Semantic Association-Based Attentional Orienting: Spatial Inhibition and Capture

Authors: Wang Huiyuan, Chen Airui, Zhang Ming, Wang Huiyuan, Zhang Ming

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Abstract

Employing a cueing paradigm, this study established semantic associations between cues and targets through three experiments to investigate the attentional orienting effects of semantic cues at different spatial locations. Results demonstrated inhibition effects in the lower visual field, with more pronounced inhibition at lower locations; capture effects in the upper visual field, with more significant capture at higher locations; and that the degree of attentional orienting effect was influenced by the properties of the guiding cues. These findings indicate that: (1) semantic associations between objects can guide visual spatial attention, producing attentional orienting effects at different spatial locations; (2) object properties can influence semantic association-driven attentional orienting, such that higher object vividness corresponds to stronger modulatory ability, while higher object abstractness corresponds to weaker modulatory ability; and (3) attentional orienting via semantic associations exhibits systematic variation, manifesting as inhibition and capture effects based on spatial location.

Full Text

Meaningful Contingent Attentional Orienting Effects: Spatial Location-Based Inhibition and Capture

WANG Huiyuan[1], **CHEN Airui**[2], **ZHANG Ming**[3]
([1] Department of Psychology, Changchun Normal University, Changchun 130032, China)
([2] Department of Psychology, Suzhou University of Science and Technology, Suzhou 215009, China)
([3] Department of Psychology, Soochow University, Suzhou 215123, China)

Abstract

Using a cuing paradigm, three experiments established meaningful associations between cues and targets to examine attentional orienting effects induced by meaningful cues at different spatial locations. The results demonstrated inhibition effects in the lower visual field that became more pronounced with increasing eccentricity, and capture effects in the upper visual field that became more pronounced with higher positions. Additionally, the magnitude of attentional orienting effects was influenced by the nature of the cue stimuli. These findings indicate that: (1) meaningful associations between objects can guide visuospatial attention, manifesting as distinct attentional orienting effects across spatial locations; (2) object properties modulate meaning-based attentional orienting, with more vivid objects exerting stronger modulatory capacity and more abstract objects showing weaker modulation; and (3) meaning-based attentional orienting exhibits systematic variation across space, characterized by location-dependent inhibition and capture effects.

Keywords: meaningful association; attentional orienting; spatial location; inhibition; capture

Introduction

In daily life, we encounter diverse information but cannot and need not process all of it. Instead, we consciously or unconsciously select certain information for deeper processing based on specific criteria. The attentional orienting system guides psychological processing of objects and environments through two primary pathways. One pathway is determined by stimulus properties and operates independently of volitional control—for instance, a sudden loud noise outside a window involuntarily draws our attention outward. This represents a bottom-up, exogenous, stimulus-driven orienting process (Posner & Snyder, 1975; Jonides, 1981). The alternative pathway is governed by intention or task strategy, such as reading in a noisy environment, representing a top-down, endogenous, goal-driven orienting process. Generally, bottom-up orienting is considered resource-independent, unaffected by expectations or working memory load, operating without conscious participation and resistant to inhibition. In contrast, top-down orienting is resource-limited, influenced by expectations and working memory load, requiring conscious participation and susceptible to inhibition.

Research on attentional orienting systems predominantly employs the cuing paradigm to reveal how unexpected objects guide attention. In this paradigm, a cue object appears before the target object, with both appearing randomly at locations in the visual field. When they appear at the same location, this constitutes a valid cue condition; when at different locations, an invalid cue condition. Classic findings show that with short cue-target stimulus onset asynchrony (SOA < 200 ms), valid cues produce faster responses than invalid cues, reflecting facilitation or capture effects. Researchers interpret this as the cue attracting attention to its location, enabling rapid responses when the target appears there. With longer SOAs (> 300 ms), valid cues produce slower responses than invalid cues, reflecting inhibition effects. This is attributed to inhibition of reorienting attention back to the cued location, thereby optimizing visual search (Posner & Cohen, 1984).

Research indicates that an object’ s ability to capture attention is not determined solely by its features; attentional control settings play a crucial role. Only objects matching observers’ mental preparedness can potentially attract attention, leading to the concept of contingent or conditional attentional capture (Folk et al., 1992). This suggests that the information carried by objects is critically important—when objects possess meaningful information that matches observers’ needs, they receive greater attention and demonstrate their value. Early research focused primarily on relationships between information properties (e.g., color, motion) and task demands (Folk et al., 1992, 1994; Huang et al., 2016). More recent work has increasingly examined how information meaning influences contingent attention. In real life, although most information is unpredictable and captures attention involuntarily, potentially attractive information is nevertheless related to observers’ preparatory states, as information better matching these states receives more attention. Studies have shown that when controlling for feature-based influences on attentional orienting, meaningful associations between objects and targets can still cause objects to attract attention and modulate attentional allocation (Goodhew et al., 2014; Sun et al., 2015; Wang et al., 2018). Additionally, when objects appear as distractors, they can be strategically inhibited if they relate to individual memory (Lu et al., 2017). Thus, meaningful information or meaningful associations between objects can influence visuospatial involuntary attentional shifts and allocation to some extent.

However, how do meaning-guided capture or inhibition effects distribute across visual space? Regarding visuospatial attention distribution, attentional resources are generally believed to gradually decrease from the attentional focus to peripheral locations, with response speed to targets depending on distance from the focus—closer locations yield faster responses, more distant locations slower responses (Eriksen & Murphy, 1987; Hollingworth et al., 2012). Compared to central locations, peripheral locations receive fewer attentional resources and thus exhibit more pronounced selective attention characteristics, such as greater inhibition effects than central locations (Bao et al., 2013). Research shows that socially meaningful stimuli like faces exhibit a more pronounced upper visual field advantage (Quek & Finkbeiner, 2016), though head orientation and gaze direction show inconsistent attentional guidance between upper and lower visual fields (Palanica & Itier, 2017). Additionally, holistic face processing shows left visual field advantages, while face target recognition shows upper visual field advantages (Carlei et al., 2017). Other researchers, by increasing stimulus size to alter salience, propose two attention allocation mechanisms: bottom-up, stimulus-driven allocation shows right visual field advantages, while top-down, subjectively influenced allocation shows left visual field advantages (Bergerbest et al., 2017).

Thus, the specific distribution of meaning-based attentional orienting in non-central locations remains unclear. As positions change at the same eccentricity, does attentional resource distribution vary, and what are the underlying patterns? Furthermore, research indicates that object properties influence attentional modulation—for example, Chinese characters attract more attention than pictures in visual processing, and color properties facilitate object recognition (Wurm et al., 1993; Guo et al., 2016). However, it remains unclear whether different object properties differentially modulate attentional allocation in semantic-level contingent attentional orienting tasks. Specifically, do picture-, Chinese character-, and color-guided meaning-based attentional orienting patterns differ within the same paradigm? Based on these considerations, the present research addresses meaning-based attentional orienting effects by examining: (1) how meaningful associations between objects guide attentional orienting; (2) how object properties influence meaning-based attentional orienting; and (3) comparisons of attentional allocation across multiple spatial locations. We employed a cuing paradigm to establish meaningful associations between cue and target objects, investigating how cue objects guide attentional orienting and exploring the spatial distribution patterns of meaning-based attentional orienting.

Experiment 1: Meaning-Based Attentional Orienting Guided by Sketch Cues

Using a cuing paradigm with strawberry and watermelon sketches as cue objects and red and green squares as target objects, we examined how typical red objects (strawberries) and typical green objects (whole watermelons) influence attentional selection when searching for red or green items. The experiment hypothesized that if attentional orienting effects (capture or inhibition) emerged, this would support meaning-level contingent attentional orienting theory. If attentional orienting effects varied by object location, this would indicate that contingent attentional resources distribute differently across spatial regions.

2.1.1 Participants

Sample size was calculated using G*Power software (Faul et al., 2007) for a repeated-measures ANOVA with factors of cue-target semantic consistency (consistent vs. inconsistent) × cue validity (valid vs. invalid) × cue location (upper, lower, left, right). With effect size f = 0.25, $\alpha = 0.05$, and power = 0.80, the required sample size was 26. We recruited 27 university students (18 female, 9 male) aged 20-25 years (M = 22.37, SD = 1.36). One participant was left-handed; all others were right-handed. All had normal or corrected-to-normal vision without color blindness. Participants received compensation after the experiment.

2.1.2 Apparatus

Stimuli were presented on a 14-inch color monitor with resolution of 1366$×$768 px and refresh rate of 60 Hz.

2.1.3 Materials

Three basic stimulus displays were used: fixation, cue, and target displays (see Figure 1 [Figure 1: see original paper]). The fixation display contained a central fixation cross (0.48°$×0.48°*visualangle*)*withfoursquares*(1.53°×$1.53°) positioned above, below, left, and right of center at 4.4° eccentricity. The fixation cross was white, squares were gray (RGB: 128, 128, 128), and the background was black. In the cue display, a sketch matching the square size randomly occupied one square position, depicting either a "strawberry" or "watermelon." The target display modified the fixation display by changing all squares to red (RGB: 255, 0, 0), green (RGB: 0, 255, 0), blue (RGB: 0, 0, 255), or yellow (RGB: 255, 255, 0) with random color assignment. Each square contained a gap on either its left or right side, with two gaps on each side.

2.1.4 Procedure

Participants were tested individually in a dimly lit room. After reading instructions, they sat 48 cm from the display. Each trial began with a 500 ms fixation display, followed by a 100 ms cue display. After cue offset, the fixation display reappeared for 100 ms, then the target display for 500 ms. The SOA from cue to target onset was 200 ms, a duration generally considered too brief for saccades to the cue or other locations (Colgate et al., 1973). With four possible locations, targets appeared at the cued location on 25% of trials (valid cues) and at uncued locations on 75% of trials (invalid cues). Participants were informed about the cue display but instructed to ignore it as task-irrelevant. Their task was to discriminate the gap location in the target square (red or green) as quickly and accurately as possible using both hands: left index finger pressed "Z" for left gaps, right index finger pressed "/" for right gaps. Trials without responses within 2000 ms were counted as errors. After a response or 2000 ms, an inter-trial interval of 1400–1600 ms blank screen preceded the next trial.

2.1.5 Design

A 2$×2×$4 within-subjects design was employed. The first factor was cue-target semantic consistency (consistent vs. inconsistent). For red targets, the typically red "strawberry" sketch was semantically consistent, while the typically green "watermelon" sketch was inconsistent; the reverse applied for green targets. The second factor was cue validity (valid vs. invalid). The third factor was cue location (upper, lower, left, right positions). To maximize establishment of attentional control settings for specific attributes, cue and target properties were presented in blocked design. With two cue types (strawberry and watermelon sketches) and two target types (red and green squares), four blocks were created in random order: strawberry-red target, strawberry-green target, watermelon-red target, and watermelon-green target blocks. Because cue and target were fixed within each block, participants knew which sketch and which color would appear. Each block contained 12 practice trials and 128 experimental trials divided into four sub-blocks with self-paced rest periods. The experiment lasted approximately 30 minutes.

2.2 Results and Analysis

Data from two participants with accuracy below 80% were excluded. Error trials and reaction times (RTs) beyond three standard deviations from each participant' s mean were removed (6.27% of data). Table 1 presents mean RTs and accuracy rates for all combinations of semantic consistency, cue validity, and cue location.

A repeated-measures ANOVA on RTs revealed a significant main effect of cue validity, $F(1, 24) = 38.83$, $p < 0.001$, $\mathrm{p}^2 = 0.62$, with faster responses to targets at cued locations (505.86 ms) than uncued locations (518.41 ms), 95% CI [8.39, 16.70]. Neither semantic consistency, $F(1, 24) = 0.07$, $p = 0.80$, $\mathrm{p}^2 = 0.003$, nor cue location, $F(3, 72) = 2.20$, $p = 0.10$, $\mathrm{p}^2 = 0.08$, showed significant main effects. The three-way interaction was not significant, $F(3, 72) = 0.33$, $p = 0.80$, $\mathrm{p}^2 = 0.01$.

Critically, the interaction between cue validity and cue location was significant, $F(3, 72) = 8.91$, $p < 0.001$, $\mathrm{p}^2 = 0.27$. Follow-up analyses showed that when cues appeared in the lower location, invalid cues produced faster responses than valid cues, $F(1, 24) = 5.84$, $p = 0.024$, $\mathrm{p}^2 = 0.20$, 95% CI [1.60, 20.37], indicating inhibition. For other locations, invalid cues produced slower responses than valid cues: left location, $F(1, 24) = 8.72$, $p = 0.007$, $\mathrm{p}^2 = 0.27$, 95% CI [5.09, 28.69]; right location, $F(1, 24) = 10.36$, $p = 0.004$, $\mathrm{p}^2 = 0.30$, 95% CI [6.13, 28.02]; upper location, $F(1, 24) = 28.26$, $p < 0.001$, $\mathrm{p}^2 = 0.54$, 95% CI [16.67, 37.82], indicating capture (see Figure 2 [Figure 2: see original paper]). No other two-way interactions were significant: semantic consistency × cue validity, $F(1, 24) = 0.27$, $p = 0.61$, $\mathrm{p}^2 = 0.01$; semantic consistency × cue location, $F(3, 72) = 2.16$, $p = 0.10$, $\mathrm{p}^2 = 0.08$. Target location showed no interactions with other factors, all $F\text{s} \leq 1.17$, $\mathrm{p}^2\text{s} \leq 0.05$, $p\text{s} \geq 0.31$.

An ANOVA on accuracy revealed a significant main effect of cue validity, $F(1, 24) = 7.95$, $p = 0.01$, $\mathrm{p}^2 = 0.25$, with higher accuracy for cued targets (95.00%) than uncued targets (93.30%), 95% CI [0.46%, 2.94%]. No other main effects or interactions were significant. Statistical power for all significant effects exceeded 0.95, with no speed-accuracy trade-offs, validating the RT analyses.

2.3 Discussion

Experiment 1 manipulated cue-target semantic consistency, cue validity, and cue location to examine how color-meaningful sketches modulated attentional selection across visual fields. Results showed that cue effects differed by location. Lower location cues produced inhibition, suggesting that locations marked by task-irrelevant but meaning-associated cues were suppressed, reducing allocated attentional resources and slowing responses when targets reappeared there. Cues in left, right, and upper locations produced capture effects, indicating these locations received more attention after cue presentation, facilitating rapid target identification. Simple effects tests showed consistent capture effects for left and right locations, with more pronounced capture in the upper location.

These results demonstrate that even task-irrelevant objects can modulate attentional allocation when they share meaningful associations with targets, supporting the contingent attentional orienting hypothesis and extending it to abstract meaning-level associations. The findings also reveal a vertical spatial gradient in meaning-based attentional orienting: lower visual field inhibition that diminishes with upward progression, with upper locations receiving more attentional resources.

The absence of interactions involving semantic consistency suggests two possible explanations. First, participants may have adopted attentional control settings based on display-wide visual features (Gibson & Kelsey, 1998; Burnham, 2007). Display-wide features characterize the entire target display as a task-relevant whole, where any feature property (whether belonging to targets or nontargets) signals task onset. In this experiment, both red and green appeared in the target display, making both potential display-wide features. Consequently, the typically red strawberry sketch and typically green watermelon sketch both gained attention-modulating capacity through their association with display-wide features, rendering semantic consistency irrelevant.

Alternatively, participants may have adopted a nonspecific attentional control setting based on general feature attributes (Folk & Remington, 1998; Folk & Anderson, 2010). Under such settings, all features within a general attribute category gain equivalent attention-modulating capacity. The task required searching for red or green, so participants may have adopted a color-based attentional control setting, giving both sketches equivalent semantic-level associational capacity. Regardless of which setting was adopted, the task was influenced by top-down factors guided by meaning associations, representing meaning-based attentional orienting.

Experiment 2: Meaning-Based Attentional Orienting Guided by Chinese Character Cues

To examine how cue property differences affect meaning-based attentional orienting, Experiment 2 used more abstract Chinese characters "红" (red) and "绿" (green) as cues, which maintain meaningful associations with red and green targets. Additionally, to more clearly depict attentional orienting trends across visual fields, possible locations increased from four to six. This experiment investigated how task-irrelevant but meaning-associated character cues guide attentional allocation. We hypothesized that attentional orienting effects would support meaning-level contingent attentional orienting theory. Different effect magnitudes from Experiment 1 would suggest cue properties modulate attentional resource allocation, and location-dependent effects would indicate differential distribution patterns of contingent attentional resources across spatial regions.

3.1.1 Participants

Sample size was calculated using G*Power for a 2 (semantic consistency) × 2 (cue validity) × 6 (cue location: upper, lower, upper-left, lower-left, upper-right, lower-right) repeated-measures ANOVA. With effect size* f* $= 0.25$, $\alpha = 0.05$, and power $= 0.80$, the required sample was 24. We recruited 22 university students (15 female, 7 male) aged 20–25 years (M = 22.23, SD = 1.31). Two were left-handed; all others were right-handed. All had normal or corrected-to-normal vision without color blindness. None had participated in similar experiments and received compensation afterward.

3.1.2 Apparatus, Materials, Procedure, and Design

The visual field was divided into six regions: above, upper-right, lower-right, below, lower-left, and upper-left of the central fixation. With six locations, targets appeared at cued locations on 1/6 of trials (valid cues) and at uncued locations on 5/6 of trials (invalid cues). In cue displays, a white Chinese character randomly appeared in one square, either "红" or "绿." Target displays modified the fixation display by changing square colors, adding purple (RGB: 255, 0, 255) and cyan (RGB: 0, 255, 255) to the original four colors (see Figure 3 [Figure 3: see original paper]). Participants discriminated gap locations in red or green target squares. Other procedures matched Experiment 1.

A 2$×2×$6 within-subjects design was employed. Semantic consistency had two levels (consistent vs. inconsistent). For red targets, the "红" cue was consistent and "绿" inconsistent; the reverse applied for green targets. Cue validity and cue location (upper, lower, upper-left, lower-left, upper-right, lower-right) were the other factors. Block design was used for cue and target properties, creating four blocks in random order: "红" cue-red target, "红" cue-green target, "绿" cue-red target, and "绿" cue-green target blocks. Each block contained 12 practice trials and 72 experimental trials divided into two sub-blocks with self-paced rest. The experiment lasted approximately 20 minutes.

3.2 Results and Analysis

Error trials and RTs beyond three standard deviations were removed (3.22% of data). Table 2 presents mean RTs and accuracy for all conditions.

The ANOVA on RTs revealed a significant main effect of cue location, $F(5, 105) = 3.58$, $p = 0.005$, $\text{p}^2 = 0.15$, with mean RTs of 532.33 ms (upper), 531.95

ms (upper-right), 543.80 ms (lower-right), 545.04 ms (lower), 546.74 ms (lower-left), and 533.87 ms (upper-left). Bonferroni-corrected comparisons showed a significant difference between upper-right and lower-right locations, $p = 0.04$, 95% CI [0.33, 23.37]. Neither semantic consistency, $F(1, 21) = 1.64$, $p = 0.21$, $p^2 = 0.07$, nor cue validity, $F(1, 21) = 2.04$, $p = 0.17$, $p^2 = 0.09$, showed significant main effects. The three-way interaction was not significant, $F(5, 105) = 0.27$, $p = 0.93$, $p^2 = 0.01$.

The interaction between cue validity and cue location was significant, $F(5, 105) = 4.10$, $p = 0.002$, $p^2 = 0.16$. Follow-up analyses showed that for lower and lower-left locations, invalid cues produced faster responses than valid cues: lower location, $F(1, 21) = 7.76$, $p = 0.01$, $p^2 = 0.27$, 95% CI [6.39, 44.06]; lower-left location, $F(1, 21) = 7.59$, $p = 0.012$, $p^2 = 0.27$, 95% CI [5.62, 40.22]. For other locations, no significant differences emerged between valid and invalid cues, all $F\text{s}(1, 21) \leq 3.34$, $p^2\text{s} \leq 0.14$, $p\text{s} \geq 0.08$ (see Figure 4 [Figure 4: see original paper]). No other interactions were significant. Target location showed no interactions with other factors, all $F\text{s} \leq 0.72$, $p^2\text{s} \leq 0.03$, $p\text{s} \geq 0.61$.

The ANOVA on accuracy revealed no significant main effects or interactions. Statistical power for significant effects exceeded 0.95, with no speed-accuracy trade-offs.

3.3 Discussion

In terms of absolute RTs, responses were faster for targets in the upper visual field than the lower field, consistent with Experiment 1. More importantly, meaning-associated but nonpredictive character cues produced different attentional orienting effects across locations. Significant inhibition effects emerged only in lower-left and lower locations, with no orienting effects elsewhere. Although meaning-related but task-irrelevant cues modulated attentional orienting only in partial locations, these results still support meaning-level contingent attentional orienting theory. However, the findings suggest that changing cue object properties alters the degree of attentional guidance, with character cues showing weaker capacity, producing inhibition only in partial lower field regions.

Experiment 2 again found no differential effects of semantic consistency on spatial attention modulation, consistent with Experiment 1. Previous research using similar paradigms found that colorless characters (e.g., “纱”) did not produce cuing effects when searching for specific colors (Wang et al., 2016), indicating that character presence alone cannot influence attentional allocation. The observed cuing effects may reflect two mechanisms. First, color-meaningful characters (“红” and “绿”) associated with task-relevant display-wide features (red and green) may have led participants to adopt display-wide attentional control settings, causing involuntary attentional shifts. Alternatively, character cues may have associated with the general feature attribute (“color”), leading to nonspecific attentional control settings. As in Experiment 1, regardless of which setting was adopted, the task was influenced by top-down factors guided by meaning associations, representing meaning-based attentional orienting.

Experiment 3: Meaning-Based Attentional Orienting Guided by Color Cues

Experiment 3 further manipulated cue properties by using color attributes. To avoid perceptual color-dimensional associations between cues and targets, targets were changed to white Chinese characters with color meaning, examining how more vivid color cues modulated attentional orienting across locations. We hypothesized that attentional orienting effects would support meaning-level contingent attentional orienting theory. Different effect magnitudes from Experiments 1 and 2 would suggest cue properties modulate attentional resource allocation, and location-dependent effects would indicate differential distribution patterns of contingent attentional resources across spatial regions.

4.1.1 Participants

Using the same ANOVA design as Experiment 2, the required sample size remained 24. We recruited 23 university students (17 female, 6 male) aged 20–25 years (M = 22.30, SD = 1.27). All were right-handed with normal or corrected-to-normal vision and no color blindness. None had participated in similar experiments and received compensation afterward.

4.1.2 Apparatus, Materials, Procedure, and Design

Experiment 2’ s cue and target properties were swapped, using color cues and character targets. In cue displays, six squares changed from thin (0.12°) to thick (0.30°) borders, with one square changing from gray to red or green. Target displays presented white Chinese characters (0.63°$×$0.63°) in each square, with one target character. For “红”targets, nontarget characters were “纠,”“纤,”“约,”“纹,” and “纷” ; for “绿” targets, nontargets were “绳,” “编,” “绩,” “绣,” and “绸” (see Figure 5 [Figure 5: see original paper]). Target display duration was 1000 ms. Participants discriminated the gap location in the square containing the target character. Other procedures matched Experiment 2.

A 2$×2×$6 within-subjects design was employed. Semantic consistency had two levels (consistent vs. inconsistent). For “红” targets, red cues were consistent and green cues inconsistent; the reverse applied for “绿” targets. Cue validity and cue location were the other factors. Block design created four random-order blocks: red cue- “红” target, red cue- “绿” target, green cue- “红” target, and green cue- “绿” target blocks. Each block contained 12 practice trials and 144 experimental trials divided into four sub-blocks with self-paced rest. The experiment lasted approximately 40 minutes.

4.2 Results and Analysis

Error trials and RTs beyond three standard deviations were removed (7.76% of data). Table 3 presents mean RTs and accuracy for all conditions.

The ANOVA on RTs revealed a significant main effect of semantic consistency, $F(1, 22) = 4.81$, $p = 0.04$, $\mathrm{p}^2 = 0.18$, with faster responses for semantically consistent trials (919.33 ms) than inconsistent trials (935.24 ms), 95% CI [0.87, 30.94]. Cue location also showed a significant main effect, $F(5, 110) = 12.39$, $p < 0.001$, $\mathrm{p}^2 = 0.36$, with mean RTs of 896.02 ms (upper), 900.98 ms (upper-right), 967.64 ms (lower-right), 985.72 ms (lower), 947.75 ms (lower-left), and 865.59 ms (upper-left). Bonferroni-corrected comparisons showed significant differences between upper-left and lower-left (95% CI [35.38, 128.93]), lower-right (95% CI [29.86, 174.24]), and lower (95% CI [46.96, 193.30]) locations, all ps ≤ 0.002; between upper-right and lower (95% CI [18.11, 151.38]) and lower-right (95% CI [25.02, 108.32]) locations, all ps ≤ 0.006; and between lower and upper locations (95% CI [6.53, 172.88]), $p = 0.027$. Cue validity showed no main effect, $F(1, 22) = 2.32$, $p = 0.20$, $\mathrm{p}^2 = 0.10$.

The three-way interaction was not significant, $F(5, 110) = 0.33$, $p = 0.90$, $\mathrm{p}^2 = 0.02$. However, the interaction between cue location and cue validity was significant, $F(5, 110) = 12.83$, $p < 0.001$, $\mathrm{p}^2 = 0.37$. Follow-up analyses showed that for lower-right and lower locations, invalid cues produced faster responses than valid cues: lower-right, $F(1, 22) = 9.81$, $p = 0.005$, $\mathrm{p}^2 = 0.31$, 95% CI [32.47, 159.72]; lower, $F(1, 22) = 16.08$, $p < 0.001$, $\mathrm{p}^2 = 0.42$, 95% CI [84.72, 214.44]. For upper, upper-right, and upper-left locations, invalid cues produced slower responses than valid cues: upper, $F(1, 22) = 8.67$, $p = 0.007$, $\mathrm{p}^2 = 0.28$, 95% CI [36.31, 195.56]; upper-right, $F(1, 22) = 6.08$, $p = 0.02$, $\mathrm{p}^2 = 0.22$, 95% CI [13.24, 153.52]; upper-left, $F(1, 22) = 13.95$, $p = 0.001$, $\mathrm{p}^2 = 0.39$, 95% CI [99.85, 253.77]. For lower-left location, no difference emerged between valid and invalid cues, $F(1, 22) = 1.77$, $p = 0.20$, $\mathrm{p}^2 = 0.07$ (see Figure 6 [Figure 6: see original paper]). No other interactions were significant. Target location showed no interactions with other factors, all Fs ≤ 0.79, p^2s ≤ 0.04, ps ≥ 0.59.

The ANOVA on accuracy revealed a significant main effect of semantic consistency, $F(1, 22) = 6.27$, $p = 0.02$, $\mathrm{p}^2 = 0.22$, with higher accuracy for consistent trials (93.32%) than inconsistent trials (91.47%), 95% CI [0.32%, 3.38%]. No other main effects or interactions were significant. Statistical power exceeded 0.95 for significant effects, with no speed-accuracy trade-offs.

4.3 Discussion

Absolute RTs again showed faster responses for upper visual field targets, consistent with Experiment 2. Importantly, we found location-dependent attentional orienting effects: inhibition in lower visual field and capture in upper visual field, replicating Experiments 1 and 2. Color cues produced more robust spatial orienting effects, indicating stronger attentional guidance by color attributes. Additionally, a main effect of semantic consistency emerged, with faster responses when cues and targets were semantically consistent. We interpret this as semantic priming (Meyer & Schvaneveldt, 1971; Maxfield, 1997). Experiments 1 and 2, which required responses to color features, showed no semantic consistency main effect, suggesting that cross-dimensional semantic priming occurs only during semantic processing of words.

Previous research using similar paradigms found that color features (e.g., red) did not cause attentional shifts when searching for colorless characters (e.g., "纱") (Wang et al., 2014). Experiment 3' s cuing effects emerged because color feature cues (red and green) associated with color-meaningful characters ("红" and "绿") at an abstract semantic level, influencing attentional allocation. As in previous experiments, no interaction between semantic consistency and spatial attention modulation emerged. The task required searching for "红" or "绿" characters, likely prompting a general conceptual attentional control setting based on the "color" concept. All color features associated with this general concept at a semantic level, gaining equivalent attention-modulating capacity. Thus, these results remain evidence of meaning-based attentional orienting.

To better compare spatial attentional orienting across experiments, we plotted attentional orienting effects (difference between invalid and valid cue RTs) against vertical coordinates of stimulus locations. In Experiment 1, left and right locations shared a vertical coordinate midway between upper and lower positions, and their orienting effects did not differ (left: 16.89 ms; right: 17.08 ms), $F(1, 24) < 0.001$, $\mathrm{p}^2 < 0.001$, $p = 0.98$, so these effects were averaged. In Experiment 2, upper-left/upper-right locations shared a vertical coordinate midway between upper and horizontal positions, while lower-left/lower-right locations shared a coordinate midway between horizontal and lower positions. Orienting effects for upper-right (10.93 ms) and upper-left (-3.88 ms) did not differ, $F(1, 21) = 1.44$, $\mathrm{p}^2 = 0.06$, $p = 0.24$, nor did effects for lower-right (-10.37 ms) and lower-left (-22.92 ms), $F(1, 21) = 1.35$, $\mathrm{p}^2 = 0.06$, $p = 0.26$, so these pairs were averaged (see Figure 7 [Figure 7: see original paper]).

The slope of orienting effect trends was similar between Experiments 1 and 2 (9.56 and 9.63), with no significant difference, $t(45) = 0.03$, Cohen' s $d = 0.007$, $p = 0.98$. The difference between upper and lower location orienting effects was also equivalent: 38.23 ms for sketches (27.24 - (-10.99)) and 38.06 ms for characters (12.84 - (-25.22)). However, the intercept was larger for characters (-35.26) than sketches (-17.59), though not significantly different, $t(45) = 1.77$, Cohen' s $d = 0.51$, $p = 0.08$, suggesting more pronounced inhibition from character cues.

In Experiment 3, orienting effects for upper-right (83.38 ms) and upper-left (176.81 ms) did not differ, $F(1, 22) = 2.74$, $\mathrm{p}^2 = 0.11$, $p = 0.11$, nor did effects for lower-right (-96.09 ms) and lower-left (-44.76 ms), $F(1, 22) = 1.13$, $\mathrm{p}^2 = 0.05$, $p = 0.30$, so these pairs were averaged. All three experiments showed progressively stronger inhibition in lower visual field and progressively stronger capture in upper visual field.

The slope of orienting effect trends in Experiment 3 (73.16) was significantly steeper than in Experiment 1, $t(46) = 4.10$, Cohen' s $d = 1.16$, $p < 0.001$, 95% CI [32.33, 94.87], and Experiment 2, $t(43) = 3.82$, Cohen' s $d = 1.15$, $p < 0.001$, 95% CI [30.03, 97.03]. The intercept in Experiment 3 (-212.96) also differed significantly from Experiment 1, $t(46) = 4.26$, Cohen' s $d = 1.21$, $p < 0.001$, 95% CI [103.09, 287.65], and Experiment 2, $t(43) = 3.62$, Cohen' s $d = 1.09$, $p = 0.001$, 95% CI [78.61, 276.78]. These slope and intercept differences indicate that color cues produced stronger inhibition and capture effects. Within the same visual field range, color attributes guided attentional orienting more strongly than abstract characters and less vivid sketches. Experiment 3 again demonstrates that different cue properties differentially guide spatial attentional selection: more vivid objects produce stronger modulation, while more abstract objects produce weaker modulation.

General Discussion

Three experiments using a cuing paradigm examined how task-irrelevant but meaning-associated cues modulated attentional orienting. Experiment 1 using sketch cues found inhibition in lower visual field and progressively stronger capture in horizontal and upper fields. Experiment 2 using character cues with increased locations showed a general lower-to-upper inhibition-to-capture trend, though only partial inhibition reached significance. Experiment 3 using color cues revealed more robust inhibition and capture effects with similar location-dependent patterns.

5.1 Meaning-Associated Objects Can Guide Attentional Orienting

All three experiments, using different methods to establish meaningful cue-target associations, found varying degrees of attentional orienting effects (inhibition and capture). This demonstrates that objects meaningfully associated with current targets can guide attentional orienting, likely through attentional control settings based on display-wide visual features or general concepts, reflecting goal-driven processing. Although cues in Experiments 1 and 2 appeared as abrupt onsets, which automatically capture attention (Yantis & Jonides, 1984; Schoeberl et al., 2015), previous research using this paradigm found no attentional orienting effects when objects lacked feature- or meaning-level associations (Wang et al., 2014, 2016). Therefore, the observed inhibition and capture effects likely stemmed from top-down guidance by meaning-associated cues.

Related research requiring identification of auditory words while viewing printed visual words found semantic competition effects for semantically related visual words, indicating semantic information influences visual attention allocation (Shen et al., 2016). Stimuli matching target meaning receive attentional selection (Goodhew et al., 2014; Sun et al., 2015; Wang et al., 2018). In visual word search, task-consistent perceptual or semantic features more readily capture attention or resist rejection (Dampuré et al., 2014), while distractors can be strategically inhibited when related to individual memory (Lu et al., 2017). Socially meaningful head and gaze orientation combinations influence exogenous attentional orienting to faces, with strongest effects when head and gaze directions align (Palanica & Itier, 2015). These findings highlight the importance of meaning consistency in attentional orienting, enabling appropriate task processing through contextual background understanding (Zhao et al., 2017). Visual search in real scenes shows that objects semantically related to target categories capture attention (Seidl-Rathkopf et al., 2015), with natural images decoded into conceptual meaning to guide attention shifts (Wyble et al., 2013). The present study replicates these findings while focusing specifically on interactions between attentional selection modulation and spatial location.

5.2 Object Properties Influence Meaning-Based Attentional Orienting

While establishing meaningful cue-target associations, we manipulated cue properties to examine how object characteristics affect meaning-based attentional orienting. Experiment 1' s vivid sketches produced inhibition in lower locations and varying capture elsewhere. Experiment 2' s abstract characters produced inhibition only in partial lower field locations but showed orienting trends elsewhere. Despite different location numbers, the magnitude of attentional orienting changes was equivalent between sketches and characters, though sketches showed more pronounced capture overall while characters showed primarily inhibition. Experiment 3' s vivid color cues produced more significant inhibition and capture effects. Compared to abstract characters and moderately vivid sketches, highly vivid color cues produced the strongest attentional orienting changes, with robust effects in both inhibition and capture. Thus, for meaning-based attentional orienting, object properties produce differential modulation: more vivid objects exert stronger modulation, while more abstract objects exert weaker modulation.

Similar findings show that perceptual representations activated by semantic concepts modulate spatial attention similarly to but less strongly than their actual features (Wang et al., 2018), demonstrating differential attentional modulation capacities across object properties. We speculate that object influences on involuntary attentional orienting may share a common processing mechanism, producing only quantitative rather than qualitative differences. Comparative studies of gaze cues with social meaning and arrow cues without social meaning found no qualitative differences in attentional guidance at the cortical level (Greene et al., 2009; Sato et al., 2009; Joseph et al., 2015). Comparative semantic processing of Chinese characters, English words, and pictures activated identical brain regions with only quantitative differences (Chee et al., 2000). Semantic concepts are represented by multiple features or attributes, with perceptual representations partially experienced during conceptual processing (Binder et al., 2016). Features can be encoded and stored separately in working memory with resource limitations and minimal cross-dimensional interference (Wang et al., 2016). Therefore, different object properties may guide attentional orienting through a common semantic processing system, showing qualitative similarity but quantitative differences due to inherent property variations.

5.3 Regular Variation of Meaning-Based Attentional Orienting Across Visual Space

Establishing meaningful cue-target associations revealed systematic patterns in meaning-based attentional orienting across visual space. Experiment 1 found significant inhibition in lower locations, significant capture in upper locations, and weaker but significant capture in horizontal locations. Experiments 2 and 3, with increased cue locations, showed inhibition or trends in lower visual field and capture or trends in upper visual field, with inhibition decreasing and capture increasing from lower to upper locations. Comparing left-right pairs at the same horizontal level (Experiment 1' s left-right; Experiments 2-3' s upper-left/upper-right and lower-left/lower-right pairs) revealed no significant differences, all *p*s > 0.11, indicating consistent meaning-based attentional orienting effects across same-eccentricity horizontal locations. The lower-to-upper inhibition-to-capture trend progressed at equal rates in left and right hemifields, with no left-right visual field or hemispheric differences.

Reorienting theory explains inhibition and capture effects (Klein, 2000). Cue onset attracts attention to its location. With short SOAs (100–200 ms), targets at cued locations require no attention shift, producing faster responses; targets at other locations require disengagement and shifting, producing slower responses (capture/facilitation). With long SOAs, instructions (e.g., maintain central fixation) or design features cause attention to disengage from cues and return to center. When targets then appear, inhibitory mechanisms prevent attention from returning to previously attended locations, producing slower responses at cued locations (inhibition). Notably, lower field cues produced inhibition even with short SOAs (200 ms), suggesting meaning-based attentional orienting may disengage more quickly from lower locations, enabling rapid reorienting and inhibitory mechanism activation within brief intervals. Inhibition showed location-dependent gradation: more inferior positions produced stronger inhibition. Correspondingly, upper field locations showed stable capture effects or trends, indicating attention 停留 longer at superior locations, also showing location-dependent gradation: more superior positions produced stronger capture.

These results suggest that objects meaningfully associated with potential targets more readily capture attention in upper visual field and more readily receive inhibition in lower visual field. Previous research suggesting superior lower field processing may reflect early visual cortex processing stages influenced by neuronal sensory responses (Liu et al., 2006) or attentional resolution (He et al., 1997). Those studies focused on perceptual-level features, whereas the present research examined higher-level conceptual associations between objects, potentially involving different mechanisms producing opposite patterns. Although some research suggests leftward bias in spatial attention (Yang et al., 2012; Thomas et al., 2015), we found no left-right differences, suggesting semantic-based attention may process vertically (Loetscher et al., 2015). Future research should further explore visual spatial attention allocation patterns.

5.4 Summary and Outlook

This study precisely characterized the spatial distribution of meaning-based attentional orienting, demonstrating upper-field advantage in location-based contingent involuntary attention: within the same eccentricity range, more superior locations are more readily selected, while more inferior locations are more readily rejected. In real scenes, meaning plays a more primary role than visual salience in guiding human attention (Henderson & Hayes, 2017). These findings provide theoretical guidance for real-world applications including advertising design, traffic safety, and product placement. For instance, capturing potential consumers' attention is a prerequisite for subsequent purchasing behavior, and advertisements meaningfully related to consumers' expectations have greater potential attractiveness, with presentation location further influencing attentional capture.

Future research should explore meaning-based attentional orienting in three-dimensional contexts, as real-world environments are three-dimensional while the present study examined only two-dimensional situations. The current findings demonstrate that: (1) meaningful associations between objects guide visuospatial attention, showing location-dependent attentional orienting effects; (2) object properties modulate meaning-based attentional orienting, with more vivid objects producing stronger modulation and more abstract objects weaker modulation; and (3) meaning-based attentional orienting shows systematic spatial variation, characterized by location-dependent inhibition and capture effects.

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