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Object-based suppression in target search but not in distractor inhibition

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Abstract

The present study investigated the effect of object representation on attentional priority regarding distractor inhibition and target search processes while the statistical regularities of singleton distractor location were biased. A color singleton distractor appeared more frequently at one of six stimulus locations, called the 'high-probability location,' to induce location-based suppression. Critically, three objects were presented, each of which paired two adjacent stimuli in a target display by adding background contours (Experiment 1) or using perceptual grouping (Experiments 2 and 3). The results revealed that attention capture by singleton distractors was hardly modulated by objects. In contrast, target selection was impeded at the location in the object containing the high-probability location compared to an equidistant location in a different object. This object-based suppression in target selection was evident when object-related features were parts of task-relevant features. These findings suggest that task-irrelevant objects modulate attentional suppression. Moreover, different features are engaged in determining attentional priority for distractor inhibition and target search processes.

Keywords Attentional suppression · Statistical learning · Object-based attention

Introduction

The environment we live in contains an overwhelming amount of information at any moment, ranging from important information required for survival and the accomplishment of task goals at hand to extraneous and unnecessary information. To process necessary information, attentional resources are necessarily allocated to it (Treisman & Gelade, 1980). However, attentional resources are limited, allowing only a portion of information to be processed at one time (Desimone & Duncan, 1995). Thus, for visual information, specific locations of the visual field containing various stimuli are prioritized for selection so that locations with higher priority are attended earlier than those with lower priority. This representation of attentional resources across the visual field is referred to as 'attentional priority' (Yantis & Johnson, 1990) and is often visualized in an 'attentional priority map' (Wolfe, 1994, 2021).

An attentional priority map is updated continuously based on implicit or explicit control and inputs from various features across the visual field (Luck et al., 2021). It is widely known that the relevance to task goals and physical salience of stimuli affect attentional allocation. For example, attention might be allocated to a stimulus when its feature (e.g., onset, color) is contingent with that of the target (Folk et al., 1992) or 'stands out' from other stimuli (Jonides & Yantis, 1988; Theeuwes, 1992). Recently, selection history has been suggested as a factor that influences attentional priority as well (Anderson et al., 2021; Awh et al., 2012; Wolfe, 2021; Wolfe & Horowitz, 2017). For instance, the statistical learning of task-irrelevant features frequently exhibited in targets (Cosman & Vecera, 2014) and the recurring locational configuration of targets and distractors (Chun & Jiang, 1999) enhance attentional allocation to a specific stimulus location. Stimuli associated with a large reward also capture attention compared to those associated with a relatively small reward or no reward (Anderson et al., 2011).

The aforementioned factors guide attention *towards* locations containing certain stimuli based on an attentional priority map. However, increasing evidence shows that attention

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can also be directed *away* from a stimulus location. In particular, attentional priority can decrease at a specific location via statistical learning in selection history, which is referred to as 'location-based suppression' of attention (Failing et al., 2019; Lin et al., 2021; Van Moorselaar & Theeuwes, 2022; Wang & Theeuwes, 2018a, 2018b, 2018c; see Theeuwes et al., 2022, for review). For instance, Wang and Theeuwes (2018a, 2018b, 2018c) demonstrated that the spatial regularities of a singleton distractor, which differs in visual features from other homogenous stimuli, modulate attention in a location-based manner. In their experiments, a color singleton distractor appeared more frequently at one location (high-probability location) than at all other locations (low-probability locations). Participants were instructed to search for a shape singleton target (Wang & Theeuwes, 2018a, 2018b) or a specific shape target (Wang & Theeuwes, 2018c) while ignoring the color singleton. The distractor interference effect was smaller when the singleton distractor appeared at the high-probability location than at a low-probability location. When the color singleton was absent, it took longer for participants to find the target appearing at the high-probability location than the one appearing at a low-probability location. In addition, the magnitude of the distractor interference effect increased as the distance between the high-probability location and the color singleton increased when the color singleton was presented at a low-probability location. Likewise, the efficiency of target selection decreased as the distance between the high-probability location and the target increased. These findings, including increased inhibition of distractors and decreased effectiveness of target search at the high-probability location compared to low-probability locations, collectively support the concept of location-based suppression. This phenomenon involves the formation of a spatial gradient with the strongest attentional suppression (i.e., lowest attentional priority) at the high-probability location.

Although most studies have primarily focused on the allocation of attention to or drawing attention away from specific locations, other lines of research have proposed that objects as well as locations are considered units of attention (Scholl, 2001). Object-based attention suggests that objects, or grouped representations of visual elements (Chen, 2012), serve as a representational basis of selection (Egeth & Yantis, 1997; Kahneman & Henik, 1981). Considering this view, the response to a stimulus presented at a location might indicate the allocation of attention to the stimulus location, the representation of the stimulus itself, or both. Thus, it is necessary to consider whether the attentional priority of a stimulus is determined based solely on its location or is also affected by objects that occupy the corresponding locations. To clarify the influence of objects on attentional priority from that of other features affecting location-based activation, Van Moorselaar and Theeuwes (2023) used the terms 'spatial priorities' to refer to the priorities computed in a location-based way and 'attentional priorities' to refer to the final priorities reflecting both space-based and object-based activations that determine where attention will be allocated.

Evidence suggests that object-based advantages in attentional selection occur at locations within the same object compared to between different objects. One of the commonly used methods to investigate the object-based enhancement of attention is the two-rectangle paradigm developed by Egly et al. (1994). In the two-rectangle paradigm, two identical rectangles are presented horizontally or vertically, with the two ends of each rectangle being possible cue/target locations. A cue is presented at one of four locations. After a short delay, a target is shown at one of three locations: the cued end (valid), the opposite end of the cued end in the same rectangle (invalid same-object), or the end of the other rectangle at the equidistant location from the cued spot (invalid different-object). Two key outcomes have led to important insights regarding attentional mechanism. First, targets appearing at the valid location are detected faster and more accurately than those at any other location, supporting space-based attention. Secondly and crucially, targets presented at the invalid same-object location are detected faster and more accurately than those at the invalid different-object location despite their equal distance from the cued location. Similar results have been found in experiments that replaced the detection tasks with a target identification task using a target and three distractors in the target display (Drummond & Shomstein, 2010; Nah et al., 2018; Shomstein & Behrmann, 2008). This object-based advantage implies that attentional priority is influenced not only by the spatial distance from the cued location but also by object representation.

Although relatively few studies have examined object-based inhibition, it has been demonstrated that attention could be inhibited based on continuous object representations rather than on fixed spatial coordinates (Jordan & Tipper, 1998; Tipper, 1985; Tipper et al., 1990, 1991, 1994). For instance, when a moving object is cued at a specific location, target search process is impeded on the moving object that was cued rather than on the spatial coordinate of the cue, which is called object-based inhibition of return (IOR; Tipper et al., 1991). These previous findings about object-based effects show that object representations are capable of modulating attentional priorities.

The interplay between attentional selection and object recognition is also illuminated by computational models of visual attention (Itti & Koch, 2001; Lindsay, 2020). Objects are recognized by extracting features from an incoming visual scene. Those features are processed using acquired knowledge to determine which category of known objects the perceived features best belong to. The object information obtained, in turn, guides attention to locations that maximize information gain (Itti & Koch, 2001). In a similar vein, behavioral studies demonstrated that the attentional priority map can be configured in an 'object-based' manner (Huang & Li, 2023; Van Moorselaar & Theeuwes, 2023).

Nonetheless, spatial priority maps depicting activation across the visual field have been suggested to be prioritized over object representations in the formation of an attentional priority map (Cave & Bichot, 1999; Lamy & Tsal, 2001). This is exhibited in the findings of cue-validity effects even when no object-based effect was observed in studies employing the two-rectangle paradigm (Chou & Yeh, 2018; Drummond & Shomstein, 2010; Nah & Shomstein, 2020). When the influence of an object representation on the attentional priority map is strong enough to induce a difference in attentional allocation between the same-object and different-object locations, an object-based effect would be observed. For instance, in the two-rectangle paradigm, the cued location is activated on the spatial priority map due to top-down guidance and bottom-up salience. This leads to activation at the invalid same-object location when object representation is formed. The activation increases eventual attentional priority and enhances detection/identification performance at invalid same-object locations compared to invalid different-object locations (Egly et al., 1994; Farah et al., 1993).

Building on these factors, if object representations exert a comparable influence on attentional suppression as they do on attentional enhancement, downregulated spatial priority at a particular location would lead to decreased activation at other locations within the same object compared to locations outside the object. Consequently, the resulting attentional priority would be lower at the location within the same object as the originally suppressed location than at the location equidistant from the suppressed location but in a different object.

It is hard to predict whether the impacts of objects on attentional priorities remain equivalent during target search and distractor inhibition processes. This is due to the disparity in experimental designs used to demonstrate attentional suppression and object-based attention. In the former case, experiments inevitably contain a singleton distractor with a salient task-irrelevant feature value to induce consistent downregulation at the corresponding location (Failing et al., 2019; Kong et al., 2020; Lin et al., 2021; Van Moorselaar & Theeuwes, 2022; Wang & Theeuwes, 2018a, 2018b, 2018c). In contrast, such a distractor is often not present in the paradigms used in the latter case. Cues given in the two-rectangle paradigm may distract attention as well when invalid, but the stimulus-onset synchrony (SOA) between the presentations of the cue and target makes it difficult to compare the effect of cues with interference by singleton distractors (Chou & Yeh, 2018; Drummond & Shomstein, 2010; Egly et al., 1994; Lamy & Egeth, 2002; Nah et al., 2018; Nah & Shomstein, 2020; Theeuwes et al., 2010). Previous research on attentional suppression has shown mixed results on attentional priorities exhibited in distractor inhibition and target selection. Hindered target selection and effective distractor inhibition were typically observed together at the suppressed location (Failing et al., 2019; Wang & Theeuwes, 2018a, 2018b). However, these two phenomena did not consistently co-occur in other studies that used similar experimental designs, even under conditions promoting location-based suppression (Lin et al., 2021; Van Moorselaar & Theeuwes, 2022).

To date, no empirical research has examined whether and how object representation modulates attentional suppression. Thus, the present study investigated whether objects decrease the attentional priority of a location when another location within the same object is suppressed, as compared to any other location in the visual field. Note that this suppression should be distinguished from that used in the context of object-based IOR (Jordan & Tipper, 1998; Tipper et al., 1991, 1994). Suppression refers to attentional priority being depressed at the high-probability distractor location prior to the presentation of any stimulus such as distractors or targets at that location, due to statistical learning on the spatial probabilities of singleton distractors. In contrast, the IOR refers to inhibition of attention from returning to previously attended stimulus locations after disengagement, such as cued locations or objects.

To induce effective attentional suppression at a specific location, the experimental design used by Wang and Theeuwes (2018a) was employed. For object representation, physical boundaries (Experiments 1) or perceptual grouping (Experiments 2 and 3) were used in the search display.

Experiment 1

The goal of Experiment 1 was to examine whether objects affect attentional priority while statistical regularities of singleton distractor location were manipulated in the additional singleton paradigm. The design of the experiment was similar to that of Wang and Theeuwes (2018a) with several critical modifications. First, we used six stimuli instead of eight in the search display. Second, the probabilities of the target and singleton distractor appearing at each of the six stimulus locations were modified. The singleton distractor was present in 70% of the total trials; it appeared more frequently at one of the six locations, which is called 'high-probability location' (45% of the total trials), than at the other five locations, which are called 'low-probability locations' (25% of the total trials, 5% at each of the five locations). When no singleton distractor was presented (30% of the total trials), the target was presented with an equal probability at each location (5% at each location). Most importantly, three objects were presented in addition so that two adjacent stimulus locations were located inside one object. Consequently, low-probability locations were divided depending on their distance from the high-probability location and the object they belonged to. The location that is adjacent to and part of the same object as the high-probability location is referred to as the 'same-object location.' Similarly, the location that is adjacent to the high-probability location but is in a different object is referred to as the 'different-object location.' The rest of the low-probability locations are called 'other low-probability locations' (Fig. 1).

Based on these manipulations, two different factors could affect attentional priority: *statistical regularities of singleton distractor location* and *object representation*. Statistical regularities of singleton distractor location are involved in determining location-based activations on the spatial priority map through statistical learning (Failing et al., 2019; Lin et al., 2021; Van Moorselaar & Theeuwes, 2022; Wang & Theeuwes, 2018a, 2018b, 2018c). On the other hand, object representation is expected to be engaged in attentional prioritization after location-based activation takes place. Modulation of attentional priority by these factors is also in line with findings in neuroscience that indicate the separate processing of spatial information and object perception through distinct pathways, specifically the dorsal and ventral pathways (Duhamel et al., 1997; Ungerleider & Haxby, 1994). Note that the two factors – statistical regularities and object representation – are not mutually exclusive in their effects on attentional priority.

Two separate hypotheses can be developed with this scheme. First, if attentional suppression occurs at the high-probability location due to biased statistical regularities, attention capture by singleton distractors and efficiency in target selection would be reduced at the high-probability location compared to the other locations. This reflects the effect of statistical regularities on the spatial priority map. Second, if objects affect the spatial priority map, distractor interference would be weaker and target selection would be slower at the same-object location than at the different-object location. Otherwise, the same-object and different-object locations would show no difference in attention capture by singleton distractors or target selection. This difference between the same-object and different-object locations reflects the effect of object representation on the spatial priority map in generating the final attentional priority map.

Attentional suppression was examined via two measures: attention capture by singleton distractors on distractor-present trials and target selection efficiency on distractor-absent trials. In addition, we examined the impact of singleton distractor capture on target selection to assess the influence of both statistical learning and physical salience on object-based suppression (see Fig. 2).

Methods

Participants

Because there was no previous research with similar design to ours, the sample size was determined considering two branches of research. Prior studies that have used a similar probability distribution of singleton distractor location with the current experiment have reported reliable location-based suppression with 20–24 participants (Wang & Theeuwes, 2018a, 2018b, 2018c). Based on the smallest effect size ($\eta^2_{p\,=\,.}23$) from the attention capture analyses in those studies and using a power analysis based on G*Power 3.1 (Faul et al., 2009) for repeated-measures analysis of variance (ANOVA) as a function of distractor location (no distractor, high-probability, same-object, different-object, other low-probability locations), a sample size of 18 was needed to achieve an alpha level of .95 and a power of .95.

On the other hand, prior research on object-based cuing effects using the two-rectangle paradigm varied greatly in the number of participants for each experiment, ranging

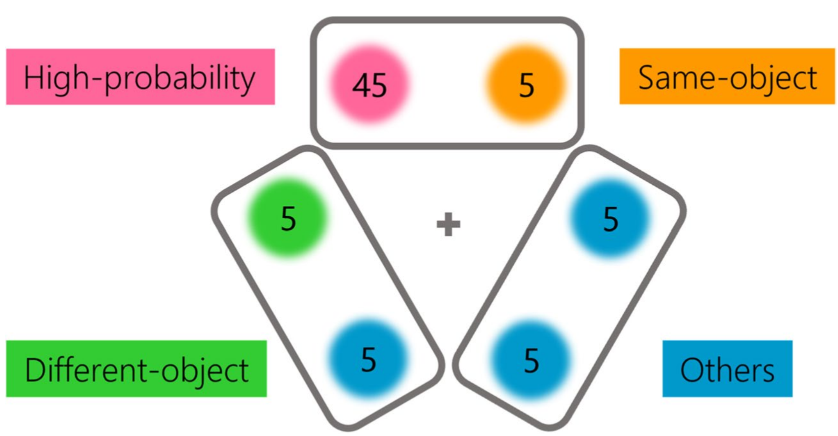

Fig. 1 A diagram representing location types and spatial regularities of the singleton distractor appearing at each location. Numbers indicate the probabilities (%) of the singleton distractor appearing at the corresponding location out of the total trials

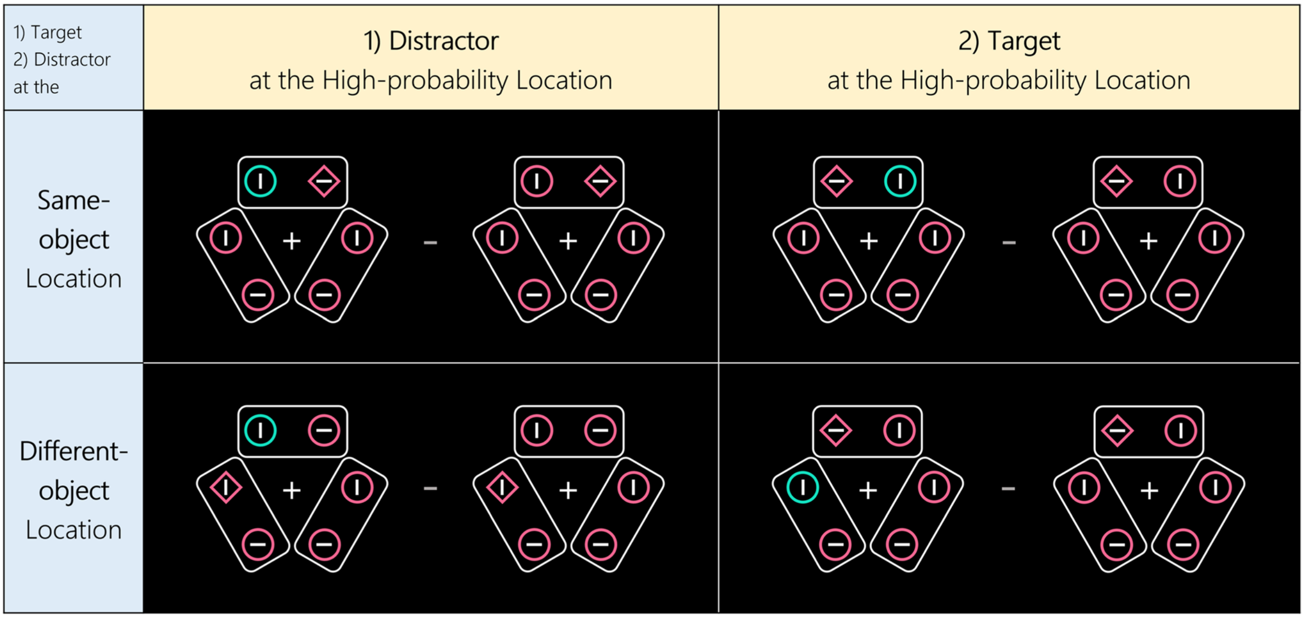

Fig. 2 Visual depiction of how distractor capture/suppression effects were calculated in Experiments 1–3. Mean reaction times (RTs) and percent errors (PEs) of distractor-absent trials were subtracted from those of distractor-present trials with the same target location. Trials in which (1) the distractor was presented at the high-probability location and the target at the same- or different-object location, or (2) the target was presented at the high-probability location and the distractor at the same- or different-object location were included for analysis

from 10 to 41 participants (Chou & Yeh, 2018; Drummond & Shomstein, 2010; Lamy & Egeth, 2002; Nah et al., 2018; Nah & Shomstein, 2020; Theeuwes et al., 2010). For effect size estimation, experiments with experimental designs closest to the current experiment in terms of critical variables were examined using three criteria. First, the ratio of invalid trials should be larger than that of valid trials so that the cue acts as a 'distracting' stimulus rather than an 'informative' stimulus. Second, the target location frequency must be equally distributed between invalid same-object and invalid-different object locations. Third, the yielded difference in the mean reaction time (RT) between the two invalid locations was significant. Of the experiments that satisfied the criteria, the smallest effect size (Cohen's $d = 0.20$, from Experiment 3 in Chou & Yeh, 2018) was used for power analysis. Using the same program resulted in a minimum sample size of 327 to achieve an alpha level of .95 and a power of .95, which is unrealistic. Thus, we recruited 44 participants (32 females, mean age: 23.0 years), which is larger than the sample sizes that are used in previous studies or estimated by previous effect sizes within practical ranges, to determine if a reliable object-based suppression effect is observed with an adequate sample size.

All participants provided informed consent before participation and were compensated with 8,500 KRW (approximately US$7) after participation. All experiments were approved by the Institutional Review Board at Korea University (KUIRB-2022-0181-01).

Apparatus

All experiments were programmed and conducted using MATLAB R2020b or MATLAB R2021b with Psychtoolbox3 extension. Stimuli were presented on a 17-in. CRT monitor at a viewing distance of approximately 60 cm in a dimly lit soundproof room. Responses were collected using a standard computer keyboard.

Stimuli

All stimuli were presented on a black background. Each trial consisted of fixation, search, and feedback displays. For the fixation display, a white fixation cross (approximately 0.3° in visual angle) was presented at the center of the screen. Three unfilled white rectangles with round corners (approximately 7.2° × 3.6°, referred to as 'objects' in Experiment 1) appeared simultaneously. The rectangles were equidistant from each other, and the innermost edge of each rectangle was approximately 2.2° away from the fixation. The search display consisted of the fixation cross, three objects, and six items. The items were either five circles (approximately 1.6° in diameter) and one diamond (approximately 1.8° × 1.8°) or five diamonds and one circle presented equidistantly along the edge of an imaginary circle (approximately 4.0° in radius) with a fixation cross at the center. Two adjacent items were located inside the boundary of one object. All visual items were the same color when no singleton distractor appeared, whereas one of the non-target items was presented in a distinct color from the rest when a singleton distractor was present. The singleton and non-singleton colors were based on two sets of two colors as in Won et al.'s (2019) Experiment 1. All colors were equally bright and only differed in hue; two colors in a set were chosen so that they were located farthest from each other on a CIELAB hue ring (L*a* b* = [70, 0, 0], radius of 39; see Bae et al., 2015). The first set was pink (CIE L*a*b* = [70, 39, 0]; RGB = [237, 143, 172]) and green (CIE L*a*b* = [70, -39, 0]; RGB = [64, 190, 170]), and the second set was blue (CIE L*a*b* = [70, 0, -39]; RGB = [119, 175, 241]) and gold (CIE L*a*b* = [70, 0, 39]; RGB = [194, 169, 100]). The color set assignment was counterbalanced across participants. The singleton color varied randomly from trial to trial with equal probability within a participant. There was a white horizontal or vertical line segment inside each item. Participants were asked to respond to the orientation of the line inside the target, which was a shape singleton, by pressing the 'Z' key for a horizontal line and the 'M' key for a vertical line.

If a correct response was made within 3,000 ms after the onset of the search display, the feedback display showed a written message "맞았습니다" ("correct" in Korean). If a response was not made within 3,000 ms or an incorrect response was made, a 1,000-Hz tone sounded for 500 ms with a written message, "틀렸습니다" ("incorrect" in Korean).

Procedure

A fixation cross and three round-cornered rectangle objects appeared and remained visible throughout the trial. After 500 ms, the search display was presented for 3,000 ms or until response, followed by the feedback display for 750 ms. The intertrial interval (ITI) was randomly determined within the range of 500–750 ms (Fig. 3).

Design

A modified additional singleton paradigm was used. A target that was defined as a shape singleton was present in every trial, and it was equally likely to be a circle or a diamond. In 70% of the total trials, a uniquely colored singleton distractor (e.g., pink or green with an equal probability) was present in the same shape as the other non-target items. The singleton distractor could appear at one of all six possible locations, but one of these locations had a high proportion of distractor appearance (high-probability location), accounting for approximately 64.3% of the distractor-present trials (i.e., 45% of the total trials). The other five locations had a low proportion of distractor appearance (low-probability location), which in sum take approximately 35.7% of the distractor-present trials (i.e., 25% of the total trials). On trials where the singleton distractor was present at the high-probability location, the target stimulus appeared equally often at the remaining stimulus locations. Likewise, when the singleton distractor was displayed at one of the low-probability locations, the target appeared at the other five locations with an equal probability. The high-probability location remained the same for each participant and was counterbalanced across participants. When no singleton distractor was presented (30% of the total trials), the target was presented equally often at each location. Participants completed 30 practice trials and six blocks of 100 trials each.

Results

Trials with incorrect or no responses and trials with RTs under 150 ms or RTs exceeding 3 standard deviations from the mean RT of each participant were excluded from the analyses (1.9% of total trials). For all experiments, p values from ANOVA were Greenhouse-Geisser corrected when assumption of sphericity was violated ($p < .05$ in Mauchly's Test of Sphericity; Tables 1 and 2; Figs. 4 and 5).

Attention capture effect by color singleton distractors: One-way ANOVA on mean RTs with distractor location (distractor-absent, high-probability location, same-object location, different-object location, and other low-probability locations) as a factor showed a significant main effect, $F(4, 172) = 22.213$, $p < .001$, $MSE = 3,624$, $\eta^2_p = .341$. Compared to when no distractor was presented ($M = 969$ ms), the mean RT was greater when a singleton distractor was presented at the high-probability ($M = 1,006$ ms), $t(43) = 5.904$, $p < .001$, Cohen's $d = 0.890$, same-object ($M = 1,040$ ms),

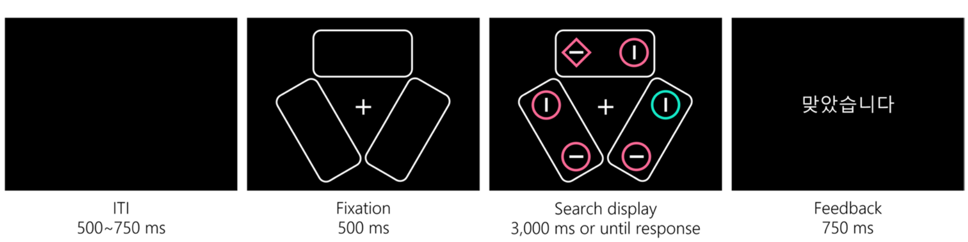

Fig. 3 Example of a trial sequence in Experiment 1

Table 1 Mean reaction times (RTs) and percent errors (PEs) as a function of singleton distractor location and target location in Experiment 1 (with standard deviations in parentheses)

	Single Distractor Location					Target Location (Distractor Absent)			
	Absent	High-probability	Same -object	Different-object	Others	High-probability	Same -object	Different-object	Others
RT (ms)	969 (247)	1006 (258)	1040 (281)	1048 (291)	1059 (253)	987 (271)	962 (249)	958 (247)	969 (252)
PE (%)	3.99 (2.54)	4.91 (4.17)	6.04 (6.94)	6.86 (7.34)	7.38 (5.69)	4.76 (5.08)	3.92 (3.92)	3.15 (4.32)	4.05 (2.88)

Table 2 Distractor capture effects in reaction time (RT) and percent error (PE) in Experiment 1. The effects are analyzed as a function of target location in trials where the distractor was presented at the high-probability location, and as a function of distractor location in trials where the target was presented at the high-probability location (with standard deviations in parentheses)

Distractor at the High-probability location		Target Location		Target at the High-probability location		Distractor Location	
		Same -object	Different-object			Same -object	Different-object
Distractor Capture Effect	RT (ms)	168 (108)	135 (108)	Distractor Capture Effect	RT (ms)	90 (63)	65 (63)
	PE (%)	5.24 (6.4)	1.3 (6.4)		PE (%)	2.38 (2.95)	1.71 (2.95)

$t(43) = 7.379$, $p < .001$, Cohen's $d = 1.112$, different-object ($M = 1{,}048$ ms), $t(43) = 5.667$, $p < .001$, Cohen's $d = 0.854$, and other low-probability locations ($M = 1{,}059$ ms), $t(43) = 9.890$, $p < .001$, Cohen's $d = 1.491$, indicating attentional interference by singleton distractors. Responses were faster when the singleton distractor was presented at the high-probability location than the same-object, $t(43) = 3.344$, $p = .002$, Cohen's $d = 0.504$, different-object, $t(43) = 3.416$, $p = .001$, Cohen's $d = 0.515$, and other low-probability locations, $t(43) = 5.914$, $p < .001$, Cohen's $d = 0.892$, suggesting less attention capture at the high-probability location than at all other locations. The difference was not significant when the distractor appeared at the same-object location as compared to the different-object location, $t(43) = 0.578$, $p = .566$.

The same analyses on percent error (PE) revealed that the main effect of distractor location was significant, $F(4, 172) = 6.657$, $p < .001$, $MSE = 17.67$, $\eta_p^2 = .134$. Compared to when no singleton distractor was present (4.0%), reliable attentional interference was obtained when a singleton distractor was presented at the high-probability (4.9%), $t(43) = 2.591$, $p = .013$, Cohen's $d = 0.391$, same-object (6.0%), $t(43) = 2.287$, $p = .027$, Cohen's $d = 0.345$, different-object (6.9%), $t(43) = 3.302$, $p = .002$, Cohen's $d = 0.498$, and other low-probability locations (7.4%), $t(43) = 5.600$, $p < .001$, Cohen's $d = 0.844$. No significant difference was obtained when a singleton distractor was displayed at the high-probability location and the same-object location, $t(43) = 1.443$, $p = .156$. Nonetheless, PE was lower when a singleton distractor appeared at the high-probability location than at the different-object, $t(43) = 2.781$, $p = .008$, Cohen's $d = 0.419$, and other low-probability locations, $t(43) = 4.610$, $p < .001$, Cohen's $d = 0.695$, similar to RT. No significant difference was obtained when a singleton distractor was presented at the same-object and different-object locations, $t(43) = 0.854$, $p = .398$.

Efficiency of target selection: A one-way ANOVA was conducted on mean RTs in distractor-absent trials with target location (high-probability location, same-object location, different-object location, and other low-probability locations) as a within-subject factor. The main effect of target location was not significant, $F(3, 129) = 1.427$, $p = .243$.

Analyses on PE revealed that, similar to mean RTs, the main effect of target location was not significant, $F(3, 129) = 1.507$, $p = .216$.

Effects of singleton distractor capture on target selection: First, when the singleton distractor was displayed at the high-probability location, there was no significant difference in distractor capture effects between when the target appeared at the same-object (90 ms and 2.38%) and different-object locations (65 ms and 1.71%) in RT $t(43) = 1.304$, $p = .199$ and PE, $t(43) = 0.752$, $p = .456$. These results suggest that the effect of singleton distractor capture at the high-probability location on target selection was not modulated by object representations.

Second, with the target displayed at the high-probability location, distractor capture effects in RT were numerically greater when the singleton distractor appeared at the same-object location (168 ms) than the different-object location (135 ms), but the difference was not statistically significant, $t(43) = 1.037$, $p = .306$. However, the differences were significant for distractor capture effects in PE, with a larger capture effect from singleton distractors displayed at the same-object location (5.24%) than different-object location (1.3%), $t(43) = 2.041$, $p = .047$, Cohen's $d = 0.308$. These results suggest that object representation played a role in modulating interference by singleton distractors when participants

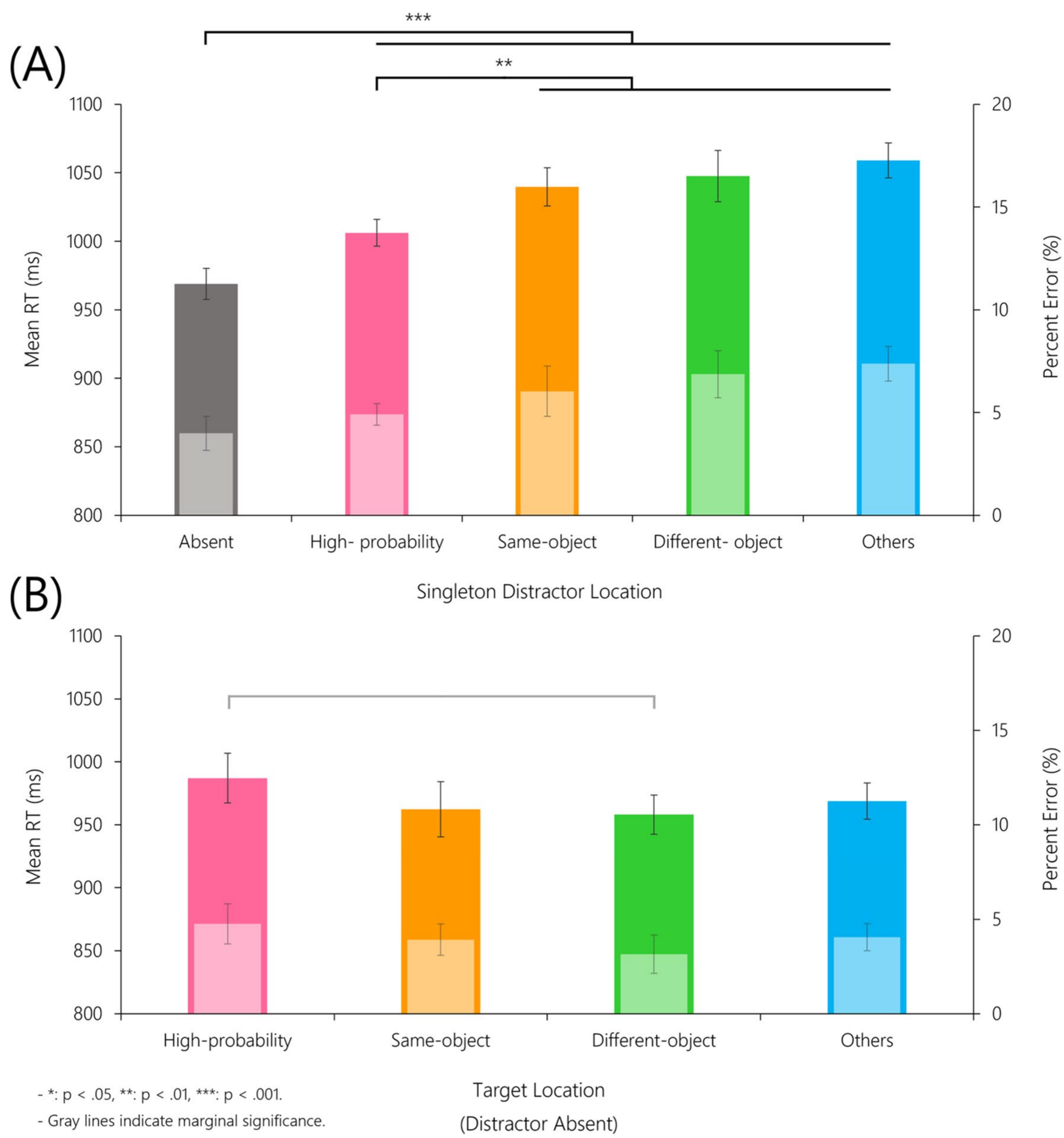

Fig. 4 Mean reaction times (RTs) and percent errors (PEs; light-colored) as a function of (**A**) singleton distractor location and (**B**) target location in Experiment 1. Error bars indicate 95% confidence intervals for the mean (Loftus & Masson, 1994)

searched for a target at the high-probability location, where suppression was the strongest.

Discussion

The objective of Experiment 1 was to assess whether objects modulate the attentional priority of stimulus locations when a singleton distractor frequently appeared at the high-probability location. While the attention capture by singleton distractors was weakened at the high-probability location compared to any other locations, no difference in attention capture by singleton distractors was observed between the same-object and different-object locations. Thus, distractor inhibition was influenced by the spatial priority map in which the high-probability location was downregulated but was not affected by object representations. In contrast, target selection efficiency was hardly modulated by target locations. This is somewhat unexpected because previous studies manipulating the spatial probability of the distractors to induce suppression observed less efficient target selection, as well as less attention capture by singleton distractors, at the high-probability distractor location (Failing et al., 2019; Wang & Theeuwes, 2018a, 2018b, 2018c). However, other studies with similar designs reported suppression effects in

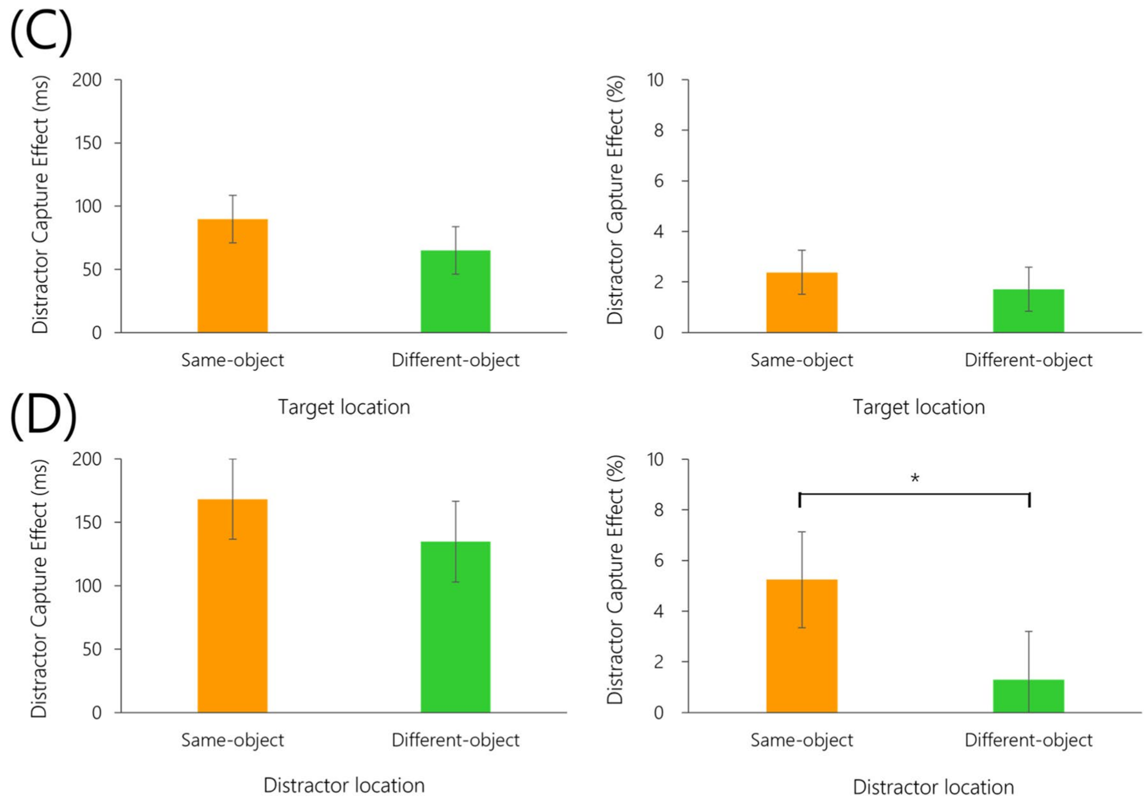

Fig. 5 Distractor capture effects in reaction time (RT) and percent error (PE) in Experiment 1. (**C**) Distractor capture effects in trials where the distractor appeared at the high-probability location as a function of target locations. (**D**) Distractor capture effects in trials where the target appeared at the high-probability location as a function of distractor locations. Error bars indicate 95% confidence intervals for the mean (Loftus & Masson, 1994)

attention capture by distractors with no significant effect in target selection efficiency (Lin et al., 2021; Van Moorselaar & Theeuwes, 2022). These findings imply that the spatial priority learned through biased distractor locations plays a limited role in target selection. Consequently, the disparity between the attention capture by distractor and target selection indicates that distinct factors were involved in distractor inhibition and target search, respectively.

The further examination of distractor-present trials revealed that distractor inhibition at the high-probability location had no effect on target selection, regardless of whether the target was located within the same object as the suppressed location or not. This contributes to our understanding of distractor inhibition characteristics, indicating that suppressing the salient distractor at the high-probability location does not automatically extend to another location within the same object, aligning with our findings on the location-based characteristics of distractor inhibition. In contrast, target selection at the high-probability location was more significantly hindered by the singleton distractor when a singleton distractor appeared at the same-object location than the different-object location. This suggests that when target search involves challenging the spatial priorities learned through statistics, suppression is more effectively released within the same object as the highly suppressed location, leading to increased distractor interference at the same-object location compared to the different-object location. This observation may elucidate why the location-based suppression effect was not statistically significant during target search, as suppression is attenuated when participants need to override the spatial priorities learned through statistics in the same-object location. These findings indicate that during target searches, spatial priority learned through statistical regularities is reconfigured by incorporating object representation, allowing greater influence of physical salience at the same-object location than different-object location.

The absence of the location-based and object-based effects in target selection, on the surface, seems to indicate that neither statistical regularities nor object representation contributed to target search. Yet alternatively, it is possible that the target search was influenced by both features. That is, the high-probability location was suppressed compared to the other locations due to biased locational probabilities of singleton distractors, but the differences in attentional suppression across locations were attenuated by object representation. For instance, participants could have searched for an object containing a singleton first and subsequently selected the target from the items within the object. Such a search strategy inevitably weakens the effect of statistical regularities, as the learning of the locational probabilities of singleton distractors would occur based on an object rather than at specific locations. Consistent with this possibility, target selection was numerically, but not statistically, less efficient at the high-probability location than at the same-object location in both the mean RT and PE ($ps < .3$). In contrast, target selection was marginally less efficient at the high-probability location than the different-object location in both the mean RT, $t(43) = 1.857$, $p = .070$, Cohen's $d = 0.280$, and PE, $t(43) = 1.767$, $p = .084$, Cohen's $d = 0.266$. Nevertheless, the effect of objects was not strong enough to induce a significant difference between the same-object and different-object locations in target selection, $t(43) = 0.249$, $p = .804$, Cohen's $d = 0.038$. These trends are suggestive of the influences of both statistical regularities and object representation on target search.

Experiment 2

Experiment 2 aimed to examine whether the discrepancy observed between distractor inhibition and target search in Experiment 1 was due to the influence of object-based attention only in target search. The findings of Experiment 1 raise the possibility that object representation was activated in target search, but the way objects were represented could have weakened their effects. The objects were task-irrelevant and physically distinguishable from the search items in Experiment 1. Thus, in Experiment 2, we used perceptual grouping to pair two items together. Partially-open circles or partially open diamonds were presented as search items so that a pair of items facing each other's open side was perceived as an object by creating illusory contours. Consequently, the shape of each relevant item was also utilized as a defining characteristic of the object.

It has been shown that perceptually-grouped stimuli act like closed objects in terms of attention (Moore et al., 1998). For example, in two-rectangle paradigm experiments, using two pairs of parallel lines grouped by proximity induced a same-object advantage as two closed rectangles did (Marino & Scholl, 2005). Moreover, evidence suggests that perceptually-grouped stimuli have attentional advantages over clusters of perceptually-ungrouped stimuli, even when object representations are unrelated to the task. For instance, stimuli grouped into an object by task-irrelevant Gestalt factors enhanced target detection (Kimchi et al., 2007) and induced larger N2pc that signals stronger attention capture (Marini & Marzi, 2016) than a set of stimuli that did not induce perceptual grouping. Considering these findings, perceptual grouping of items would form a reliable object representation.

If statistical regularities of the singleton distractor location induce location-based suppression, the attention capture by singleton distractors would be smaller, and target selection would be less efficient at the high-probability location than at the low-probability location. Crucially, if object representations formed by perceptual grouping of items reliably modulate suppression at the high-probability location, the attention capture by singleton distractors would be reduced, and target selection would be deterred at the same-object location than at the different-object location.

Methods

Participants

A new group of 44 participants (34 females, mean age: 22.4 years) participated in Experiment 2. As in the previous experiment, all participants provided informed consent and were compensated with 8,500 KRW (approximately US$7) for participation.

Apparatus

The apparatus for Experiment 2 was the same as that used in Experiment 1.

Stimuli, procedure, and design

The stimuli, procedure, and design of the current experiment were identical to those of the previous experiment except for the following. First, white rectangles were removed from the fixation and search displays; thus, only a fixation cross was presented in the fixation display, and then a fixation cross and six items were shown in the search display. Secondly and crucially, a gap was inserted in the shape of each item by removing approximately one-third of the circumference of the circle and diamond shapes used in Experiment 1. Six items with gaps were grouped into three pairs, with two items in a pair facing the gapped side of each other. Participants were instructed to find the target item in a distinct shape, which was a partially open circle out of five partially open diamonds or vice versa, and to press the corresponding keys on a keyboard according to the line orientation inside the target (Fig. 6).

Results

Trials on which responses were incorrect or absent, took less than 150 ms, or exceeded 3 standard deviations from the mean RT of each participant were excluded from the analyses (1.9% of total trials; Tables 3 and 4; Figs. 7 and 8).

Attention capture effect by color singleton distractors: One-way ANOVA on mean RTs with distractor location

Fig. 6 Example of a trial sequence in Experiment 2

Table 3 Mean reaction times (RTs) and percent errors (PEs) as a function of singleton distractor location and target location in Experiment 2 (with standard deviations in parentheses)

	Single Distractor Location					Target Location (Distractor Absent)			
	Absent	High-probability	Same -object	Different-object	Others	High-probability	Same -object	Different-object	Others
RT (ms)	958 (176)	997 (187)	1038 (212)	1046 (212)	1052 (181)	998 (194)	971 (199)	936 (186)	949 (172)
PE (%)	3.28 (3)	4.5 (4.13)	5.51 (5.45)	4.71 (4.98)	5.84 (4.75)	4.07 (5.48)	3.15 (4.2)	2.63 (3.77)	3.29 (2.92)

Table 4 Distractor capture effects in reaction time (RT) and percent error (PE) in Experiment 2. The effects are analyzed as a function of target location in trials where the distractor was presented at the high-probability location, and as a function of distractor location in trials where the target was presented at the high-probability location (with standard deviations in parentheses)

Distractor at the High-probability location		Target Location	
		Same -object	Different-object
Distractor Capture Effect	RT (ms)	83 (62)	108 (62)
	PE (%)	2.4 (3)	2.69 (3)

Target at the High-probability location		Distractor Location	
		Same -object	Different-object
Distractor Capture Effect	RT (ms)	103 (73)	149 (73)
	PE (%)	4.04 (9.48)	4.57 (9.48)

(distractor-absent, high-probability location, same-object location, different-object location, and other low-probability locations) as a factor showed a significant main effect, $F(4, 172) = 25.416$, $p < .001$, $MSE = 4{,}024$, $\eta^2_p = .371$. Subsequent planned comparisons revealed significant interference by singleton distractors at all locations compared to distractor-absent trials ($M = 958$ ms); high-probability ($M = 997$ ms), $t(43) = 5.888$, $p < .001$, Cohen's $d = 0.888$, same-object ($M = 1{,}038$ ms), $t(43) = 6.592$, $p < .001$, Cohen's $d = 0.994$, different-object ($M = 1{,}046$ ms), $t(43) = 6.563$, $p < .001$, Cohen's $d = 0.989$, and other low-probability locations ($M = 1{,}052$ ms), $t(43) = 11.883$, $p < .001$, Cohen's $d = 1.791$. The mean RT was shorter when a singleton distractor was presented at the high-probability location than the same-object, $t(43) = 3.960$, $p < .001$, Cohen's $d = 0.597$, different-object, $t(43) = 4.052$, $p < .001$, Cohen's $d = 0.611$, and other low-probability locations, $t(43) = 8.379$, $p < .001$, Cohen's $d = 1.263$, showing inhibition at the high-probability location compared to all other locations. No significant difference was obtained between when the singleton distractor was presented at the same-object and different-object locations, $t(43) = 0.516$, $p = .609$.

The PE data showed a main effect of distractor location, $F(4, 172) = 4.296$, $p = .010$, $MSE = 15.92$, $\eta^2_p = .091$, and reliable interferences by singleton distractors compared to distractor-absent trials (3.3%) at the high-probability location (4.5%), $t(43) = 3.756$, $p = .001$, Cohen's $d = 0.566$, same-object location (5.5%), $t(43) = 3.161$, $p = .003$, Cohen's $d = 0.477$, different-object location (4.7%), $t(43) = 2.469$, $p = .018$, Cohen's $d = 0.372$, and other low-probability locations (5.8%), $t(43) = 5.296$, $p < .001$, Cohen's $d = 0.798$. Unlike the RT results, no significant difference was obtained between when singleton distractors were presented at the high-probability and same-object locations, $t(43) = 1.437$, $p = .158$, or between when they were presented at the high-probability and different-object locations, $t(43) = 0.327$, $p = .745$. The PE was higher when a singleton distractor was presented at the high-probability location than at the other low-probability locations, $t(43) = 2.563$, $p = .014$, Cohen's $d = 0.386$. No significant difference was obtained between when singleton distractors were presented at the same-object and different-object locations, $t(43) = 0.802$, $p = .427$.

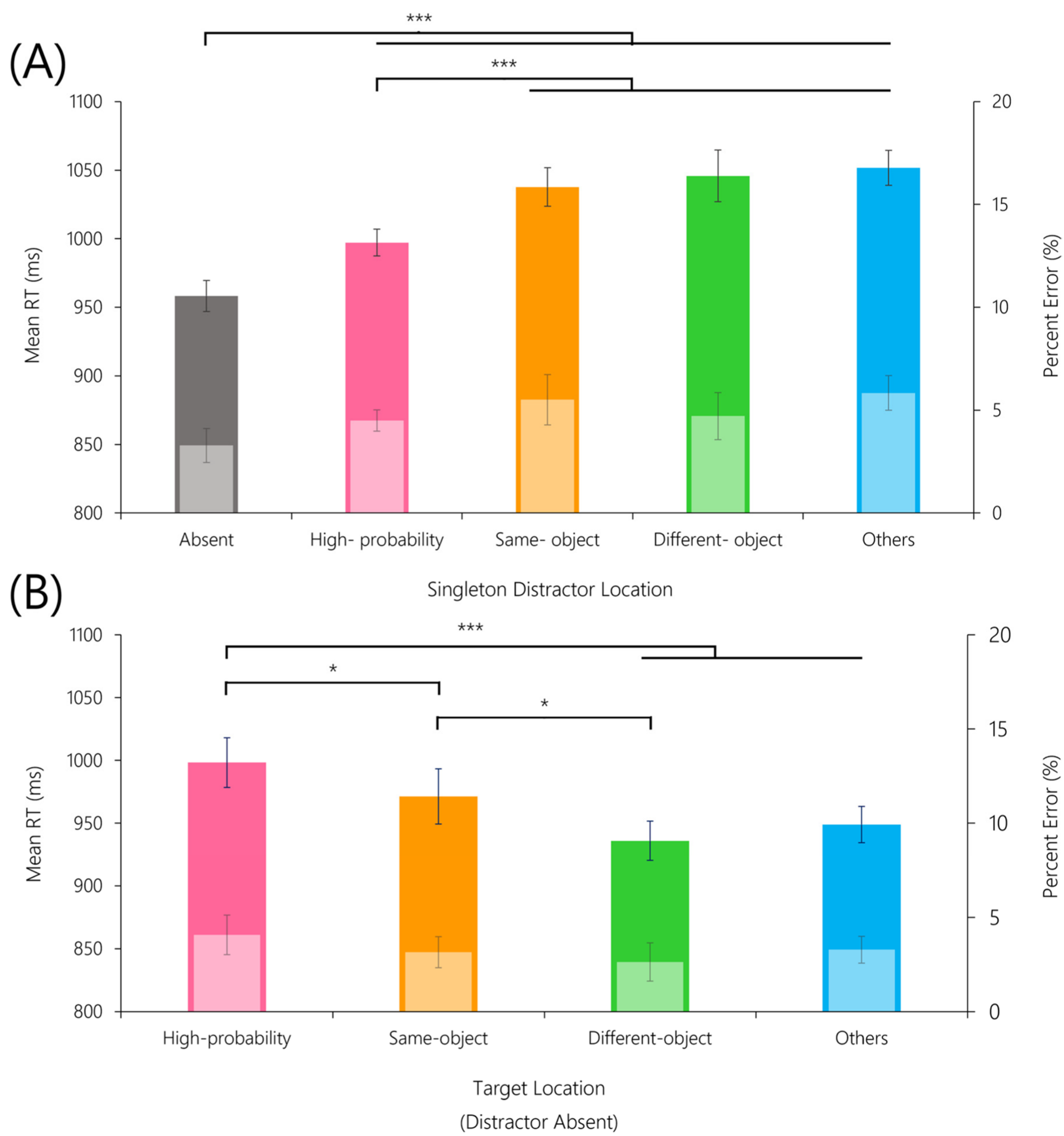

Fig. 7 Mean reaction times (RTs) and percent errors (PEs; light-colored) as a function of (**A**) singleton distractor location and (**B**) target location in Experiment 2. Error bars indicate 95% confidence intervals for the mean (Loftus & Masson, 1994)

Efficiency of target selection: A one-way ANOVA was conducted on the mean RTs of distractor-absent trials with the target location (high-probability location, same-object location, different-object location, and other low-probability locations) as a factor. Unlike in Experiment 1, the main effect of target location was significant, $F(3, 129) = 8.178$, $p < .001$, $MSE = 5{,}364$, $\eta_p^2 = .16$. Subsequent planned comparisons showed that the mean RT was greater when the target appeared at the high-probability location ($M = 998$ ms) than at the same-object ($M = 971$ ms), $t(43) = 2.274$, $p = .028$, Cohen's $d = 0.343$, different-object ($M = 936$ ms), $t(43) = 3.874$, $p < .001$, Cohen's $d = 0.584$, and other low-probability locations ($M = 949$ ms), $t(43) = 4.331$, $p < .001$, Cohen's $d = 0.653$. Furthermore, the mean RT was significantly longer at the same-object location than at the different-object location, $t(43) = 2.052$, $p = .046$, Cohen's $d = 0.309$.

For the PE analyses, the main effect of target location was not significant, $F(3, 129) = 1.684$, $p = .185$.

Effects of singleton distractor capture on target selection: When the singleton distractor was located at the high-probability location, as in Experiment 1, no significant difference in distractor capture effects was obtained between trials where the target appeared at the

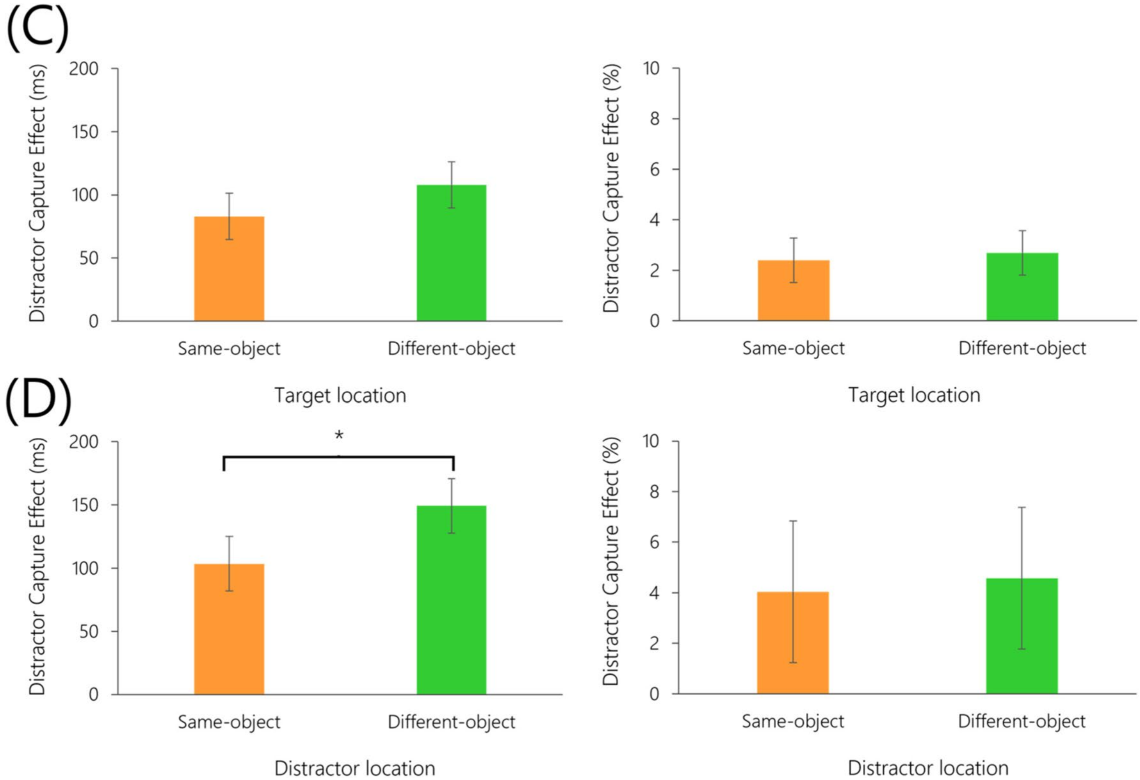

Fig. 8 Distractor capture effects in reaction time (RT) and percent error (PE) in Experiment 2. (**C**) Distractor capture effects in trials where the distractor appeared at the high-probability location as a function of target locations. (**D**) Distractor capture effects in trials where the target appeared at the high-probability location as a function of distractor locations. Error bars indicate 95% confidence intervals for the mean (Loftus & Masson, 1994)

same-object (83 ms and 2.4%) and different-object locations (108 ms and 2.69%), $t(43) = 1.338$, $p = .188$ in RT and $t(43) = 0.323$, $p = .748$ in PE. These results indicate that the effect of singleton distractor capture at the high-probability location on target selection at the neighboring locations was not modulated by object representations.

In contrast, when the target appeared at the high-probability location, distractor capture effects in RT were significantly smaller when the singleton distractor appeared at the same-object location (103 ms) than the different-object location (149 ms), $t(43) = 2.091$, $p = .042$, Cohen's $d = 0.315$. This implies that object representation influenced the interference caused by singleton distractors when participants searched for a target at the high-probability location, where suppression was the strongest. The difference was not significant for distractor capture effects in PE when singleton distractors were displayed at the same-object location (4.04%) and at the different-object location (4.57%), $t(43) = 0.186$, $p = .854$.

Discussion

Experiment 2 investigated if attentional priority is influenced by object representation when a task-relevant feature (item shape) also constituted objects through perceptual grouping. As in Experiment 1, singleton distractors were effectively inhibited when they appeared at the high-probability location compared to all other locations. However, there was no difference in singleton distractor inhibition between the same-object and different-object locations. This finding implies that interference by singleton distractors was modulated by statistical regularities but not by objects, indicating that only the spatial priority map affected by statistical regularities was engaged in distractor inhibition and that object representation did not modulate the spatial priorities. In contrast to the previous experiment, however, target selection was impeded at the high-probability location compared to all low-probability locations, indicating that spatial priorities were engaged when searching for targets. Importantly, the same-object location showed lower attentional priority than the different-object location in the target search. This finding indicates that object representations were successfully formed via perceptual grouping and modulated the spatial priority at the stimulus locations during target search.

These findings suggest that objects were engaged in attentional prioritization during target search but not distractor inhibition. Object representations effectively modulated location-based suppression during target search but not distractor inhibition. This highlights the difference between target search and distractor inhibition processes (Noonan et al., 2016), which was the trend observed in Experiment 1. Furthermore, unlike in Experiment 1, object representations successfully reconfigured spatial priority in Experiment 2. A potential reason for this difference between the two experiments is that task-relevant features (i.e., item shape) were also associated with objects only in Experiment 2 (Lamy & Tsal, 2000, 2001). Attending to the task-relevant feature entailed attending to object-related information at least in part, heightening the overall activation of object representations (Valdes-Sosa et al., 1998; He et al., 2008). According to this explanation, attention to object-related features would be important in determining the effectiveness of object representations in modulating attentional suppression.

Moreover, the distractor capture effects revealed that inhibition on the salient distractor at the high-probability location did not have a significant effect on target selection within the same or different object, as in Experiment 1. This aligns with our findings on the location-based characteristics of distractor inhibition. In contrast, target selection at the high-probability location was more impeded by singleton distractor at the same-object location than the different-object location. This suggests that when searching for a target at the most suppressed location, interference by the salient distractor was more effectively mitigated at the same-object location than the different-object location. The observation of distractor capture effects indicates that object-based suppression occurred in the process of reconfiguring the learned spatial priorities to search for the target required in the task, shedding light on why object-based suppression was evident primarily in the analyses for target selection efficiency.

Additionally, Experiment 2 provided contrasting outcomes in distractor capture effect analyses compared to Experiment 1. Specifically, there was a reduced distractor capture at the same-object location compared to different-object location when the target appeared at the high-probability location. One possible explanation is that attentional priorities were similarly diminished at locations with high probabilities and those involving the same object in Experiment 1, as indicated by the target selection efficiency analysis. This resulted in easier release of suppression at the same-object location than the different-object location when the learned spatial priorities needed to be overcome to find the target at the high-probability location. This dynamic allowed for a greater influence of physical salience over statistical regularities in reconfiguring attentional priorities with object representations. As a result, the distractor at the same-object location captured attention and interfered with target selection. In contrast, Experiment 2 demonstrated stronger suppression at the high-probability location than its adjacent locations, evidenced by the significantly inefficient target selection at the high-probability location compared to the same- and different-object locations. This heightened suppression enabled the object-based modulation of the spatial priority map while maintaining an overall spatial gradient that was downregulated at the high-probability location, leading to more effective suppression of salient distractors at the same-object location than the different-object location during target selection at the high-probability location. These findings indicate that the suppression induced by statistical learning overrode the impact of physical salience when attentional priority map was reconfigured by object representations.

Cross-experiment analyses

The effects of object-based suppression observed in Experiments 1 and 2 were relatively small and primarily limited to target search processes, in contrast to the more substantial impact of location-based suppression. It has been consistently demonstrated that the impact of object-based effects tends to be less pronounced than location-based effects in studies employing the two-rectangle cuing paradigm (Egly et al., 1994; Lou et al., 2023; Moore et al., 1998; Pilz et al., 2012) and in studies manipulating the statistical regularities of target locations (Nah & Shomstein, 2020; Van Moorselaar & Theeuwes, 2023). We examined whether the relatively limited manifestation of object-based suppression observed in Experiments 1 and 2 stemmed from inherent characteristics of object-based effects or insufficient statistical power. To increase the power of analyses on capture by singleton distractors and the efficiency of target selection, the data of both experiments were analyzed together.

Also, previous research indicates that typical object-based effects, such as the same-object advantage in a two-rectangle paradigm, could be affected by the differences in the visual hemispheres responsible for processing same- and different-object locations (Barnas & Greenberg, 2016; Chen & Cave, 2019; Sereno & Kosslyn, 1991). Thus, we tested whether the hemispheric distinctions in the three primary locations of examination, namely, high-probability, same-object, and different-object locations, might introduce confounding factors that could influence the observed effects of object representations in the present study. To explore this, we divided the participants into two groups depending on whether the three primary locations assigned to them were situated within a single visual hemisphere or across different visual hemispheres (see Fig. 9). We addressed these possibilities in the following analyses.

Results

Attention capture effect by color singleton distractors: A mixed ANOVA was conducted on the data of 88 participants with distractor location (distractor-absent, high-probability location, same-object location, different-object location, and other low-probability locations) as a within-subjects factor, and experiment type (Experiments 1 and 2) and hemispheric distribution of the three primary locations of interest (within a hemisphere and across two hemispheres) as between-subjects factors.

For mean RTs, the main effect of distractor location was significant, $F(4, 336) = 41.279$, $p < .001$, $MSE = 3{,}716$, $\eta^2_p = .329$. Compared to when no distractor was presented ($M = 964$ ms), the mean RT was greater when a singleton distractor was presented at the high-probability ($M = 1{,}002$ ms), $t(87) = 8.384$, $p < .001$, Cohen’s $d = 0.894$, same-object ($M = 1{,}039$ ms), $t(87) = 9.795$, $p < .001$, Cohen's $d = 1.044$, different-object ($M = 1{,}047$ ms), $t(87) = 8.672$, $p < .001$, Cohen's $d = 0.924$, and other low-probability locations ($M = 1{,}055$ ms), $t(87) = 15.33$, $p < .001$, Cohen's $d = 1.634$, indicating attentional interference by singleton distractors. Responses were faster when the singleton distractor was presented at the high-probability location than the same-object, $t(87) = 5.192$, $p < .001$, Cohen's $d = 0.553$, different-object, $t(87) = 5.304$, $p < .001$, Cohen's $d = 0.565$, and other low-probability locations, $t(87) = 9.768$, $p < .001$, Cohen's $d = 1.041$, suggesting smaller attention capture at the high-probability location than all other locations. No significant difference was found when a distractor appeared at the same-object location and the different-object location, $t(87) = 0.773$, $p = .442$, even when combining data from Experiments 1 and 2.

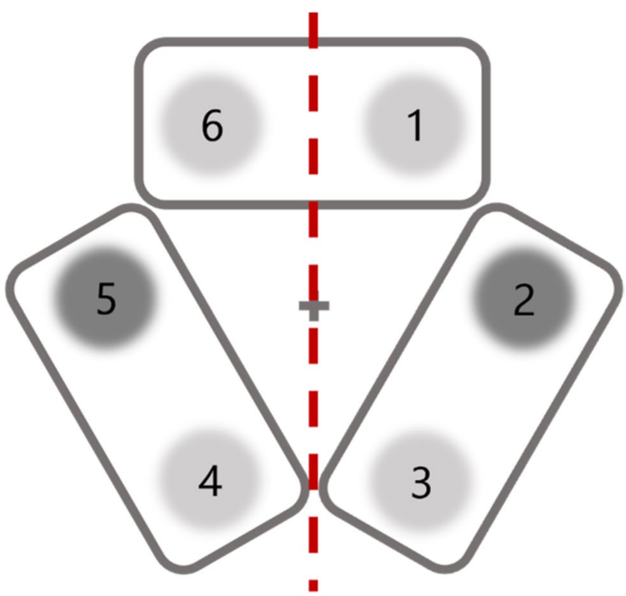

Fig. 9 A diagram representing stimulus locations (high-probability distractor location counterbalanced across participants). When the high-probability location is assigned at the stimulus location #2 or #5, the high-probability, same-object, and different-object locations reside within one visual hemisphere. In contrast, either a same-object location or a different-object location is placed on a different visual hemisphere when the stimulus location #1, #3, #4, or #6 is assigned as the high-probability location

The main effect of experiment type was not significant, $F(1, 84) < 1$, $p = .719$. The main effect of hemispheric distribution of the primary locations was also not significant, $F(1, 84) < 1$, $p = .74$. There was no interaction between these two between-subject factors, $F(1, 84) < 1$, $p = .464$. Critically, neither experiment type, $F(4, 336) < 1$, $p = .718$, nor hemispheric distribution of the primary locations, $F(4, 336) < 1$, $p = .756$, interacted with distractor location. The three-way interaction of distractor location, experiment type, and hemispheric distribution was not significant, $F(4, 336) = 1.169$, $p = .322$.

The same analyses on PE revealed that the main effect of distractor location was significant, $F(4, 336) = 8.909$, $p < .001$, $MSE = 15.96$, $\eta^2_p = .096$. A noticeable attentional interference was observed when a singleton distractor was presented at the high-probability location (4.7%), $t(87) = 4.462$, $p < .001$, Cohen’s $d = 0.476$, same-object (5.8%), $t(87) = 3.773$, $p = .001$, Cohen’s $d = 0.402$, different-object (5.8%), $t(87) = 4.095$, $p < .001$, Cohen’s $d = 0.437$, and other low-probability locations (6.6%), $t(87) = 7.673$, $p < .001$, Cohen’s $d = 0.818$, compared to trials in which no singleton distractor was present (3.6%). Participants made less errors when singleton distractors were presented at the high-probability locations than same-object locations, $t(87) = 2.045$, $p = .044$, Cohen’s $d = 0.218$, different-object locations, $t(87) = 2.231$, $p = .028$, Cohen’s $d = 0.238$, and other low-probability locations, $t(87) = 5.053$, $p < .001$, Cohen’s $d = 0.539$, showing that singleton distractors captured less attention at the high-probability location than other locations. No significant difference was obtained when a singleton distractor was presented at the same-object and different-object locations, $t(87) = 0.025$, $p = .98$.

The main effect of experiment type was not significant, $F(1, 84) = 1.034$, $p = .312$. Also, the main effect of hemispheric distribution of the three primary locations was not significant, $F(1, 84) < 1$, $p = .463$. No interaction was observed between these two between-subject variables, $F(1, 84) < 1$, $p = .693$. As in mean RT analysis, distractor location did not interact with experiment type, $F(4, 336) < 1$, $p = .779$, nor with hemispheric distribution of the primary locations, $F(4, 336) < 1$, $p = .752$. The three-way interaction of distractor location, experiment type, and hemispheric distribution was not significant, $F(4, 336) = 1.715$, $p = .167$.

Efficiency of target selection: A mixed repeated-measures ANOVA was conducted with target location (high-probability location, same-object location, different-object location, and other low-probability locations) as a within-subjects factor, and experiment type (Experiments 1 and 2) and distribution of the three primary locations of examination (within a hemisphere and across two hemispheres) as between-subjects factors.

Analyses on mean RTs showed a significant main effect of target location, $F(3, 252) = 6.836$, $p < .001$, $MSE = 5{,}373$, $\eta^2_p = .075$. Subsequent planned comparisons showed that participants were slower to respond when the target appeared at the high-probability location ($M = 993$ ms) than at the same-object ($M = 967$ ms), $t(87) = 2.495$, $p = .014$, Cohen's $d = 0.266$, different-object ($M = 947$ ms), $t(87) = 4.047$, $p < .001$, Cohen's $d = .431$, and other low-probability locations ($M = 959$ ms), $t(87) = 3.61$, $p = .001$, Cohen's $d = 0.385$. The mean RT was numerically but not significantly longer when the target was presented at the same-object location than at the different-object location, $t(87) = 1.641$, $p = .104$, Cohen's $d = 0.175$.

Neither the main effect of experiment type, $F(1, 84) < 1$, $p = .681$, nor the main effect of hemispheric distribution of the primary locations, $F(1, 84) < 1$, $p = .649$, was significant. The interaction between these two between-subject factors was not significant either, $F(1, 84) < 1$, $p = .362$. Critically, neither experiment type, $F(3, 252) < 1$, $p = .458$, nor hemispheric distribution of primary locations, $F(3, 252) < 1$, $p = .558$, interacted with distractor location. The three-way interaction of distractor location, experiment type, and hemispheric distribution was not significant, $F(3, 252) < 1$, $p = .871$.

The same analyses on PE data revealed a significant main effect of target location, $F(3, 252) = 3.049$, $p = .037$, $MSE = 13.08$, $\eta^2_p = .035$. Error rates were higher when the target appeared at the high-probability location (4.4%) than at the same-object location (3.5%) with marginal significance, $t(87) = 1.7$, $p = .093$, Cohen's $d = 0.181$, and at the different-object location (2.9%) with significance, $t(87) = 2.488$, $p = .015$, Cohen's $d = 0.265$. Differences between the high-probability and other low-probability locations (3.7%) did not reach significance, $t(87) = 1.489$, $p = .14$. Responses were slightly more inaccurate when a target appeared at the same-object location compared to the different-object location, though this difference was not statistically significant, $t(87) = 1.297$, $p = .198$.

Neither the main effects of experiment type, $F(1, 84) < 1$, $p = .382$, nor hemispheric distribution of the primary locations, $F(1, 84) < 1$, $p = .614$, was significant. There was no interaction between these two between-subject variables, $F(1, 84) < 1$, $p = .716$. Importantly, as in the mean RT analysis, neither experiment type, $F(3, 252) < 1$, $p = .921$, nor hemispheric distribution of the primary locations, $F(3, 252) < 1$, $p = .527$, interacted with distractor location. The three-way interaction of distractor location, experiment type, and hemispheric distribution was not significant, $F(3, 252) < 1$, $p = .733$.

Effects of singleton distractor capture on target selection: A mixed ANOVA was conducted on the size of distractor capture effects in RT and PE, with either target location or distractor location (same-object and different-object locations) as a within-subject factor and experiment type (Experiments 1 and 2) and hemispheric distribution of the three locations of interest (within a hemisphere and across two hemispheres) as between-subjects factors.

When the singleton distractor was presented at the high-probability location, there was no significant difference in distractor capture effects between trials where the target appeared at the same-object (86 ms and 2.39%) and different-object locations (86 ms and 2.20%), $t(87) = 0$, $p = 1$ in RT and $t(87) = 0.298$, $p = .766$ in PE.

The main effect of experiment type was not significant in both RT, $F(1, 84) = 2.117$, $p = .149$, and PE, $F(1, 84) < 1$, $p = .738$. The main effect of hemispheric distribution of the primary locations was not significant in RT, $F(1, 84) = 1.452$, $p = .232$, and marginally significant in PE, $F(1, 84) = 2.999$, $p = .087$, $MSE = 31.15$, $\eta^2_p = .034$. Participants who saw the high-probability, same-object, and different-object locations in the same visual hemifield tended to show higher error rates (3.34%) than those whose primary locations of interest were distributed across different visual hemifields (1.79%). There was no interaction between these two between-subject factors, $F(1, 84) = 1.215$, $p = .273$ in RT and $F(1, 84) < 1$, $p = .605$ in PE. Importantly, the interaction between experiment type and target location was not significant in either RT, $F(1, 84) = 1.375$, $p = .244$, or PE, $F(1, 84) < 1$, $p = .677$. The two-way interaction between the hemispheric distribution of the primary locations and the target location was also not significant, $F(1, 84) < 1$, $p = .823$ in RT and $F(1, 84) < 1$, $p = .766$ in PE. The three-way interaction of target location, experiment type, and hemispheric distribution was marginally significant in RT, $F(1, 84) = 2.969$, $p = .089$, $MSE = 7{,}748$, $\eta^2_p = .034$, but not in PE, $F(1, 84) < 1$, $p = .410$. Subsequent analyses on RT data showed a significant interaction between target location and experiment type when the three locations of interest were distributed across the left and right visual fields, $F(1, 57) = 6.945$, $p = .011$, $MSE = 7{,}100$, $\eta^2_p = .109$. Distractor capture effect at the high-probability location tended to be larger when the target appeared at the same-object location (98 ms) compared to different-object location (56 ms) in Experiment 1, $t(29) = 1.866$, $p = .072$, Cohen's $d = .341$, while the reversed trend was observed in Experiment 2, $t(28) = 1.870$, $p = .072$, Cohen's $d = .347$, with smaller distractor capture effect when the target appeared at the same-object location (63 ms) compared to different-object location (102 ms). When the locations of interest were located in the same visual field, the interaction between target location and experiment type was not significant, $F(1, 27) < 1$, $p = .759$.

On the other hand, when the target was at the high-probability location, distractor capture effects in RT were not significantly different between when the singleton distractor appeared at the same-object location (136 ms and 4.64%) compared to the different-object location (142 ms and 2.94%) in both RT, $t(87) = .306$, $p = .760$, and PE, $t(87) = 0.985$, $p = .327$.

The main effect of experiment type was not significant in both RT, $F(1, 84) < 1$, $p = .556$, and PE, $F(1, 84) < 1$, $p = .676$. The main effect of hemispheric distribution of the primary locations was also not significant, $F(1, 84) < 1$, $p = .871$ in RT and $F(1, 84) < 1$, $p = .601$ in PE. There was no interaction between these two between-subject factors, $F(1, 84) < 1$, $p = .550$ in RT and $F(1, 84) < 1$, $p = .922$ in PE. The interaction between experiment type and distractor location was marginally significant in both RT, $F(1, 84) = 3.053$, $p = .084$, $MSE = 17{,}200$, $\eta^2_p = .035$, and PE, $F(1, 84) = 2.965$, $p = .089$, MSE = 130, $\eta^2_p = .034$. (For subsequent analysis, see the *Effects of singleton distractor capture on target selection* based on distractor location in the *Results* section of Experiments 1 and 2.) This shows that the difference in distractor capture effects at the same- and different-object locations was affected by how objects were presented. The two-way interaction between the hemispheric distribution of the primary locations and target location was not significant, $F(1, 84) < 1$, $p = .673$ in RT and $F(1, 84) < 1$, $p = .688$ in PE. The three-way interaction of target location, experiment type, and hemispheric distribution was also not significant, $F(1, 84) < 1$, $p = .657$ in RT and $F(1, 84) = 2.237$, $p = .138$ in PE.

Discussion

We combined the data from Experiments 1 and 2 to examine whether the limited object-based suppression effects, evident only in target selection efficiency and not in singleton distractor capture, stemmed from inherent characteristics of object-based attention or inefficient statistical power. In the singleton distractor capture analysis, there was no difference in RTs and PEs at the same- and different-object locations. This suggests that the absence of object-based suppression effect in distractor capture is unlikely due to insufficient statistical power, indicating that object information may not be involved in the inhibition process of distractors. The experiment type, hemispheric distribution of the three primary locations, and the interaction between these between-subject factors did not confound distractor inhibition and target selection performances.

In additional analyses, distractor capture effects with the distractor or target at the high-probability location, on the surface, were not modulated by objects. When analyzing the capture effects of distractors at the high-probability location, a weak trend of the three-way interaction of target location, experiment type, and hemispheric distribution of primary locations was observed. This interaction was due to the different influences of hemispheric distribution in modulating the interaction between target location and experiment type. Despite this, there was no significant difference in distractor capture effects at the high-probability location based on target location in both Experiments 1 and 2. Consequently, hemispheric distribution does not appear to have confounded the results in these experiments. Considering these findings, it can be inferred that suppression at the high-probability location diminishes capture by physically salient stimuli, but this suppression does not inherently extend to another location within the same object.

Moreover, the interactions between distractor location and experiment type suggest that the null effect resulted from collapsing the data from the two experiments showing opposite trends of object-based effects. This aligns with our findings from the corresponding analyses in Experiments 1 and 2, where task performance was more interrupted with the distractor at the same-object location than the different-object location in Experiment 1, and less interrupted in Experiment 2. This implies that the way objects are represented modulates the influence of physical salience when participants searched for a target based on statistically learned spatial priority.

In summary, we demonstrated that the lack of differences between same- and different-object locations in distractor inhibition was not due to inadequate statistical power in each experiment. Additionally, we observed that the type of experiment and the hemispheric distribution of the high-probability, same-object, and different-object locations do not exert a critical impact on target selection and distractor inhibition.

Experiment 3

Experiment 3 examined if attention allocated to object-related features is necessary to establish object representations. In Experiment 3, the target was defined by the line segment orientation inside each item (identifying a horizontal or vertical line among five oblique lines), while objects were represented via perceptual grouping as in Experiment 2. Consequently, the effect of goal-driven attention on object perception was minimized while the shapes of the items were included as part of the objects. Moreover, by changing the target-defining feature, attention capture by color singleton distractors was minimized. Because a ‘shape’ can be defined by discontinuities in color against its background, using the item shape as a target feature could have automatically strengthened the effect of singleton distractor interference on distractor inhibition and target search (Gouras, 2002). Thus, if attention allocation towards the object-related feature (i.e., item shape) is required for object representation to modulate the spatial priority map, the object-based effect in target selection efficiency would be eliminated. Alternatively, if the object representation exerts its influence on the spatial priority map regardless of whether the object-related feature was attended or not, an object-based effect would be observed in target selection efficiency as in Experiment 2.

Methods

Participants

A new group of 45 participants (29 females, mean age: 23.7 years) participated in Experiment 3. One participant was excluded from the analyses because this participant misunderstood the task instructions. As a result, data from 44 participants were analyzed. All participants provided informed consent and were compensated with 8,500 KRW (approximately US$7) for their participation as in the previous experiments.

Apparatus

The apparatus was the same as in the previous experiments.

Stimuli, procedure, and design

The task and search displays were modified from those of Experiment 2. Two critical changes were made. First, one horizontal or vertical line and five oblique lines tilted 45° clockwise or counterclockwise were presented with each line located inside one of the six partially open shapes in the search display. The task was to find the horizontal or vertical line and respond according to its orientation. The target (a horizontal or vertical line) never appeared inside a color singleton distractor in distractor-present trials. The mapping between the line orientations and response keys was identical to that of the previous experiment. Secondly, no shape singleton item was presented, as the target was defined by orientation. Therefore, all six items were identical in shape; six partially open circles or six partially open diamonds were shown in the search display equally often. The rest of the stimulus, procedure, and experimental design were identical to those of Experiment 2 (Fig. 10), including item colors, the probability distribution of the singleton distractor locations, and arrangement of six partially open items to form three perceptually grouped objects.

Results

Trials with incorrect or no responses and those with RTs under 150 ms or exceeding 3 standard deviations from the mean RT of each participant were excluded from the analyses (1.5% of total trials; Tables 5 and 6; Figs. 11 and 12).

Attention capture effect by color singleton distractors: One-way ANOVA was conducted on mean RTs with distractor location (distractor-absent, high-probability

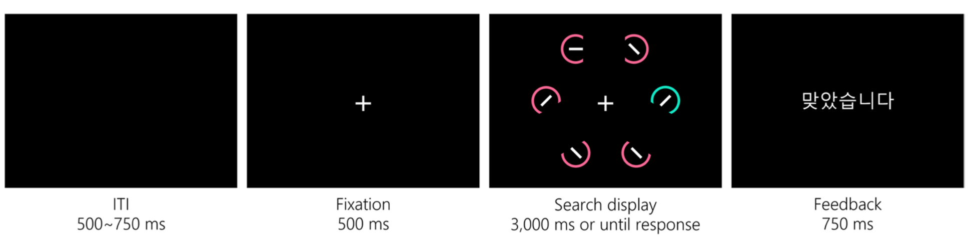

Fig. 10 Example of a trial sequence in Experiment 3

Table 5 Mean reaction times (RTs) and percent errors (PEs) as a function of singleton distractor location and target location in Experiment 3 (with standard deviations in parentheses)

	Single Distractor Location					Target Location (Distractor Absent)			
	Absent	High-probability	Same -object	Different-object	Others	High-probability	Same -object	Different-object	Others
RT (ms)	910 (177)	908 (191)	916 (200)	929 (217)	930 (180)	981 (268)	913 (247)	913 (245)	886 (192)
PE (%)	2.74 (3.92)	2.69 (4.32)	2.46 (3.98)	3.56 (5.39)	2.64 (4.15)	2.98 (5.49)	2.76 (5.23)	3.51 (5.04)	2.4 (3.56)

Table 6 Distractor capture/suppression effects in reaction time (RT) and percent error (PE) in Experiment 3. The effects are analyzed as a function of target location in trials where the distractor was presented at the high-probability location, and as a function of distractor location in trials where the target was presented at the high-probability location (with standard deviations in parentheses)

Distractor at the High-probability location		Target Location		Target at the High-probability location		Distractor Location	
		Same -object	Different-object			Same -object	Different-object
Distractor Capture/Suppression Effect	RT (ms)	-3 (50)	20 (50)	Distractor Capture/Suppression Effect	RT (ms)	-8 (112)	58 (112)
	PE (%)	0.39 (2.91)	-1.16 (2.91)		PE (%)	-1.46 (4.78)	2.36 (4.78)

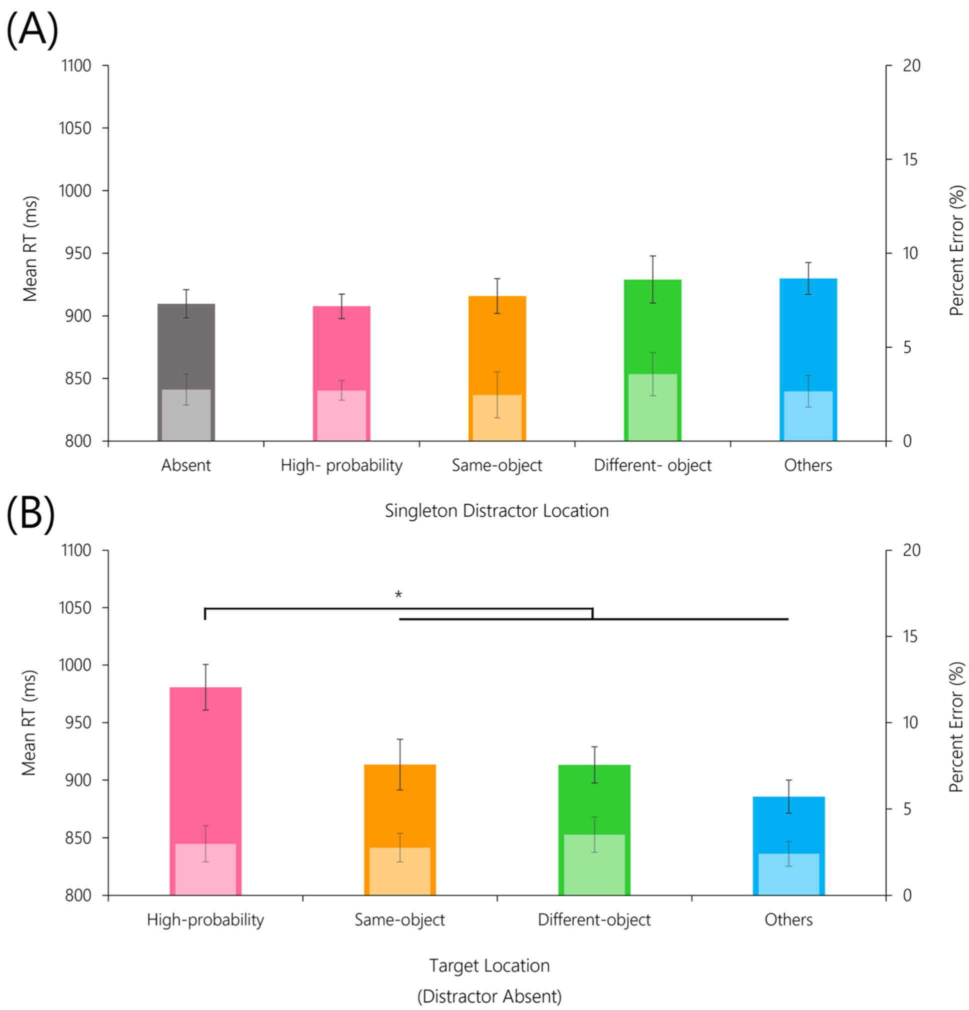

Fig. 11 Mean reaction times (RTs) and percent errors (PEs; light-colored) as a function of (**A**) singleton distractor location and (**B**) target location in Experiment 3. Error bars indicate 95% confidence intervals for the mean (Loftus & Masson, 1994)

location, same-object location, different-object location, and other low-probability locations) as a factor. Unlike the results of Experiments 1 and 2, the main effect was not significant, $F(4, 172) = 1.835$, $p = .156$, showing that target search was not modulated by the appearance or location of the singleton distractor. The PE data also showed no significant main effect of distractor location, $F(4, 172) = 1.387$, $p = .255$.

Efficiency of target selection: A one-way ANOVA was conducted on mean RTs on distractor-absent trials with target location (high-probability location, same-object location, different-object location, and other low-probability locations) as a within-subject factor. The main effect was marginally significant, $F(3, 129) = 2.420$, $p = .085$, $MSE = 38{,}158$, $\eta^2_p = .053$. In subsequent planned comparisons, the mean RT was significantly greater when a target appeared

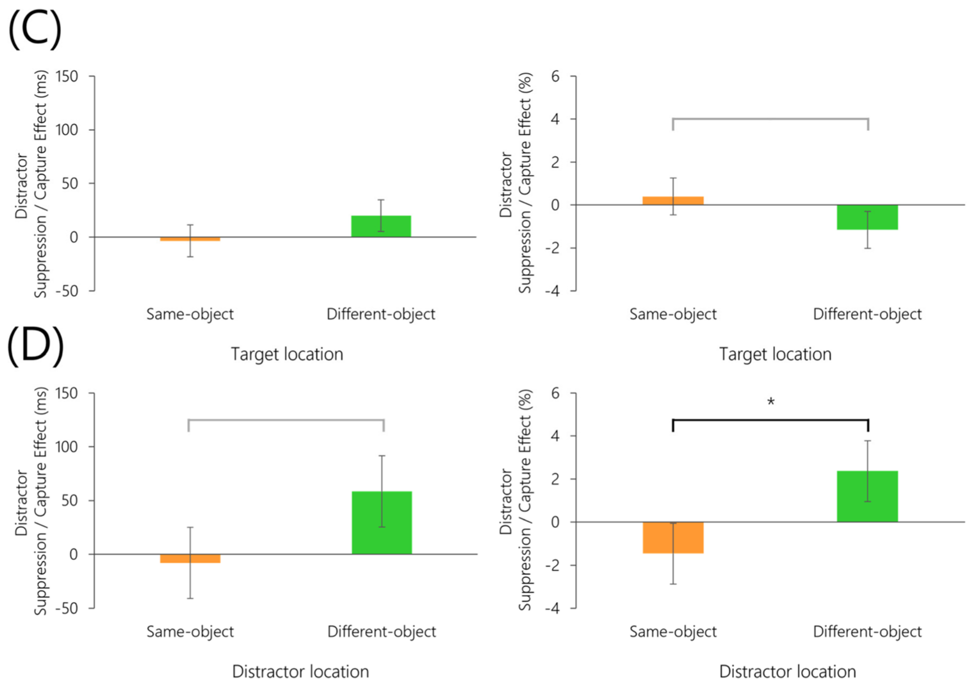

Fig. 12 Distractor capture/suppression effects in reaction time (RT) and percent error (PE) in Experiment 3. (**C**) Distractor capture effects in trials where the distractor appeared at the high-probability location as a function of target locations. (**D**) Distractor capture effects in trials where the target appeared at the high-probability location as a function of distractor locations. Error bars indicate 95% confidence intervals for the mean (Loftus & Masson, 1994)

at the high-probability location (M = 981 ms) than at the same-object (M = 913 ms), $t(43) = 2.101$, $p = .042$, Cohen's $d = 0.317$, different-object (M = 981 ms), $t(43) = 2.170$, $p = .036$, Cohen's $d = 0.327$, and other low-probability locations (M = 886 ms), $t(43) = 2.493$, $p = .017$, Cohen's $d = 0.376$. However, no significant difference was found between the same-object and different-object locations, $t(43) = 0.004$, $p = .997$. The PE data showed no significant main effect of target location, $F(3, 129) = 1.324$, $p = .271$.

Effects of singleton distractor capture on target selection in distractor-present trials: On trials where distractors appeared at the high-probability location, the distractor suppression effect was observed when the target appeared at the same-object location (-3 ms) while distractors captured attention when targets were presented at the different-object location (20 ms), although this difference was not statistically significant, $t(43) = 1.55$, $p = .128$. For distractor capture effects in PE, there was a marginal difference between trials with the target at the same-object (0.39%) and different-object locations (-1.16%), $t(43) = 1.762$, $p = .085$, Cohen's $d = 0.266$.

When the target was presented at the high-probability location on distractor-present trials, singleton distractors were suppressed at the same-object location (-8 ms and -1.46%) while they captured attention at the different-object location (58 ms and 2.36%) with approaching significance in RT, $t(43) = 1.971$, $p = .055$, Cohen's $d = 0.297$, and significance in PE, $t(43) = 2.656$, $p = .011$, Cohen's $d = 0.4$. These results indicate that when searching for a non-singleton target at the most deprioritized location, the interference by singleton distractors was eliminated only at the same-object location compared to the interference at the different-object location.

Discussion

The purpose of Experiment 3 was to investigate whether attention to object-related features is necessary to incorporate object representation in computing attentional priority. Attention capture by singleton distractors was not modulated by the singleton distractor location, suggesting that statistical regularities and object representation did not influence attentional priorities in distractor inhibition. On the other hand, the impact of the target location on target selection efficiency was relatively limited. Target search was impeded at the high-probability location compared to the same-object and different-object locations, indicating a minimal effect from statistical regularities on target search. Importantly, however, there was no difference in the target selection efficiency between the same-object and different-object locations. This indicates that object representation did not affect attentional priorities in the target search process. Overall, the findings of Experiment 3 suggest that object representations influence target selection only when attention is allocated to object-related features (Lamy & Tsal, 2000, 2001).

Notably, the effects of statistical regularities on attentional suppression at the high-probability location were absent in the distractor inhibition process. Presumably, this lack of location-based suppression during distractor inhibition only is related to reduced attention capture by singleton distractors (Wang & Theeuwes, 2018c). Wang and Theeuwes showed that attention capture effects by singleton distractors were successfully eliminated at both high- and low-probability locations when searching for a target with a specific shape from different-shaped stimuli. Critically, however, the suppression of singleton distractors presented at the high-probability location was comparable to the suppression for singleton distractors at low-probability locations, showing no difference in the mean RTs and only a marginal difference in the PEs between the high- and low-probability locations. In contrast, target selection was substantially more delayed when targets were displayed at the high- than at the low-probability locations. Considering that participants were asked to search for a target with a specific orientation from lines with diverse orientations in the current experiment, distractor inhibition was not affected by statistical regularities because of the lack of attention capture by singleton distractors.

The analyses of the impact of singleton distractor capture on target selection suggest that attentional capture or suppression was influenced by object representation only in specific combinations of distractor-target locations. The results demonstrated that the target selection at the same-object location tended to be less accurate than at the different-object location, suggesting that the same-object location was less suppressed than the different-object location. However, examining the contrasting trends of suppression between RT and PE in Experiment 3, as opposed to consistent trends in Experiments 1 and 2, it raises the possibility of speed-accuracy tradeoff due to the quicker release of attentional suppression at the same-object location. To address this possibility, we calculated the Inverse Efficiency Score (IES, calculated by RT / (1-PE/100) in each condition for each participant) for the distractor capture effects at the high-probability location between the two target locations. Upon analysis, there was no significant difference in target selection when the target appeared at the same-object (2) and different-object locations (8), $t(43) = 0.296$, $p = .768$, Cohen's $d = 0.045$. These results indicate that the capture by a singleton distractor at the high-probability location had a limited effect on target selection at both the same- and different-object locations.

In contrast, when the target appeared at the high-probability location, the distractor at the same-object location was more effectively suppressed than at the different-object location, as observed in Experiment 2. Notably in Experiment 3, the physical salience of singleton distractors was effectively inhibited at the same-object location when overcoming the learned spatial priority was crucial for successful target selection. In other words, a singleton-presence benefit was induced when the distractor appeared at the same-object location but not when it appeared at the different-object location. This finding can be attributed to the task which requires searching for a specific target orientation that does not 'stand out' from other stimuli and differs in featural dimension from the singleton distractor item. When the 'singleton' feature of an item does not provide useful information for target selection, the singleton presence cost is eliminated, and a singleton presence benefit is induced in distractor-present trials compared to distractor-absent trials (Wang & Theeuwes, 2018c).

The object information involved in reshaping the spatial priority map downregulated the priority at the same-object location to an extent that surpasses the impact of the distractors' physical salience. Since object-based suppression was not observed in target selection during distractor-absent trials in Experiment 3, it can be inferred that the presence of singleton distractors causes active inhibition that is modulated by object representations. Taken together, the current experiment demonstrates that attention towards the object-related feature was essential for object-based suppression in the absence of singleton distractors. When the distractors were present, however, they were effectively inhibited at the same-object location, preventing capture during target search while overcoming learned spatial probabilities.

General discussion

The present study investigated the effect of object representation on attentional suppression in distractor inhibition and target search processes. In three experiments that used a modified additional singleton paradigm, attentional suppression was induced by biasing the spatial probabilities of color singleton distractors at the high-probability location. Object representations were created by pairing two stimuli using physical boundaries (Experiment 1) or perceptual grouping (Experiments 2 and 3). Attention capture by singleton distractors and target search efficiency were measured to examine distractor inhibition and target selection in each stimulus location. Statistical regularities and object representations had separate effects on distractor inhibition and target search processes, respectively, in Experiments 1 and 2. Specifically, the modulation of attentional priority during target search was influenced by object representations, with no impact on distractor inhibition. In Experiment 2, both types of processing were influenced by statistical regularities. Finally, attentional allocation to object-defining features was shown to be critical for object representation to exert its influence on attentional priority in Experiment 3. Furthermore, in the suppression of the singleton distractor at the high-probability location, there was no significant difference in suppression between the location within the same object and a different object. However, overcoming the statistically learned suppression to find the target indicated the utilization of object information in the reconfiguration of attentional priorities. Together, these findings provide evidence supporting the involvement of object representation in determining attentional priority, emphasizing the role of different features in diverse cognitive processes.

Dissociating distractor inhibition and target search

The findings of the current study, demonstrating an object-based suppression effect during target selection but not during distractor inhibition, align with previous research using the two-rectangle paradigm, which failed to observe object-based effects when the probability of the target location was concentrated at a specific location (Drummond & Shomstein, 2010; Shomstein & Yantis, 2004). This lack of effect was attributed to the efficient allocation of attentional resources of our visual system to available sources of information. When information about the statistical regularity of target locations reduces uncertainty in target search, it efficiently guides attention, thereby diminishing the influence of object representation. Alternatively, when uncertainty persists, attention integrates all available information in the scene, including object representations (Shomstein, 2012; Shomstein & Yantis, 2002).

The role of object representations in this study can be elucidated in a similar way. During distractor inhibition, attention is efficiently guided away from the high-probability distractor location by the learned statistical regularities associated with them (Failing et al., 2019; Wang & Theeuwes, 2018a, 2018b, 2018c). In such a case, the predictability of distractor appearance at a specific location, and subsequently the lower probability of targets appearing there, reduce the uncertainty regarding where to allocate attentional resources (Ferrante et al., 2018; Geng et al., 2019). These processes could lead to minimal roles of object representations in influencing attentional priority. On the contrary, when the probability of target appearance is uniform across all locations during distractor-absent trials (Goldsmith & Yeari, 2003), the uncertainty regarding possible target locations increases (Hirsh et al., 2012). This encourages the utilization and integration of object information into attentional priority configuration (Van Moorselaar & Theeuwes, 2023; Van Moorselaar & Theeuwes, 2024), leading to object-based effects in which suppression at the high-probability distractor location downregulates the same-object location more than the different-object location. Essentially, when relying on spatial probability information of distractors proved inefficient for task performance, object information comes into play in computing attentional priorities. This engagement allows the visual system to optimize the utilization of available visual information (Lee et al., 2012; Vatterott et al., 2018; Wolfe et al., 1989).

Regarding the nature of suppression in distractor inhibition and target search processes, previous studies that examined location-based suppression have used attention capture by singleton distractors and target selection efficiency together as indicators of suppression. Many of those studies have yielded a consistent "spatial gradient" in both attention capture by singleton distractors and target search efficiency (Failing et al., 2019; Wang & Theeuwes, 2018a, 2018b, 2018c). Contrary to these findings, the present study demonstrated the impact of object-based suppression on target search efficiency but not on attention capture by singleton distractors.

It is noteworthy that not all studies that used biased statistical regularities of distractor location showed consistent location-based suppression in both the attention capture by distractors and target selection. Lin et al. (2021) varied the ratio of a singleton distractor appearing at the high- and low-probability locations (high-low ratio) from 2:1 to 8:1. A suppression effect at the high-probability location was obtained in both the attention capture by distractors and target selection when the high-low ratio was 8:1. However, the suppression effect was present only in the attention capture by distractors when the ratio was lower than 8:1. These findings imply that in order for location-based statistical learning to induce a suppression effect in both attention capture by singleton distractors and target selection, a substantial high-low ratio is necessary. Van Moorselaar and Theeuwes (2022) also found that the probabilities of singleton distractor locations did not affect target detection when no singleton distractor was presented. Their high-low probability ratio was 13:1, which was identical to that of Wang and Theeuwes (2018a, 2018b, 2018c). Based on these findings, Van Moorselaar and Theeuwes suggested the possibility that a spatial priority map that reflected the frequencies of singleton distractor locations was established but that the map was not utilized in target detection when no singleton distractor was presented.

According to the findings of Lin et al. (2021), the high-low ratio of 9:1 used in the present study is sufficient to induce a clear suppression effect both in attention capture by singleton distractors and target selection. In addition, attention capture by singleton distractors was strongly modulated by the statistical regularities of singleton distractor location. Thus, it is reasonable to infer that location-based suppression acted in the target search process, which was strong enough to induce a significant difference between the high- and low-probability locations in Experiments 1 and 2.

The question remains why the locational bias of singleton distractors did not influence target selection in Experiment 1. The most plausible explanation is that some factors other than statistical regularities were involved in computing attentional priority. These factors attenuated the downregulation at the high-probability location in the spatial priority map. The only critical difference between Experiment 1 and Wang and Theeuwes' (2018a) experiment was the presence of object representations; therefore, it is reasonable to assume that participants utilized the object information when searching for targets. As a result, this considerably decreased the effects of statistical regularities at the high-probability location during target selection. Although the mean RTs and PEs in target search efficiency were not modulated by the target location, there was a tendency that is consistent with the results for distractor interference. This could have been due to the influence of the statistical regularities on the spatial priority map. In addition, the comparison between the high-probability location and the different-object location, which was marginally significant in both mean RT and PE in Experiment 1, indicates a limited effect of object representation. These findings are consistent with the idea that object representations are involved in computing attentional priority during target search (Fecteau & Munoz, 2006; Greenberg et al., 2015).

Different features associated with attentional priorities in distractor inhibition and target search processes are in accordance with findings in neuroscience research suggesting that different cognitive mechanisms are involved in target facilitation and distractor suppression (Noonan et al., 2016). In their experiment, Noonan and colleagues used a modified Posner cuing paradigm, where cues predicted either the location of an upcoming target or distractor or provided no information. The cued locations varied from trial to trial in the flexible condition, while they remained fixed throughout a block in the blocked condition. Participants were able to use a target cue to facilitate target processing in both the blocked and flexible conditions, but a distractor cue was only effective in the blocked condition. According to Noonan et al., these findings suggest that effective suppression of distractors depends on a reliable prediction of distractor locations and/or previous experiences. Moreover, electroencephalography (EEG) data showed that preparatory distractor suppression was associated with a diminished P1. This reduction of the P1 component was not mediated by target cuing, which was associated with oscillatory activity in the alpha band. Based on these results, Noonan et al. concluded that the inhibition of distractors is not governed by the same top-down control mechanisms as those involved in target processing. Consistent with this view, the findings that object representations were employed for target selection but not for distractor inhibition imply that visual information is flexibly used to allocate attention only in target search, though object representation remained consistent across trials in the present study.

Object and attentional suppression

The current study demonstrated that object-defining features relevant to the task are important in establishing object representations that can influence spatial priority. Similarly, Lamy and Tsal (2000) found that the cued location was attended regardless of whether space was task-relevant or not, whereas the features of the cued object, such as the color and form, were attended only when these features were task-relevant (Table 7). The finding that attention plays an important role in utilizing object information throughout a task aligns with the feature integration theory (FIT). According to the FIT, attention binds different features together, and only individual parts and properties are perceived without attention (Treisman & Gelade, 1980). In a visual search task, individual features at a location are initially processed automatically and in parallel; then, those features are bound into a coherent object when their location is attended (Treisman, 1998).

When searching for targets, attentional resources are required to find and process task-relevant features (Folk et al., 1992). This joins multiple features including the statistical regularities of singleton distractor locations (Luck et al., 2021) that are processed at the corresponding locations into coherent representations (Kristjansson & Egeth, 2020; Martinez et al., 2006; Treisman & Gormican, 1988). Crucially, when task-relevant features are also object-relevant, attention to task-relevant features associates object representations with spatial probabilities of singleton distractors and other locational features (Baker et al., 2004; Lamy & Tsal, 2000). Consequently, spatial priority reflecting statistical regularities is reconfigured in an object-based manner (Van Moorselaar & Theeuwes, 2023), deprioritizing same-object

Table 7 Task-relevant, task-irrelevant, and object-related features in Experiments 1, 2, and 3

	Task-relevant feature	Task-irrelevant feature	Object-related feature
Exp. 1	item shape	item color	round-edged rectangles
Exp. 2	item shape	item color	item shape
Exp. 3	line orientation	item color	item shape

locations more than different-object locations as in Experiment 2 and guiding subsequent target selections. The degree of object-based effect may differ depending on how much object representations are informative or salient in the target search (Al-Janabi & Greenberg, 2016; Fecteau & Munoz, 2006; Shomstein, 2012), as in Experiments 1 and 3.

Distractor inhibition, on the other hand, accompanies drawing attention away from task-irrelevant features in nature (Wang & Theeuwes, 2018a). Thus, inhibition of distractors with salient task-irrelevant features seems to occur before the features at the corresponding location are bound into an item (Moore et al., 1998). If distractor inhibition took place after feature integration, spatial probabilities of singleton distractors would have been bound with item shapes that form an object representation, allowing the object representation to affect distractor inhibition. However, the effect of object representation on attention capture by singleton distractors was not found in any experiments in the present study. Taken together, the inhibition of singleton distractors occurs on the level of the task-irrelevant feature with the singleton feature value (Dent, 2023; Failing et al., 2019), and attention to task-relevant features plays an important role in comprehensively integrating features and object representations (Kristjansson & Egeth, 2020; Treisman, 1977).

Attentional priority map and object representation

Recently, Van Moorselaar and Theeuwes (2023) provided evidence for the impact of object representation on the attentional priority map. By repeatedly presenting targets at a particular location inside an object, which was either a shoe or a hammer, they induced an attentional bias towards that location. Then, attentional priority was assessed at the possible target locations within the object while the axis on which the object was presented varied so that the target locations were superimposed on spatial coordinates where no prior learning had occurred. The results revealed that spatial priorities learned within objects can be generalized to new locations where the learning did not occur when the object is repositioned. The researchers concluded that the attentional priority map is established only after the object has been identified and that the map associated with the object biases attention towards a particular location within the object.

While the object-based priority map was emphasized in Van Moorselaar and Theeuwes' (2023) study, no clear explanation was provided regarding how attentional priority is configured in an object-based way. The findings of the present study suggest a possibility that object representation can be devised into a map similar to other feature maps. Simply re-calculating spatial priorities on individual locations according to object representation cannot explain the disparity in priorities between different processes because object information is utilized only in some attentional processes and not in others. Introducing a separate map that reflects object representation makes it easy to account for the disparity between those processes. In fact, Van Moorselaar and Theeuwes (2022) used similar logic to account for the absence of location-based suppression in a visual detection task. The only difference is that the spatial priority map (instead of the object representation map) was suggested to have been omitted in the process of target detection only when a singleton distractor was not present.

Research in neuroscience and computational modeling also supports the differentiation between the object representation map and the spatial priority map. Spatial information is processed through the dorsal stream or "where" pathway, while object processing occurs via the ventral stream or "what" pathway in the brain (Duhamel et al., 1997; Goodale & Milner, 1992; Mishkin & Ungerleider, 1982; Ungerleider & Haxby, 1994). These distinct pathways collaborate to generate an attentional priority map (Van Moorselaar & Theeuwes, 2023; Van Moorselaar & Theeuwes, 2024). Furthermore, when viewing real-world images, object-based models incorporating object maps demonstrate greater efficacy in predicting attentional guidance than salience-based models using saliency maps (Stoll et al., 2015). Considering that weights on individual feature maps can be adjusted flexibly by soft feature attention (Lindsay, 2020), the potential exists to modulate the influence of an object map on attentional priority in accordance with different attentional processes.

Conclusion

The findings of the present study imply that object representations affect attentional priority by reconfiguring spatial priorities reflecting locational information, such as statistical regularities. Attention towards task-relevant and object-associated features is crucial for object information to exert an influence on target search but not distractor inhibition processes. Thus, the influence of an object on attention extends to suppression, and an attentional priority map established by taking these object representations into account is utilized flexibly in different cognitive processes.

Open Practices Statement The data and materials for all experiments are available at https://osf.io/zwea2/.

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Availability of data and materials The datasets analyzed during the current study are available in the "Object-based Suppression in Target Search but not in Distractor Inhibition" project, https://osf.io/zwea2/.

Declarations

Conflicts of interests The authors have no conflicts of interest to declare.

Ethics approval All experiments in this study were approved by the Institutional Review Board at Korea University (KUIRB-2022-0181-01). All necessary ethical considerations were addressed in accordance with institutional guidelines.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication Human research participants provided informed consent for publication.

References

Al-Janabi, S., & Greenberg, A. S. (2016). Target–object integration, attention distribution, and object orientation interactively modulate object-based selection. *Attention, Perception, & Psychophysics, 78*(7), 1968–1984. https://doi.org/10.3758/s13414-016-1126-3

Anderson, B. A., Kim, H., Kim, A. J., Liao, M.-R., Mrkonja, L., Clement, A., & Grégoire, L. (2021). The past, present, and future of selection history. *Neuroscience & Biobehavioral Reviews, 130*, 326–350. https://doi.org/10.1016/j.neubiorev.2021.09.004

Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences, 108*(25), 10367–10371. https://doi.org/10.1073/pnas.1104047108

Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: a failed theoretical dichotomy. *Trends in Cognitive Sciences, 16*(8), 437–443. https://doi.org/10.1016/j.tics.2012.06.010

Bae, G.-Y., Olkkonen, M., Allred, S. R., & Flombaum, J. I. (2015). Why some colors appear more memorable than others: A model combining categories and particulars in color working memory. *Journal of Experimental Psychology: General, 144*(4), 744–763. https://doi.org/10.1037/xge0000076

Baker, C. I., Olson, C. R., & Behrmann, M. (2004). Role of attention and perceptual grouping in visual statistical learning. *Psychological Science, 15*(7), 460–466. https://doi.org/10.1111/j.0956-7976.2004.00702.x

Barnas, A. J., & Greenberg, A. S. (2016). Visual field meridians modulate the reallocation of object-based attention. *Attention, Perception, & Psychophysics, 78*(7), 1985–1997. https://doi.org/10.3758/s13414-016-1116-5

Cave, K. R., & Bichot, N. P. (1999). Visuospatial attention: Beyond a spotlight model. *Psychonomic Bulletin & Review, 6*, 204–223. https://doi.org/10.3758/BF03212327

Chen, Z. (2012). Object-based attention: A tutorial review. *Attention, Perception, & Psychophysics, 74*(5), 784–802. https://doi.org/10.3758/s13414-012-0322-z

Chen, Z., & Cave, K. R. (2019). When is object-based attention not based on objects? *Journal of Experimental Psychology: Human Perception and Performance, 45*(8), 1062–1082. https://doi.org/10.1037/xhp0000657

Chou, W.-L., & Yeh, S.-L. (2018). Dissociating location-based and object-based cue validity effects in object-based attention. *Vision Research, 143*, 34–41. https://doi.org/10.1016/j.visres.2017.11.008

Chun, M. M., & Jiang, Y. (1999). Top-down attentional guidance based on implicit learning of visual covariation. *Psychological Science, 10*(4), 360–365. https://doi.org/10.1111/1467-9280.00168

Cosman, J. D., & Vecera, S. P. (2014). Establishment of an attentional set via statistical learning. *Journal of Experimental Psychology: Human Perception and Performance, 40*(1), 1–6. https://doi.org/10.1037/a0034489

Dent, K. (2023). On the role of top-down and bottom-up guidance in conjunction search: Singleton interference revisited. *Attention, Perception, & Psychophysics, 85*(6), 1784–1810. https://doi.org/10.3758/s13414-023-02691-8

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*, 193–222. https://doi.org/10.1146/annurev.ne.18.030195.001205

Drummond, L., & Shomstein, S. (2010). Object-based attention: Shifting or uncertainty? *Attention, Perception & Psychophysics, 72*(7), 1743–1755. https://doi.org/10.3758/app.72.7.1743

Duhamel, J. R., Bremmer, F., Ben Hamed, S., & Graf, W. (1997). Spatial invariance of visual receptive fields in parietal cortex neurons. *Nature, 389*(6653), 845–848. https://doi.org/10.1038/39865

Egeth, H. E., & Yantis, S. (1997). Visual attention: Control, representation, and time course. *Annual Review of Psychology, 48*(1), 269–297. https://doi.org/10.1146/annurev.psych.48.1.269

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123*(2), 161–177. https://doi.org/10.1037//0096-3445.123.2.161

Failing, M., Feldmann-Wüstefeld, T., Wang, B., Olivers, C., & Theeuwes, J. (2019). Statistical regularities induce spatial as well as feature-specific suppression. *Journal of Experimental Psychology: Human Perception and Performance, 45*(10), 1291–1303. https://doi.org/10.1037/xhp0000660

Farah, M. J., Wallace, M. A., & Vecera, S. P. (1993). "What" and "where" in visual attention: Evidence from the neglect syndrome. In I. H. Robertson & J. C. Marshall (Eds.), *Unilateral neglect: Clinical and experimental studies* (pp. 123–137). Lawrence Erlbaum Associates Inc.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Fecteau, J. H., & Munoz, D. P. (2006). Salience, relevance, and firing: a priority map for target selection. *Trends in Cognitive Sciences, 10*(8), 382–390. https://doi.org/10.1016/j.tics.2006.06.011

Ferrante, O., Patacca, A., Di Caro, V., Della Libera, C., Santandrea, E., & Chelazzi, L. (2018). Altering spatial priority maps via statistical learning of target selection and distractor filtering. *Cortex, 102*, 67–95. https://doi.org/10.1016/j.cortex.2017.09.027

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 1030–1044. https://doi.org/10.1037/0096-1523.18.4.1030

Geng, J. J., Won, B.-Y., & Carlisle, N. B. (2019). Distractor Ignoring: Strategies, Learning, and Passive Filtering. *Current Directions in Psychological Science, 28*(6), 600–606. https://doi.org/10.1177/0963721419867099

Goldsmith, M., & Yeari, M. (2003). Modulation of object-based attention by spatial focus under endogenous and exogenous orienting. *Journal of Experimental Psychology: Human Perception and Performance, 29*(5), 897–918. https://doi.org/10.1037/0096-1523.29.5.897

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15*(1), 20–25. https://doi.org/10.1016/0166-2236(92)90344-8

Gouras, P. (2002). Color Processing and Color Processing Disorders. In V. S. Ramachandran (Ed.), *Encyclopedia of the Human Brain* (pp. 1–14). Academic Press. https://doi.org/10.1016/B0-12-227210-2/00103-5

Greenberg, A. S., Rosen, M., Cutrone, E., & Behrmann, M. (2015). The effects of visual search efficiency on object-based attention. *Attention, Perception, & Psychophysics, 77*(5), 1544–1557. https://doi.org/10.3758/s13414-015-0892-7

He, X., Humphreys, G., Fan, S., Chen, L., & Han, S. (2008). Differentiating spatial and object-based effects on attention: An event-related brain potential study with peripheral cueing. *Brain Research, 1245*, 116–125. https://doi.org/10.1016/j.brainres.2008.09.092

Hirsh, J. B., Mar, R. A., & Peterson, J. B. (2012). Psychological entropy: A framework for understanding uncertainty-related anxiety. *Psychological review, 119*(2), 304–320. https://doi.org/10.1037/a0026767

Huang, Z., & Li, S. (2023). Learned low priority of attention after training to suppress color singleton distractor. *Attention, Perception, & Psychophysics, 85*(3), 814–824. https://doi.org/10.3758/s13414-022-02571-7

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience, 2*(3), 194–203. https://doi.org/10.1038/35058500

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics, 43*(4), 346–354. https://doi.org/10.3758/BF03208805

Jordan, H., & Tipper, S. P. (1998). Object-based inhibition of return in static displays. *Psychonomic Bulletin & Review, 5*, 504–509. https://doi.org/10.3758/BF03208829

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual Organization* (pp. 181–211). Lawrence Erlbaum Associates.

Kimchi, R., Yeshurun, Y., & Cohen-Savransky, A. (2007). Automatic, stimulus-driven attentional capture by objecthood. *Psychonomic Bulletin & Review, 14*(1), 166–172. https://doi.org/10.3758/bf03194045

Kong, S., Li, X., Wang, B., & Theeuwes, J. (2020). Proactively location-based suppression elicited by statistical learning. *PLOS ONE, 15*(6), e0233544. https://doi.org/10.1371/journal.pone.0233544

Kristjansson, A., & Egeth, H. (2020). How feature integration theory integrated cognitive psychology, neurophysiology, and psychophysics. *Attention, Perception, & Psychophysics, 82*(1), 7–23. https://doi.org/10.3758/s13414-019-01803-7

Lamy, D., & Egeth, H. (2002). Object-based selection: The role of attentional shifts. *Perception & Psychophysics, 64*(1), 52–66. https://doi.org/10.3758/bf03194557

Lamy, D., & Tsal, Y. (2000). Object features, object locations, and object files: Which does selective attention activate and when? *Journal of Experimental Psychology: Human Perception and Performance, 26*, 1387–1400. https://doi.org/10.1037/0096-1523.26.4.1387

Lamy, D., & Tsal, Y. (2001). On the status of location in visual attention. *European Journal of Cognitive Psychology, 13*(3), 305–342. https://doi.org/10.1080/09541440125789

Lee, H., Mozer, M. C., Kramer, A. F., & Vecera, S. P. (2012). Object-based control of attention is sensitive to recent experience. *Journal of Experimental Psychology: Human Perception and Performance, 38*(2), 314–325. https://doi.org/10.1037/a0025597

Lin, R., Li, X., Wang, B., & Theeuwes, J. (2021). Spatial suppression due to statistical learning tracks the estimated spatial probability. *Attention, Perception, & Psychophysics, 83*(1), 283–291. https://doi.org/10.3758/s13414-020-02156-2

Lindsay, G. W. (2020). Attention in Psychology, Neuroscience, and Machine Learning. *Frontiers in Computational Neuroscience*, *14*. https://doi.org/10.3389/fncom.2020.00029

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review, 1*(4), 476–490. https://doi.org/10.3758/bf03210951

Lou, H., Lorist, M. M., & Pilz, K. S. (2023). Variability in the temporal dynamics of object-based attentional selection. *PLOS ONE, 18*(11), e0294252. https://doi.org/10.1371/journal.pone.0294252

Luck, S. J., Gaspelin, N., Folk, C. L., Remington, R. W., & Theeuwes, J. (2021). Progress toward resolving the attentional capture debate. *Visual Cognition, 29*(1), 1–21. https://doi.org/10.1080/13506285.2020.1848949

Marini, F., & Marzi, C. A. (2016). Gestalt perceptual organization of visual stimuli captures attention automatically: Electrophysiological evidence. *Frontiers in Human Neuroscience*, *10*. https://doi.org/10.3389/fnhum.2016.00446

Marino, A. C., & Scholl, B. J. (2005). The role of closure in defining the "objects" of object-based attention. *Perception & Psychophysics, 67*(7), 1140–1149. https://doi.org/10.3758/bf03193547

Martínez, A., Teder-Sälejärvi, W., Vazquez, M., Molholm, S., Foxe, J. J., Javitt, D. C., Di Russo, F., Worden, M. S., & Hillyard, S. A. (2006). Objects Are Highlighted by Spatial Attention. *Journal of Cognitive Neuroscience, 18*(2), 298–310. https://doi.org/10.1162/jocn.2006.18.2.298

Mishkin, M., & Ungerleider, L. G. (1982). Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys. *Behavioural Brain Research, 6*(1), 57–77. https://doi.org/10.1016/0166-4328(82)90081-X

Moore, C. M., Yantis, S., & Vaughan, B. (1998). Object-based visual selection: Evidence from perceptual completion. *Psychological Science, 9*(2), 104–110. https://doi.org/10.1111/1467-9280.00019

Nah, J. C., Neppi-Modona, M., Strother, L., Behrmann, M., & Shomstein, S. (2018). Object width modulates object-based attentional selection. *Attention, Perception, & Psychophysics, 80*(6), 1375–1389. https://doi.org/10.3758/s13414-018-1530-y

Nah, J. C., & Shomstein, S. (2020). Target frequency modulates object-based attention. *Psychonomic Bulletin & Review, 27*(5), 981–989. https://doi.org/10.3758/s13423-020-01746-3

Noonan, M. P., Adamian, N., Pike, A., Printzlau, F., Crittenden, B. M., & Stokes, M. G. (2016). Distinct mechanisms for distractor suppression and target facilitation. *The Journal of Neuroscience, 36*(6), 1797–1807. https://doi.org/10.1523/jneurosci.2133-15.2016

Pilz, K. S., Roggeveen, A. B., Creighton, S. E., Bennett, P. J., & Sekuler, A. B. (2012). How prevalent is object-based attention? *PLOS ONE, 7*(2), e30693. https://doi.org/10.1371/journal.pone.0030693

Scholl, B. J. (2001). Objects and attention: the state of the art. *Cognition, 80*(1), 1–46. https://doi.org/10.1016/S0010-0277(00)00152-9

Sereno, A. B., & Kosslyn, S. M. (1991). Discrimination within and between hemifields: A new constraint on theories of attention. *Neuropsychologia, 29*(7), 659–675. https://doi.org/10.1016/0028-3932(91)90100-M

Shomstein, S. (2012). Object-based attention: strategy versus automaticity. *WIREs Cognitive Science, 3*(2), 163–169. https://doi.org/10.1002/wcs.1162

Shomstein, S., & Behrmann, M. (2008). Object-based attention: Strength of object representation and attentional guidance. *Perception & Psychophysics, 70*(1), 132–144. https://doi.org/10.3758/pp.70.1.132

Shomstein, S., & Yantis, S. (2002). Object-based attention: Sensory modulation or priority setting? *Perception & Psychophysics, 64*(1), 41–51. https://doi.org/10.3758/BF03194556

Shomstein, S., & Yantis, S. (2004). Configural and contextual prioritization in object-based attention. *Psychonomic Bulletin & Review, 11*(2), 247–253. https://doi.org/10.3758/BF03196566

Stoll, J., Thrun, M., Nuthmann, A., & Einhäuser, W. (2015). Overt attention in natural scenes: Objects dominate features. *Vision*

Research, 107, 36–48. https://doi.org/10.1016/j.visres.2014.11.006

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics, 51*(6), 599–606. https://doi.org/10.3758/BF03211656

Theeuwes, J., Bogaerts, L., & Van Moorselaar, D. (2022). What to expect where and when: how statistical learning drives visual selection. *Trends in Cognitive Sciences, 26*(10), 860–872. https://doi.org/10.1016/j.tics.2022.06.001

Theeuwes, J., Mathôt, S., & Kingstone, A. (2010). Object-based eye movements: The eyes prefer to stay within the same object. *Attention, Perception, & Psychophysics, 72*(3), 597–601. https://doi.org/10.3758/APP.72.3.597

Tipper, S. P. (1985). The Negative Priming Effect: Inhibitory Priming by Ignored Objects. *The Quarterly Journal of Experimental Psychology A, 37A*(4), 571–590. https://doi.org/10.1080/14640748508400920

Tipper, S. P., Brehaut, J. C., & Driver, J. (1990). Selection of moving and static objects for the control of spatially directed action. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 492–504. https://doi.org/10.1037/0096-1523.16.3.492

Tipper, S. P., Driver, J., & Weaver, B. (1991). Object-centred inhibition of return of visual attention. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 43A*, 289–298. https://doi.org/10.1080/14640749108400971

Tipper, S. P., Weaver, B., Jerreat, L. M., & Burak, A. L. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 20*(3), 478–499. https://doi.org/10.1037/0096-1523.20.3.478

Treisman, A. (1977). Focused attention in the perception and retrieval of multidimensional stimuli. *Perception & Psychophysics, 22*(1), 1–11. https://doi.org/10.3758/BF03206074

Treisman, A. (1998). Feature binding, attention and object perception. *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences, 353*(1373), 1295–1306. https://doi.org/10.1098/rstb.1998.0284

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*(1), 97–136. https://doi.org/10.1016/0010-0285(80)90005-5

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: evidence from search asymmetries. *Psychological Review, 95*(1), 15–48. https://doi.org/10.1037/0033-295x.95.1.15

Ungerleider, L. G., & Haxby, J. V. (1994). 'What' and 'where' in the human brain. *Current Opinion in Neurobiology, 4*(2), 157–165. https://doi.org/10.1016/0959-4388(94)90066-3

Valdes-Sosa, M., Bobes, M. A., Rodriguez, V., & Pinilla, T. (1998). Switching attention without shifting the spotlight object-based attentional modulation of brain potentials. *Journal of Cognitive Neuroscience, 10*(1), 137–151. https://doi.org/10.1162/089892998563743

Van Moorselaar, D., & Theeuwes, J. (2022). Spatial suppression due to statistical regularities in a visual detection task. *Attention, Perception, & Psychophysics, 84*(2), 450–458. https://doi.org/10.3758/s13414-021-02330-0

Van Moorselaar, D., & Theeuwes, J. (2023). Statistical learning within objects. *Psychological Science, 34*(4), 501–511. https://doi.org/10.1177/09567976231154804

Van Moorselaar, D., & Theeuwes, J. (2024). Spatial transfer of object-based statistical learning. *Attention, Perception, & Psychophysics.* https://doi.org/10.3758/s13414-024-02852-3

Vatterott, D. B., Mozer, M. C., & Vecera, S. P. (2018). Rejecting salient distractors: Generalization from experience. *Attention, Perception, & Psychophysics, 80*(2), 485–499. https://doi.org/10.3758/s13414-017-1465-8

Wang, B., & Theeuwes, J. (2018a). Statistical regularities modulate attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 44*(1), 13–17. https://doi.org/10.1037/xhp0000472

Wang, B., & Theeuwes, J. (2018b). How to inhibit a distractor location? Statistical learning versus active, top-down suppression. *Attention, Perception, & Psychophysics, 80*(4), 860–870. https://doi.org/10.3758/s13414-018-1493-z

Wang, B., & Theeuwes, J. (2018c). Statistical regularities modulate attentional capture independent of search strategy. *Attention, Perception, & Psychophysics, 80*(7), 1763–1774. https://doi.org/10.3758/s13414-018-1562-3

Wolfe, J. M. (1994). Guided Search 2.0 A revised model of visual search. *Psychonomic Bulletin & Review, 1*(2), 202–238. https://doi.org/10.3758/bf03200774

Wolfe, J. M. (2021). Guided Search 6.0: An updated model of visual search. *Psychonomic Bulletin & Review, 28*(4), 1060–1092. https://doi.org/10.3758/s13423-020-01859-9

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception and Performance, 15*(3), 419–433. https://doi.org/10.1037/0096-1523.15.3.419

Wolfe, J. M., & Horowitz, T. S. (2017). Five factors that guide attention in visual search. *Nature Human Behaviour, 1*(3), 0058. https://doi.org/10.1038/s41562-017-0058

Won, B.-Y., Kosoyan, M., & Geng, J. J. (2019). Evidence for second-order singleton suppression based on probabilistic expectations. *Journal of Experimental Psychology: Human Perception and Performance, 45*(1), 125–138. https://doi.org/10.1037/xhp0000594

Yantis, S., & Johnson, D. N. (1990). Mechanisms of attentional priority. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 812–825. https://doi.org/10.1037/0096-1523.16.4.812