color varied on a trial-by-trial basis. However, this observation seems to be inconsistent with previous results suggesting that singletons are suppressed based on their color dimension (first-order suppression: Gaspelin & Luck, 2018a). Vatterott and Vecera (2012) asked participants to perform a visual search task where singleton color was constant for block 1 (48 trials) before changing to a different color in block 2. These authors found that the singleton captured the participants' attention (singleton-presence cost) in the first half of block 1, while this cost was eliminated (singleton-presence benefit) in the second half of block 1, indicating that the participants learned to suppress the salient item (see also Vatterott, Mozer, & Vecera, 2018). Notably, the singleton-presence cost was observed again in the first half of block 2, where the singleton color was changed. Similarly, Gaspelin and Luck (2018a) demonstrated that oculomotor suppression effects (Gaspelin, Leonard, & Luck, 2017) were reduced when the singleton color was changed, suggesting that first-order feature suppression plays a crucial role. However, our results show that even when the singleton color was changed from trial to trial, a singleton-presence benefit was observed for the RTs (Figure 2C). One difference between the previous studies and ours is the frequency of changes in the singleton colors on a blocked or trial-by-trial basis. Following the observation that attentional capture by distractors can be suppressed by increasing repetitions (repetition suppression: Bonetti & Turatto, 2019; Thompson, 2009), our frequent changes in singleton color may have prevented this habituation-based inhibition, instead promoting a conceptual suppression of the singleton. Thus, our finding of a changing-color singleton-presence benefit suggests that singletons can be suppressed based not only on color information but also on a higher conceptual level of information, such as the semantic levels of the description of saliency (second-order suppression: Gaspelin & Luck, 2018a). This second-order suppression has also been reported in the domain of spatial attention (Won, Kosoyan, & Geng, 2019; Won, Forloines, Zhou, & Geng, 2020). Another concept for the mechanisms underlying the singleton-presence benefit is figure-background segregation. In Experiment 3, where the target color was fixed, and the distractor color was varied across trials, the participants learned to search for the target color while segregating the distractor colors as background, which led to the singleton-presence benefit. Thus, future studies are required to elucidate the mechanisms underlying the singleton-presence benefit.

The participant-level analysis presented in Figure 5B shows a negative correlation between the RT effects of target enhancement and distractor suppression. This result does not support the idea of concurrent attentional guidance through enhancement and suppression proposed by Chang and Egeth (2019). Rather, this negative correlation indicates that the two are not independent. Combining the observations that the distributions of target enhancement and distractor suppression effects in Experiment 1 (Figure 5B) resembled those in Experiments 2 (Figure 5A) and 3 (Figure 5C), the results indicate that participants encountered difficulties in using the two representations for enhancement and suppression—that is, whether attentional enhancement or distractor suppression works depends on the observer's choice of search strategy. Some participants would cease suppressing irrelevant distractors because of the effort required: an empirical study showed that participants selectively encode positive information for visual search even when both positive and negative cues are provided (Rajsic *et al.*, 2020). Thus, those who attempt to focus more on the target dimension would be more drawn to the distractor and vice versa.

This difference in search strategy across individuals may be one reason why no attentional enhancement or distractor suppression was observed in group-level analysis. Although a singleton-presence benefit of RTs was observed in visual search, we found no target enhancement or distractor suppression in the probe task in Experiment 1 (Figures 3A and 4A). Thus, we failed to replicate the previous findings of Chang and Egeth (2019), thereby casting doubt on their claim that attention can be guided concurrently by enhancement and suppression. Here, we propose instead that differences in search strategy among the participants might have made group-level effects invisible.

Chang and Egeth's (2019) data showed a numerically negative but nonsignificant correlation between target enhancement and distractor suppression. This was in contrast to our argument that participants select and rely on a single search strategy to perform the search task. Why were we unable to find group-level effects for enhancement and suppression, unlike Chang and Egeth (2019)? It is possible that our failure of replication was due to our less controlled setting—a result of the online constraints of our experiments. However, we believe that this account is incomplete because we replicated the singleton-presence benefit in visual search in experimental online settings, showing the precise measurements for RT (e.g., 5.7 ms benefit in Experiment 1). In addition, we found no probe effect in inverse efficiency scores, indicating that enhancement and suppression effects were still not observed even when a larger variability in accuracy was incorporated. Thus, we believe that a potential lack of complete engagement by the participants in the task because of the online setting cannot fully explain our results. Another possible reason is differences in instruction. Previous studies have shown that an awareness of distractors modulates the interference of the distractor (Chisholm & Kingstone, 2014: Huffman, Rajsic, & Pratt, 2019). Chisholm and Kingstone (2014) assessed the influence of awareness on attentional capture by informing some participants of the presence of the distractor (aware condition) and asking others to avoid attending to the distractor (avoid condition). Their results showed that the oculomotor capture of the distractor in the avoid condition was larger than that in the aware condition, suggesting that too much of an emphasis on distractor suppression could lead to a larger interference. Based on these findings, the slight differences in instructions between Chang and Egeth (2019) and our study might have resulted in the observed inconsistency in the results. For our online experiment, the instruction was presented as screen text, and understanding it was entirely dependent on the participants. For onsite experiments, as in Chang and Egeth (2019), generally, the instructions can be repeated several times, and their emphasis is dependent on the experimenter. Although this attribution is speculative, such a difference in instruction could yield a different attentional set to the task, which may be a reason for the failure of replication. Future research is required to control the attentional set through the instructions for exploring the mechanism of distractor suppression, particularly regarding the comparison of online and offline results. In addition, the online experimental settings enable the collection of various populations compared with laboratory experiments. Hence, the difference in data from online and laboratory experiments should be interpreted with caution.

Another possibility concerns methodological differences. Chang and Egeth (2019) gave 32 probe and 48 search practice trials; to save time, we gave 10 probe and search practice trials. These differences in the exposure to target and distractor prior to the task might have led to the weak enhancement and suppression in the current study. To test this assumption, we divided trials into first and second halves and used the second half of the trials for analysis. The visual search performance pointed to the singleton-benefit effect (n = 40, −7.2 ms [95% CI: −12.68 to −1.81]; t (39) = 2.70, p = .010, d = 0.43). For RTs in the probe task, the study observed a significant interaction (F (1, 39) = 4.68, p = .037, η_p^2 = .11), which reflected a significant target enhancement effect (F (1, 39) = 4.47, p = .041, η_p^2 = .10) but not a distractor suppression effect (F (1, 39) = 1.07, p = .307, η_p^2 = .03). Importantly, the study also observed a significant negative correlation between enhancement and suppression effects (r = −.34, 95% CI [−.59, −.03], p = .031). Thus, the study noted no clear distractor suppression effect even in the second half of the trials, where the participants were sufficiently exposed to the target and the distractor. Instead, the data support our idea that attentional guidance is dependent on the search strategy of the participants. Future work should consider the role of practice in the mechanism of attentional guidance.

Finally, the limitation of this study is that the sample size was rather small for observing the correlation between target enhancement and distractor suppression. Although the combined correlation coefficients of those in Experiment 1 and in Chang and Egeth (2019) showed a negative trend (Figure 6), future studies with a larger sample size and controlled settings might confirm our findings.

Furthermore, the study observed that the mean accuracy of the probe task in Experiments 1–3 was less than 80%, whereas Chang and Egeth (2019) reported more than 90%. This difference may suggest that the participants in the online experiments only partially focused on the task compared with experiments conducted in laboratory settings. The current study investigated whether or not target enhancement and distractor suppression can work in parallel with sufficient attentional focus on the task in an exploratory manner. We selected participants with relatively higher accuracy (above 70%) on each condition of the probe task and re-analyzed their reaction times (see Figure 4 for the distribution of accuracy data). In Experiment 1, the study selected 19 out of 46 participants. They displayed no target enhancement effect (13.4 ms [95% CI: −16.2 to 43.0]; t (18) = 0.95, p = .353, d = 0.22) or distractor suppression effect (18.6 ms [95% CI: −13.7 to 50.9]; t (18) = 1.21, p = .243, d = 0.28). In Experiment 2, the study selected 28 out of 48 participants, which exhibited no distractor suppression (12.3 ms [95% CI: −24.7 to 25.7]; t (27) = 0.04, p = .969, d = 0.01). In Experiment 3, 27 out of 47 participants produced no target enhancement effect (12.2 ms [95% CI, −16.1 to 34.3]; t (26) = 0.74, p = .464, d = 0.14). Thus, even the participants who would have focused their attention on the task presented no target enhancement or distractor suppression. As such, higher accuracy in the probe task seemingly does not guarantee the enhancement or suppression effect.

Although we hypothesized that the target enhancement and distractor suppression would increase in Experiments 2 and 3, a possibility exists that these effects would relatively decrease due to the smaller advantage of color expectation. The reason is that the target and distractor colors were fixed in Experiment 1, whereas the target or distractor color was randomized in Experiments 2 and 3. In fact, we were unable to identify large target enhancement and distractor suppression effects in Experiments 2 and 3, which is partially due to the weaker color expectation effect.

Our current results constitute a contribution to the understanding of how target enhancement and distractor suppression are coordinated to allocate visual attention. Some have suggested that the two operate concurrently to guide visual attention (Andersen & Müller, 2010; Navalpakkam & Itti, 2007), leading to the idea of an enhancement-and-suppression model (Chang & Egeth, 2019). Our results, however, show that, instead of attentional guidance occurring independently through enhancement and suppression, it depends on the participants' search strategy: some use target enhancement; others use distractor suppression for the guidance of visual attention. These findings suggest that maintaining these two control systems simultaneously would be cognitively demanding. Future research should examine the contributions of explicit learning (e.g., strategy choice) and implicit learning (e.g., excessive training) in suppressing distractors (Luck, Gaspelin, Folk, Remington, & Theeuwes, 2021).

Data availability

Underlying data

OSF: Can enhancement and suppression concurrently guide attention? An assessment at the individual level. DOI: 10.17605/OSF.IO/XH4TN (Kawashima & Amano, 2022b)

This project contains the following underlying data:

- raw_data.xlsx (Raw data from search trials and probe trials)

Extended data

This project contains the following extended data:

- Experiment files (JavaScript code for each Experiment 1, 2, and 3)
- Supplementary analysis file

Software availability
Source code available from:

Experiment 1 (https://gitlab.pavlovia.org/Kawashima/exp1_kawashima_amano)

Experiment 2 (https://gitlab.pavlovia.org/Kawashima/exp2_kawashima_amano)

Experiment 3 (https://gitlab.pavlovia.org/Kawashima/exp3_kawashima_amano)

Archived source code at time of publication: https://doi.org/10.5281/zenodo.5944534 (Kawashima & Amano, 2022a)

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Author contributions
T.K. performed experiments and analyzed data; and K.A. and T.K. designed experiments, defined and validated data analysis methods, and wrote the paper.

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Ru-Yuan Zhang
Institute of Psychology and Behavioral Science, Shanghai Jiao Tong University, Shanghai, China

I think the current version is substantially improved. I am OK with the publication of this paper.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Visual perception, cognitive neuroscience

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 30 June 2022

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Ru-Yuan Zhang
Institute of Psychology and Behavioral Science, Shanghai Jiao Tong University, Shanghai, China

Summary:

This study focuses on the relative contributions of target enhancement and distractor suppression in visual search. In particular, the authors designed three experiments. In Experiment 1, the authors attempted to replicate the singleton-presence benefits as reported in Chang & Egeth, 2019 and found negative results. In Experiments 2 and 3, the randomness of target colors and distractor colors in the search task was systematically manipulated. However, these manipulations seem to exert no effects on reaction time and accuracy. Most importantly, the authors independently calculated the target enhancement effect and the distractor suppression effect (i.e., RT differences as compared to the neural conditions) and discovered a negative correlation between the two. This novel negative correlation suggests target enhancement and distractor suppression may act as the two sides of the same coin—the shared cognitive mechanisms.

In general, I like the overall experimental design and the arguments here, albeit the majority of the results being negative. I especially appreciate the authors' efforts to replicate a published study and extend it. We should encourage reporting negative and replication results. I have several comments as below that may help improve the manuscript.

Major points:

1. The experimental design is OK, but the descriptions of the experimental details are hard to follow. Fig.1 is particularly confusing, and I have to read line-by-line in the methods part in a combination of Fig. 1 to comprehend what exactly the authors meant. I suggest substantially improving Fig.1 and the figure caption underneath.

2. Reaction time is usually highly skewed distributed. It seems to me that the authors performed stats on the raw RT values. I suggest trying to perform stats on log-transformed RT. That should better fit the intentions of t-tests and ANOVAs.

3. It remains unclear to me the rationales behind Experiments 2 and 3. The authors mentioned that "We hypothesized that if two attentional- guidance elements, enhancement and suppression, competed for common processing resources, the magnitude of the effect in Experiment 1 would be smaller than those in Experiments 2 and 3 because Experiment 1 required both of these attentional controls." This argument is unclear to me. If either the target or distractor color is randomly selected, the advantage of color expectation should be diminished and that would lead to a smaller enhancement or suppression effect. Can the authors elaborate on the rationales and the predictions?

Minor points:

1. "This singleton-presence benefit fits with earlier findings [8,10], allowing us to test target enhancement and distractor suppression for probe trials. " Here the numbered-style references should be replaced by inline-style references.

2. The figure captions should be improved. For example, in Fig. 2, does the black horizontal line in the box plot represent the mean or median of the group? What are the definitions of the upper and lower edges of the boxes and of the range of the whiskers?

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Visual perception, cognitive neuroscience

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 16 Sep 2022

Tomoya Kawashima,

- The experimental design is OK, but the descriptions of the experimental details are hard to follow. Fig.1 is particularly confusing, and I have to read line-by-line in the methods part in a combination of Fig. 1 to comprehend what exactly the authors meant. I suggest substantially improving Fig.1 and the figure caption underneath.

Thank you for the suggestion. We amended Figure 1 and added a few statements in the caption to further illustrate the experimental design.

Figure 1. Schematic illustration of experimental trials. The search (70% of trials) and probe trials (30% of trials) were presented to the participants randomly. In the search trials (top panel), participants were asked to report whether a dot inside the search target (diamond) was presented on the left or right. The four stimuli had the same color in half of the trials (singleton absent), whereas one of the four stimuli had a different color (singleton present) in the other half of the trials. The singleton was never the search target; thus, it functioned as a distractor. The color of the target stimulus was fixed (Experiments 1 and 3) or random (Experiment 2); the color of the distractor (singleton) was also fixed (Experiments 1 and 2) or random (Experiment 3). Notably, the task was just to identify the location of a dot inside the target (diamond), and the assigned color was irrelevant to the task. We examined whether or not the singleton-presence benefit can be obtained even when the target or distractor color was changed on a trial-by-trial basis. In the probe trials (bottom panel), the task was to detect a probe-target letter (A or B). In Experiment 1, in half of the trials, the target color (e.g., green) in the visual search was presented, while in the other half, the distractor color (e.g., red: a singleton color in the visual search) was presented. The probe-target letter appeared in a critical color (either of the target or distractor colors in search trials) or in a neutral color (a color that had not been presented in search trials). The

probe presentation in the target or distractor feature that was presented in the search trials enabled the assessment of the target enhancement and distractor suppression separately. In Experiments 2 and 3, either the distractor or target color appeared in half of the probe trials, respectively, while all items were presented in neutral colors in the other half of the trials. This process enabled the calculation of the distractor suppression and target enhancement effects in Experiments 2 and 3, respectively.

- Reaction time is usually highly skewed distributed. It seems to me that the authors performed stats on the raw RT values. I suggest trying to perform stats on log-transformed RT. That should better fit the intentions of t-tests and ANOVAs.

Thank you for the suggestion. We used the same analysis using log-transformed RT data and obtained the same results. We added these analyses in Supplementary Analysis.

Log-transformed RT was used for the analysis.

Visual Search
Experiment 1
RTs were faster for singleton-present trials than in singleton-absent trials (t (45) = 2.13, p = .039, d = 0.31).

Experiment 2
No RT differences were observed between singleton-present and -absent trials (t (47) = 0.37, p = .716, d = 0.05).

Experiment 3
RTs were faster for singleton-present trials than in singleton-absent trials (t (46) = 5.24, p < .001, d = 0.76).

Probe Task
Experiment 1
No significant main effect of critical color and probe-target location on RT (F (1, 45) = 1.23, p = .274, η_p^2 = .03; F (1, 45) = 0.74, p = .391, η_p^2 = .02) nor any significant interaction (F (1, 45) = 2.20, p = .144, η_p^2 = .05) was found.

Experiment 2
No difference was observed in the probe location for the suppression effect (t (47) = 1.07, p = .290, d = 0.16).

Experiment 3
No difference was observed in the probe location for the enhancement effect (t (46) = 0.42, p = .674, d = 0.06).

- It remains unclear to me the rationales behind Experiments 2 and 3. The authors mentioned that “We hypothesized that if two attentional guidance elements, enhancement and suppression, competed for common processing resources, the magnitude of the effect in Experiment 1 would be smaller than those in Experiments

2 and 3 because Experiment 1 required both of these attentional controls." This argument is unclear to me. If either the target or distractor color is randomly selected, the advantage of color expectation should be diminished and that would lead to a smaller enhancement or suppression effect. Can the authors elaborate on the rationales and the predictions?

Although we hypothesized that the target enhancement and distractor suppression will become larger in Experiments 2 and 3, a possibility indeed exists that these effects will become relatively smaller due to the smaller advantage of color expectation, as pointed out by the reviewer. In fact, we did not find larger target enhancement and distractor suppression in Experiments 2 and 3, which is partially due to the weaker color expectation effect. We included this aspect in the discussion.

Although we hypothesized that the target enhancement and distractor suppression would increase in Experiments 2 and 3, a possibility exists that these effects would relatively decrease due to the smaller advantage of color expectation. The reason is that the target and distractor colors were fixed in Experiment 1, whereas the target or distractor color was randomized in Experiments 2 and 3. In fact, we were unable to identify large target enhancement and distractor suppression effects in Experiments 2 and 3, which is partially due to the weaker color expectation effect.

- "This singleton-presence benefit fits with earlier findings [8,10], allowing us to test target enhancement and distractor suppression for probe trials." Here the numbered-style references should be replaced by inline-style references.

Thank you for pointing out this aspect. We replaced the references as follows:

This singleton-presence benefit fits with earlier findings (Chang & Egeth, 2019; Gaspelin et al., 2015), allowing us to test target enhancement and distractor suppression for probe trials.

- The figure captions should be improved. For example, in Fig. 2, does the black horizontal line in the box plot represent the mean or median of the group? What are the definitions of the upper and lower edges of the boxes and of the range of the whiskers?

Thank you for the suggestion. We added the required information in the caption. For example, the caption for Figure 2 is presented as follows:

Figure 2. The mean reaction times (RTs) in the visual search task as a function of the singleton condition. Each dot represents the mean RT per participant. The RT was shorter in singleton-present trials than in singleton-absent trials for Experiments 1 and 3. The box represents the interquartile range, which contains 50% of the values (median with midline), and the bottom and top edges of the whiskers represent the 1.5 × interquartile range. Figures were drawn using the "raincloudplots" package in R (Allen et al., 2021).

Competing Interests: No competing interests were disclosed.

Reviewer Report 27 June 2022

https://doi.org/10.5256/f1000research.81418.r140348

Xiangyong Yuan
State Key Laboratory of Brain and Cognitive Science, CAS Center for Excellence in Brain Science and Intelligence Technology, Institute of Psychology, Chinese Academy of Sciences, Beijing, China

The submitted paper re-examined an interesting issue whether target enhancement and distractor suppression in visual search are performed in parallel. The introduction was a thorough one, having reviewed several relevant studies, it raised a clear standpoint about why these two processes may not be weighted in an equal manner. Although failed to fully replicate a previous one, they observed a novel negative correlation between target enhancement and distractor suppression, and found that expecting only one target color compared with only one distractor color can benefit search. As the authors explained, online experiments may allow more personal strategies in search thus more individual variances than lab experiments. Overall, I agree with most of the authors' opinion about the relationship between target and distractor suppression. Besides, I fell the experiments are well-conducted and the manuscript is well-written, and would be very glad to see it published after my minor concerns below are addressed:

1. The authors noticed that after few practice trials observers may not find a stable search strategies therefore have not shown simultaneous target enhancement and distractor suppression. Suppose the search strategies were stable for a particular observer only after enough practice trials, if the first few trials, or the first block in the formal experiment was abandoned, will these two processes be found like Chang and Egeth (2019)? Or alternatively, the author may split the data into first and second halves, examining how the search strategies change over time. This may also help to reveal the individual differences if they indeed have different strategies.

2. The mean accuracies of probe task in Chang and Egeth (2019) were above 90%. In contrast, the mean accuracies were below 80% in exp. 1–3. This may suggest that the participants in the current online experiments did not fully focus on the task, compared with in the lab. Is it possible that target enhancement and distractor suppression can only work in parallel with sufficient attention resources? The authors may select and analyze the data from those participants with higher accuracies that match those in Chang and Egeth (2019), and check if this is true. This possibility may be mentioned in the discussion.

3. In discussion, a conceptual suppression of the singleton has been proposed as a possible explanation of exp. 3. But it seems the search benefit in exp. 3 can be simply explained by a figure-background segregation. If all the targets share the same color across trials while the distractor is always distinguishable from the targets, the observers could learn to only search for the targets and simultaneously ignore the distractors as an irrelevant background. I am not sure whether we actually need to suppress the singleton on a conceptual (or semantic) level of saliency. The distractors can be easily excluded from the

search pool due to their first order saliency.

4. In Page 4, the authors wrote: “Accordingly, we calculated the magnitude of the enhancement and suppression for each participant and compared the effect across experiments. We hypothesized that if two attentional guidance elements, enhancement and suppression, competed for common processing resources, the magnitude of the effect in Experiment 1 would be smaller than those in Experiments 2 and 3 because Experiment 1 required both of these attentional controls.” But I didn’t find this comparison in the result section.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: multisensory integration, selective attention

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 16 Sep 2022

Tomoya Kawashima,

- The authors noticed that after few practice trials observers may not find a stable search strategies therefore have not shown simultaneous target enhancement and distractor suppression. Suppose the search strategies were stable for a particular observer only after enough practice trials, if the first few trials, or the first block in the formal experiment was abandoned, will these two processes be found like Chang and Egeth (2019)? Or alternatively, the author may split the data into first and second halves, examining how the search strategies change over time. This may also help to reveal the individual differences if they indeed have different strategies.

Thank you for the suggestion. We divided the trials and used the second half for analysis.

The results illustrated that no distractor suppression was observed, although the target enhancement effect was significant. In a critical sense, a negative correlation once again exists between enhancement and suppression effects, which were observed for all data (Figure 5). Therefore, we deem that these data support our idea that attentional guidance is dependent on the search strategy of the participant. We added the following text:

Chang and Egeth (2019) gave 32 probe and 48 search practice trials; to save time, we gave 10 probe and search practice trials. These differences in the exposure to target and distractor prior to the task might have led to the weak enhancement and suppression in the current study. To test this assumption, we divided trials into first and second halves and used the second half of the trials for analysis. The visual search performance pointed to the singleton-benefit effect (n = 40, −7.2 ms [95% CI: −12.68 to −1.81]; t (39) = 2.70, p = .010, d = 0.43). For RTs in the probe task, the study observed a significant interaction (F (1, 39) = 4.68, p = .037, η_p^2 = .11), which reflected a significant target enhancement effect (F (1, 39) = 4.47, p = .041, η_p^2 = .10) but not a distractor suppression effect (F (1, 39) = 1.07, p = .307, η_p^2 = .03). Importantly, the study also observed a significant negative correlation between enhancement and suppression effects (r = −.34, 95% CI [−.59, −.03], p = .031). Thus, the study noted no clear distractor suppression effect even in the second half of the trials, where the participants were sufficiently exposed to the target and the distractor. Instead, the data support our idea that attentional guidance is dependent on the search strategy of the participants.

- The mean accuracies of probe task in Chang and Egeth (2019) were above 90%. In contrast, the mean accuracies were below 80% in exp. 1–3. This may suggest that the participants in the current online experiments did not fully focus on the task, compared with in the lab. Is it possible that target enhancement and distractor suppression can only work in parallel with sufficient attention resources? The authors may select and analyze the data from those participants with higher accuracies that match those in Chang and Egeth (2019), and check if this is true. This possibility may be mentioned in the discussion.

Thank you for the suggestion. In the current experiment, only a few particpants exhibited accuracies higher than 90%. We selected participants with relatively high accuracy rates (above 70%) in the probe task and assessed their RTs but found no target enhancement or distractor suppression effects. Therefore, high accuracy rates in the probe task do not seemingly guarantee the enhancement or suppression effect. We added the following text:

Furthermore, the study observed that the mean accuracy of the probe task in Experiments 1–3 was less than 80%, whereas Chang and Egeth (2019) reported more than 90%. This difference may suggest that the participants in the online experiments only partially focused on the task compared with experiments conducted in laboratory settings. The current study investigated whether or not target enhancement and distractor suppression can work in parallel with sufficient attentional focus on the task in an exploratory manner. We selected participants with relatively higher accuracy (above 70%) on each condition of the probe task and re-analyzed their reaction times (see Figure 4 for the distribution of accuracy data). In Experiment 1, the study selected 19 out of 46 participants. They displayed no target enhancement effect (13.4 ms [95% CI: −16.2 to 43.0]; t (18) = 0.95, p = .353, d = 0.22) or distractor suppression effect (18.6 ms [95% CI: −13.7 to 50.9]; t (18) = 1.21, p = .243, d = 0.28). In Experiment 2, the study selected 28 out of 48 participants, which exhibited no distractor suppression (12.3 ms [95% CI: −24.7 to 25.7]; t (27) = 0.04, p = .969, d = 0.01). In Experiment 3, 27 out of 47 participants produced no target enhancement effect (12.2 ms [95% CI, −16.1 to 34.3]; t (26) = 0.74, p = .464, d = 0.14). Thus, even the participants who would have focused their attention on the task presented no target enhancement or distractor suppression. As such, higher accuracy in the probe task seemingly does not guarantee the enhancement or suppression effect.

- In discussion, a conceptual suppression of the singleton has been proposed as a possible explanation of exp. 3. But it seems the search benefit in exp. 3 can be simply explained by a figure-background segregation. If all the targets share the same color across trials while the distractor is always distinguishable from the targets, the observers could learn to only search for the targets and simultaneously ignore the distractors as an irrelevant background. I am not sure whether we actually need to suppress the singleton on a conceptual (or semantic) level of saliency. The distractors can be easily excluded from the search pool due to their first order saliency.

Thank you for the suggestion. We added the following statement in the discussion:

Another concept for the mechanisms underlying the singleton-presence benefit is figure-background segregation. In Experiment 3, where the target color was fixed, and the distractor color was varied across trials, the participants learned to search for the target color while segregating the distractor colors as background, which led to the singleton-presence benefit. Thus, future studies are required to elucidate the mechanisms underlying the singleton-presence benefit.

- In Page 4, the authors wrote: "Accordingly, we calculated the magnitude of the enhancement and suppression for each participant and compared the effect across experiments. We hypothesized that if two attentional guidance elements, enhancement and suppression, competed for common processing resources, the magnitude of the effect in Experiment 1 would be smaller than those in Experiments 2 and 3 because Experiment 1 required both of these attentional controls." But I didn't find this comparison in the result section.

Thank you for the comment. We have planned but did not conduct this analysis, because we did not observe significant enhancement and suppression effects for all experiments. As suggested, we conducted this analysis with the following results. We added the following statement:

Although the study observed no target enhancement or distractor suppression, we compared these effects across experiments. For the target enhancement effect, no significant difference was observed between Experiments 1 and 3 (Experiment 1: −1.7 ms; Experiment 3: −8.1 ms; t (91) = 0.49, p = .624, d = 0.10). Similarly, no significant difference was observed between Experiments 1 and 2 (Experiment 1: −13.5 ms; Experiment 2: 8.5 ms; t (92) = 1.68, p = .097, d = 0.35) for the distractor effect.

Competing Interests: No competing interests were disclosed.

Reviewer Report 09 June 2022

https://doi.org/10.5256/f1000research.81418.r138946

Li Jingling
China Medical University, Taichung, Taiwan

This study tried to replicate Chang and Egeth (2019) and extended their conditions to a randomized target color or distractor color in separate blocks. Their goal was to test whether attentional setting on the task demand and distractor suppression are related or separate processing. They replicated Chang and Egeth (2019) in that presenting a distractor actually facilitated the speed of target discrimination, suggesting there was target enhancement and distractor suppression occurred simultaneously. Such effect increased when the target color was fixed and distractor color varied trial-by-trial, suggesting a varied distractor induced a stronger suppression. Nevertheless, when target color varied trial-by-trial and distractor color was fixed across trials, there was no distractor suppression. Also, the interleaved probe task with the search trials did not reveal any significant effect. The author found a negative correlation between target enhancement and probe suppression in the probe task in experiment 1, suggesting that those who enhance the target more tend to suppress distractors less. The authors also provided a meta-analysis of their own data and that of Chang and Egeth (2019) and obtained a significant correlation effect. The author, therefore, concluded that the two operations, target enhancement and distractor suppression, are related.

This study is well-conducted in method, the data are well processed, and the conclusion is clear and potentially contributes to academic literature. I suggest accepting this article with minor revisions:

1. I have difficulty understanding why non-significant probe data can generate a significant correlation in experiment 1, and why such corresponding analysis cannot apply to experiments 2 and 3. Does that mean a traditionally assumed distractor capture also occurred? Can probe data in experiments 2 and 3 also be considered separated into "target" or "distractor" colors even if they are varied?

2. I like your strategy account, which is consistent with the definition of attention in resource control. Could it be possible that online data collection essentially probes a different group of participants compared to that recruited by Chang and Egeth (2019)? For instance, those who come to the lab to complete the task might be mainly graduate students while those who complete an online experiment are more close to the heterogeneous population? The authors may add some

discussion on this point.

3. I noticed that the accuracy of experiment 2 was a bit lower than that in experiments 1 and 3, is there any significance? Randomizing target color across trials may make the task more difficult, even if the target was not defined by color. This can also be a piece of evidence on the importance of strategy induced by different task settings.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: cognitive psychology, human attention, cognitive control

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 16 Sep 2022
Tomoya Kawashima,

- I have difficulty understanding why non-significant probe data can generate a significant correlation in experiment 1, and why such corresponding analysis cannot apply to experiments 2 and 3. Does that mean a traditionally assumed distractor capture also occurred? Can probe data in experiments 2 and 3 also be considered separated into "target" or "distractor" colors even if they are varied?

Thank you for the comment. Our interpretation of the observed negative correlation between target enhancement and distractor suppression is that “whether attentional enhancement or distractor suppression works depends on the observer’s choice of search strategy”. In other words, individuals will adopt a strategy to focus their attention on the target dimension, whereas others will adopt a different strategy to focus on the distractor dimension. This variability in strategy across participants may be “one reason why no attentional enhancement or distractor suppression was observed in group-level analysis.”

We cannot apply the same analysis to Experiments 2 and 3 for distractor suppression and target enhancement, respectively, because different participants in each experiment were different. Therefore, we cannot consider the correlation between Experiments 2 and 3 (please see Figure 5).

The probe data in Experiments 2 and 3 were obtained with a fixed distractor or target color, respectively. Therefore, we can consider the data from these experiments as producing the distractor suppression and target enhancement effects.

- I like your strategy account, which is consistent with the definition of attention in resource control. Could it be possible that online data collection essentially probes a different group of participants compared to that recruited by Chang and Egeth (2019)? For instance, those who come to the lab to complete the task might be mainly graduate students while those who complete an online experiment are more close to the heterogeneous population? The authors may add some discussion on this point.

Thank you for the suggestion. We have added the following sentence:

In addition, the online experimental settings enable the collection of various populations compared with laboratory experiments. Hence, the difference in data from online and laboratory experiments should be interpreted with caution.

- I noticed that the accuracy of experiment 2 was a bit lower than that in experiments 1 and 3, is there any significance? Randomizing target color across trials may make the task more difficult, even if the target was not defined by color. This can also be a piece of evidence on the importance of strategy induced by different task settings.

Thank you for the suggestion. We performed the additional analysis to compare the accuracy of the experiments and found no significant difference. Therefore, we concluded that randomizing the target or distractor color did not change the overall difficulty of the probe task. We added the following sentences:

We further compared the accuracy of the experiments to verify whether the overall task difficulty differed among the experiments. In the target-color present condition (Figure 4B and D), two-way ANOVA with between-subject factor (experiment) and within-subject factor (probe condition) demonstrated the lack of the main effect of the experiment or probe condition (F (1, 91) = 0.24, p = .629, η_p^2 = .00; F (1, 91) = 0.16, p = .695, η_p^2 = .00) or an interaction effect (F (1, 91) = 0.43, p = .512, η_p^2 = .00). The same analysis was performed for the distractor-color present condition (Figure 4A and C), which illustrated the absence of the main effect of the experiment or probe condition (F (1, 92) = 0.005, p = .944, η_p^2 = .00; F (1, 92) = 0.22, p = .639, η_p^2 = .00) or an interaction effect (F (1, 92) = 0.06, p = .809, η_p^2 = .00). Thus, randomizing the target or distractor color did not change the overall difficulty of the probe task.

Competing Interests: No competing interests were disclosed.