Attentional Capture by Semantic Association: Evidence from the Cueing Paradigm (Postprint)

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Abstract

Using the cueing paradigm, we operationally established semantic associations between cues and targets to investigate the effect of semantic associations on attentional capture. Experiment 1 employed the form of feature cues and semantic targets, establishing an attentional control set at a specific semantic level. It was found that when cue and target were semantically consistent, the cue captured attention; when cue and target were semantically inconsistent, the same cue lost its ability to capture attention. Experiment 2 randomly presented cue colors and target Chinese characters, establishing attentional control sets for two semantic concepts. It was found that all cues exhibited capture effects, regardless of whether they were semantically consistent with the target in any specific trial. Experiment 3 swapped the attributes and concepts of cues and targets, employing the form of semantic cues and feature targets, and the results were consistent with those of Experiment 1. These results indicate that (1) attentional capture based on semantic associations conforms to the contingent involuntary orienting hypothesis, and the capture ability of stimuli is modulated by the current attentional control set; (2) perceptual representations activated by semantic concepts have the same form as the concepts themselves in modulating spatial attention allocation, but the degree is reduced; (3) attentional control sets at the perceptual feature level can activate their corresponding semantic concepts, causing them to attract attention and modulate spatial attention allocation; (4) the activation of perceptual representations and semantic concepts may be bidirectional, and after activation, they exhibit the same characteristics in guiding attentional shifts.

Full Text

Semantic Contingency in Attentional Capture: Evidence from a Spatial Cuing Paradigm

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Abstract

This study employed a modified spatial cuing paradigm to operationally establish semantic associations between cues and targets, investigating how semantic contingency influences attentional capture. Experiment 1 used feature cues and semantic targets to establish an attentional control setting at a specific semantic level. Results showed that cues captured attention when cue-target semantic meaning was congruent, but the same cues lost their capture ability when semantic meaning was incongruent. Experiment 2 randomly presented cue colors and target characters to establish attentional control settings for two semantic concepts. All cues exhibited capture effects regardless of whether they were semantically congruent with the target in any given trial. Experiment 3 swapped the attributes and concepts of cues and targets, using semantic cues and feature targets, and yielded results consistent with Experiment 1. These findings demonstrate that: (1) semantic contingency in attentional capture conforms to the contingent attentional orienting hypothesis, where a stimulus' s capture ability is modulated by current attentional control settings; (2) perceptual representations activated by semantic concepts regulate spatial attention allocation in the same manner as, but to a lesser degree than, the representations themselves; (3) attentional control settings at the perceptual feature level can activate corresponding semantic concepts, enabling them to attract attention and modulate spatial attention allocation; and (4) the activation of perceptual representations and semantic concepts may be bidirectional, exhibiting identical characteristics in guiding attentional shifts after activation.

Keywords: semantic contingency; attentional capture; attentional control setting; modified spatial cuing paradigm; semantic activation
Classification Code: B842

Introduction

The real world is saturated with information, yet humans have limited capacity to process information simultaneously. Therefore, attention must select certain information for deeper processing (Broadbent, 1958). In terms of information characteristics, sufficiently salient stimuli can automatically attract attention (Theeuwes, 1991), while humans can also select information consistent with their goals based on need. Guided by current objectives, associations between objects can determine which features attract attention and subsequently modulate spatial attention allocation (Folk, Remington, & Johnston, 1992). Folk et al. (1992) used a cuing paradigm to examine how uninformative cues influenced responses to targets appearing at different locations. The spatial relationship between cue and target had two main conditions: when cue and target appeared at the same location (valid cue condition) and when they appeared at different locations (invalid cue condition). The experimental logic was that if responses were slower in invalid than valid cue conditions for a particular cue type, this cue effect indicated that the cue had attracted attention to its location. When the target appeared at the same location as the cue, rapid responses could be made without attentional shifting; when the target appeared elsewhere, attention necessarily shifted first to the new location, causing response time prolongation. Researchers termed this cue-guided attention phenomenon "attentional capture," using the difference in reaction times between invalid and valid cue conditions as an index of capture magnitude. Folk et al. found that whether a cue captured attention was not determined by the cue's intrinsic properties but by its consistency with target attributes—only cues matching target attributes could capture attention. Based on these results, Folk et al. proposed the contingent attentional orienting hypothesis, emphasizing the important role of attentional control settings in involuntary attentional orienting. This hypothesis has received support from numerous studies (Folk, Remington, & Wright, 1994; Remington, Folk, & McLean, 2001; Eimer & Kiss, 2008; Kiss & Eimer, 2011; Huang, Su, Zhen, & Zhe, 2016), highlighting the matching relationship between stimulus attributes and long-term memory representations (Schmidt, 2014; Reeder, van Zoest, & Peelen, 2015; Giammarco, Paoletti, Guild, & Al-Aidroos, 2014, 2016).

However, evidence supporting the contingent orienting hypothesis, represented by Folk's work, has primarily come from capture phenomena involving low-level feature attributes, where both cues and targets were defined by a particular feature (e.g., color, shape, onset). The pattern of spatial attention modulation by higher-level conceptual information remains unclear. Wang (2009) first investigated attentional capture based on semantic association, finding that when targets included the character "红" (meaning red), red cues produced attentional capture, whereas the same red cues lost capture ability when searching for non-color meaning characters (e.g., "纱"). This suggested that when searching for Chinese character targets with color meaning, participants established an attentional control setting based on semantic information, and feature cues consistent with the current semantic concept could orient attention to their location and modulate spatial attention allocation. A recent study supported this view by designing multiple association forms between cues and targets while fixing cue color and target meaning in each condition (Wang, Zhang, & Sui, 2014). Results showed that without any search strategies, the same red cue captured attention when the target was the character "红" (semantic association condition) but did not produce capture when the target was "纱" (unrelated baseline condition). These results implied that involuntary attentional shifts in visual space can occur not only at the perceptual feature level but also at the higher semantic concept level. However, Wang et al. (2009, 2014) had a limitation: they only verified the semantic association of one color feature (red) in modulating attentional orienting, which could not exclude potential uniqueness of red in attention allocation. Research indicates that different colors convey different emotional information, with red exhibiting stronger excitability and joyfulness for Chinese people (Huang, Huang, & Li, 1991). Additionally, red may have special characteristics through both innate inheritance and postnatal learning that affect psychological processes and behavior—the "red psychological effect" (Hill & Barton, 2005; Li, He, & Liu, 2016; Zhang & Han, 2017). These findings suggest that selecting only red stimuli as experimental materials may compromise fairness and reduce experimental generalizability.

Addressing this issue, a contemporaneous study examined capture effects of red and green cues when targets were "RED" and "GREEN" words (Goodhew, Kendall, Ferber, & Pratt, 2014). Researchers found that only color cues semantically congruent with targets captured attention, and when target meaning changed, the capture ability of color cues reversed. They proposed that semantic concepts could maintain a semantic-level attentional set, and feature attributes consistent with this semantic set could attract attention to their location and modulate spatial attention allocation. These results aligned with Wang et al. (2009, 2014), supporting the semantic contingency attentional capture hypothesis. Similarly, research found that when manipulating a concept (e.g., "ROSE"), distractors with related color features (e.g., red disks) caused more interference in visual search tasks than unrelated color features (e.g., green disks) (Sun, Shen, Shaw, Cant, & Ferber, 2015). This indicated that differences in semantic conceptual associations between objects could influence visual spatial attention orienting, and visual working memory content could strategically modulate this process (Ye, Lu, Zhang, Wang, Tian, & Liu, 2017). However, Goodhew et al. (2014) found significant differences in capture magnitude between different color cues: under semantically congruent conditions, green cues (129 ms) produced significantly larger capture than red cues (37 ms). This suggested that green features might have stronger capture ability than red features, a trend also present in their feature condition tasks. Previous feature association studies had not found differences in attentional orienting modulation among different feature values within the same attribute (e.g., red vs. green), which the contingent attentional orienting hypothesis cannot explain. Moreover, Goodhew et al. did not explain this finding and noted no evidence for green' s superiority in capture ability. We suspect that the differential capture magnitudes in their experiment did not stem from contingent orienting itself but from other factors, such as different viewing angles caused by varying word lengths of color words, or uncertainty about cue color within a single trial due to random variation. Based on these issues, the present study used a cuing paradigm to investigate contingent attentional capture based on semantic sets with stricter controls to obtain pure capture effects and further explore the nature of attentional control in human visual spatial processing.

Experiment 1

Experiment 1 used red and green colors as cues and the Chinese characters “红” and “绿” as targets. Following Folk et al. (1992), each experimental condition fixed the current cue feature and target meaning. Additionally, due to the square configuration of Chinese characters, all target and non-target characters had identical viewing angles, minimizing visual factor influences on target responses. The hypothesis was that cue color and target character semantic meaning would show attention capture when congruent (red cue with “红” target; green cue with “绿” target), but the same cues would lose capture ability when incongruent (red cue with “绿” target; green cue with “红” target).

Method

Participants. Twenty-seven undergraduate and graduate students participated (21 female, 6 male), aged 19-27 years (M = 22.1, SD = 2.5). One was left-handed; others were right-handed. All were native Chinese speakers with normal or corrected-to-normal vision, no color blindness or weakness, and no prior participation in similar experiments.

Apparatus and Materials. Stimuli were presented on a 22-inch color monitor with 1024×768 resolution and 85 Hz refresh rate. The experimental program was developed using E-Prime and run on Windows XP.

The experiment had three basic stimulus displays: fixation display, cue display, and target display (see Figure 1). The fixation display presented a central fixation cross (0.48°×0.48°) with four boxes (1.53°×1.53°) at 0°, 90°, 180°, and 270° positions, each centered 4.4° from screen center. The central fixation cross was white, peripheral boxes were gray (RGB: 128 128 128), and the background was black. In the cue display, all peripheral box borders changed from thin (0.14°) to thick (0.43°), and one box changed from gray to red (RGB: 255 0 0) or green (RGB: 0 255 0). The target display presented a white Chinese character (0.86°×0.86°) in each peripheral box. The target was either “红” or “绿”. When the target was “红”, the three non-target characters were “纠”, “纤”, and “约”; when the target was “绿”, non-targets were “绳”, “编”, and “绩”. The four characters appeared at random positions in each trial. Additionally, each peripheral box contained a gap randomly on left or right, with exactly two gaps on each side.

Procedure and Design. Participants were tested individually in a dimly lit room. After reading instructions, they sat in a comfortable chair with eyes 74 cm from the display. As shown in Figure 1, the fixation display (central cross and four peripheral boxes) appeared for 500 ms, followed by the cue display for 100 ms. After cue offset, the fixation display reappeared for 100 ms, then the target display for 1000 ms. The target appeared at the cued location on 25% of trials (valid cue) and elsewhere on 75% of trials (invalid cue). The four characters (including the target) appeared at random positions. Four experimental conditions existed based on cue-target combinations: semantically congruent red cue with "红" target; incongruent red cue with "绿" target; incongruent green cue with "红" target; and congruent green cue with "绿" target. The experiment used a block design with random order across the four conditions–cue property and target identity were fixed within each block, and participants responded only to the specific target character. Participants were informed about the cue display arrangement beforehand but were instructed to ignore task-irrelevant cues. Their task was to judge, as quickly and accurately as possible, the gap location of the target character' s box in the current block: press "Z" with the left index finger for left gaps, and "M" with the right index finger for right gaps. Trials without responses within 2000 ms were counted as errors. After a response or 2000 ms, a blank screen appeared for 1400-1600 ms before the next trial.

The experiment used a 2×2×2 within-subjects design with factors of cue validity (valid vs. invalid), semantic congruency between cue and target (congruent vs. incongruent), and target identity ("红" vs. "绿"). Four conditions existed with fixed cue color and target character in each. Each condition included 12 practice trials and 128 experimental trials, divided into four blocks with self-paced rest between blocks. The experiment lasted approximately 40 minutes.

Results and Analysis

Trials with incorrect responses, reaction times (RTs) shorter than 200 ms or longer than 2000 ms, and RTs beyond ±3 SD from each participant' s mean were excluded (6.9% of data). Table 1 presents mean correct RTs and error rates for each condition.

A repeated-measures ANOVA on RTs revealed a significant main effect of cue validity, $F(1,26) = 15.29$, $p < 0.001$, $^2 = 0.37$, with faster responses to targets at cued locations (792.5 ms) than non-cued locations (817.3 ms). Critically, the interaction between cue validity and semantic congruency was significant, $F(1,26) = 14.92$, $p < 0.001$, $^2 = 0.37$. Further analysis showed that in the semantically congruent condition, responses were slower in invalid (828.3 ms) than valid cue conditions (787.5 ms), $F(1,26) = 24.51$, $p < 0.001$, $^2 = 0.49$, demonstrating attentional capture. In the incongruent condition, no difference existed between invalid (805.8 ms) and valid cue conditions (797.1 ms), $F(1,26) = 1.51$, $p = 0.23$, indicating no capture (see Figure 2 [Figure 2: see original paper]). The main effect of semantic congruency was not significant, $F(1,26) = 1.05$, $p = 0.32$. Target identity showed a significant main effect, $F(1,26) = 24.81$, $p < 0.001$, $^2 = 0.49$, with faster responses to "红" (785.4 ms) than "绿" (824.4 ms), likely due to higher character frequency (0.04504 vs. 0.01027) and usage (511 vs. 101) (Institute of Language Teaching and Research, 1986). No interactions involved target identity, $F\text{s}(1,26) < 2.59$, $p\text{s} > 0.12$, indicating that although absolute RTs differed between characters, they did not affect attentional capture across conditions.

A repeated-measures ANOVA on error rates showed no significant main effects or interactions, $Fs(1,26) < 3.57$, $ps > 0.07$, ruling out speed-accuracy trade-offs and validating the RT analysis.

Discussion

Experiment 1 manipulated semantic congruency between cue color and target meaning to examine how semantic-level attentional control settings guide attention allocation modulated by feature cues. Results showed that cues captured attention when feature and meaning were congruent but lost capture ability when incongruent. This demonstrates that feature cues matching semantic-level attentional control settings can attract attention to their location and influence subsequent target responses. Additionally, color cue capture effects were consistent across colors, revealing no special status for any particular color in contingent attentional capture. Through stricter experimental controls, we eliminated the non-systematic advantage of particular feature values found in Goodhew et al. (2014), showing that semantic concept-guided attentional control settings can activate corresponding feature attributes to guide attention shifts.

Thus, Experiment 1 strongly supports the existence of contingent attentional capture based on semantic sets, demonstrating that feature attributes can modulate attention allocation according to current semantic-level attentional control settings. We hypothesized that adjusting semantic-level attentional control settings would correspondingly change feature cues' capture ability, which Experiment 2 tested.

Experiment 2

Experiment 2 varied semantic-level attentional control settings by requiring participants to respond to both color-meaning characters simultaneously—discriminating whether each target was "红" or "绿". This established attentional control settings containing both red and green meanings. According to the contingent orienting hypothesis, both red and green cues should produce cuing effects regardless of whether cue color and target meaning were congruent in any specific trial.

Method

Participants. Twenty-six undergraduate and graduate students participated (21 female, 5 male), aged 18-26 years (M = 21.2, SD = 1.8). All were right-handed native Chinese speakers with normal or corrected-to-normal vision, no color blindness or weakness, and no prior participation in similar experiments.

Apparatus, Materials, Procedure, and Design. Unlike Experiment 1, both cue types and both target characters were randomized across trials. Targets were "红" or "绿" characters, with three non-target characters "线", "细", and "组". The target box contained no gap. Participants discriminated whether each target was "红" or "绿" as quickly and accurately as possible, pressing "Z" or "M" with left and right index fingers (counterbalanced across participants). Other aspects were identical to Experiment 1. The experiment included 12 practice trials and 384 experimental trials, divided into six blocks with self-paced rest between blocks, lasting approximately 40 minutes.

Results and Analysis

Trials with errors, RTs < 200 ms or > 2000 ms, and RTs beyond ± 3 SD were excluded (6.5% of data). Table 2 presents mean correct RTs and error rates.

A repeated-measures ANOVA on RTs revealed a significant main effect of cue validity, $F(1,25) = 29.73$, $p < 0.001$, $^2 = 0.54$, with faster responses to cued targets (667.3 ms) than non-cued targets (692.5 ms). Target identity showed a significant main effect, $F(1,25) = 32.76$, $p < 0.001$, $^2 = 0.57$, with faster responses to "红" (651.6 ms) than "绿" (708.2 ms), but no interactions with other factors, Fs(1,25) < 0.43, ps > 0.52. No other main effects or interactions were significant, Fs(1,25) < 0.63, ps > 0.44.

A repeated-measures ANOVA on error rates showed a significant main effect of cue validity, $F(1,25) = 6.77$, $p < 0.05$, $^2 = 0.21$, with lower error rates for cued targets (5.2%) than non-cued targets (6.9%). No other main effects or interactions were significant, Fs(1,25) < 3.99, ps > 0.06. Error rate patterns were consistent with RT results, ruling out speed-accuracy trade-offs.

Discussion

When participants' attentional control settings included both red and green meanings, both red and green cues captured attention regardless of semantic congruency with the target in specific trials. This demonstrates that semantic-level attentional capture, like feature-level capture, is influenced by current attentional control settings—stimuli matching the current setting attract attention and modulate allocation. Thus, a stimulus' s ability to attract attention is variable, determined not by its intrinsic features but by higher-level top-down factors.

Experiment 3

Experiments 1 and 2 showed that activating a semantic concept simultaneously activates its consistent physical attributes, and these activated attributes can shift spatial attention and modulate allocation. Can the reverse also occur? Does activating a feature attribute simultaneously activate its corresponding higher-level conceptual meaning to modulate visuospatial attention allocation? Evidence from Wang, Sui, and Zhang (2016) suggests this possibility. They examined how different forms of semantic cues affected responses to feature targets, finding that when cue and target were semantically congruent (white "红" cue with red target), the cue captured attention with magnitude comparable to feature cue-semantic target conditions (Wang et al., 2014). We predicted that when stimuli had semantic associations in the form of meaning-concept first and feature-attribute second, the former would similarly influence responses to the latter. Experiment 3 tested this hypothesis.

Experiment 3 swapped cue and target attributes and concepts, designing targets as feature attributes (red and green colors) and cues as semantic concepts (characters "红", "绿", plus "纱" as a semantically unrelated condition for both colors). The hypothesis was that cues would capture attention when semantically congruent with target color, but would not modulate attention when semantically incongruent or unrelated.

Method

Participants. Eighteen undergraduate and graduate students participated (14 female, 4 male), aged 20-27 years (M = 22.4, SD = 1.8). One was left-handed; others were right-handed. All were native Chinese speakers with normal or corrected-to-normal vision, no color blindness or weakness, and no prior participation in similar experiments.

Apparatus, Materials, Procedure, and Design. Unlike Experiment 1, the cue display presented a white Chinese character randomly in one peripheral box ("红", "绿", or "纱"). The target display changed peripheral box colors to red, green, blue (RGB: 0 0 255), or yellow (RGB: 255 255 0) randomly for 500 ms (see Figure 3 [Figure 3: see original paper]). Six conditions existed: for red target boxes, "红" was semantically congruent, "绿" incongruent, and "纱" unrelated; for green target boxes, "绿" was congruent, "红" incongruent, and "纱" unrelated. Other aspects were identical to Experiment 1.

The experiment used a 2×3×2 within-subjects design with factors of cue validity (valid vs. invalid), semantic congruency (congruent, incongruent, unrelated), and target color (red vs. green). A block design was employed with six conditions, each fixing cue character and target color. Participants judged the gap location of the specific color target box as quickly and accurately as possible. Each condition included 12 practice trials and 128 experimental trials, divided into four blocks with self-paced rest. The experiment lasted approximately one hour.

Results and Analysis

Trials with errors, RTs < 200 ms or > 2000 ms, and RTs beyond ± 3 SD were excluded (5.3% of data). Table 3 presents mean correct RTs and error rates.

A repeated-measures ANOVA on RTs revealed a significant main effect of cue validity, $F(1,17) = 15.66$, $p < 0.01$, $^2 = 0.48$, with faster responses to cued targets (505.6 ms) than non-cued targets (514.5 ms). Critically, the interaction between cue validity and semantic congruency was significant, $F(2,16) = 19.06$, $p < 0.001$, $^2 = 0.53$. Further analysis showed that in the congruent condition, responses were slower for invalid (521.4 ms) than valid cues (497.6 ms), $F(1,17)$

= 31.12, $p < 0.001$, $^2 = 0.65$, demonstrating attentional capture. In incongruent and unrelated conditions, no differences existed between invalid and valid cues, Fs(1,17) < 1.13, ps > 0.30, indicating no capture (see Figure 4 [Figure 4: see original paper]). The main effect of semantic congruency was not significant, $F(2,16) = 2.33$, $p = 0.11$. Target color showed a significant main effect, $F(1,17) = 16.52$, $p < 0.001$, $^2 = 0.49$, with faster responses to red targets (497.9 ms) than green targets (522.2 ms), supporting the view that red may have special properties in human psychology and behavior (Hill & Barton, 2005; Li et al., 2016; Zhang & Han, 2017). Importantly, target color did not interact with other factors, Fs < 1.47, ps > 0.24, indicating that although absolute RTs differed between colors, they did not affect attentional capture across conditions.

A repeated-measures ANOVA on error rates showed a significant interaction between cue validity and semantic congruency, $F(2,16) = 5.84$, $p < 0.01$, $^2 = 0.26$. Further analysis revealed that in the congruent condition, error rates were higher for invalid (6.0%) than valid cues (3.9%), $F(1,17) = 6.00$, $p < 0.05$, $^2 = 0.26$. No differences existed in incongruent or unrelated conditions, Fs(1,17) < 2.31, ps > 0.15. Target color showed a marginally significant main effect, $F(1,17) = 4.41$, $p = 0.051$, $^2 = 0.21$, with slightly lower error rates for red (4.0%) than green targets (6.3%). No other effects were significant, Fs < 2.03, ps > 0.15. Error rate patterns were consistent with RT results, ruling out speed-accuracy trade-offs.

Discussion

Experiment 3 used semantic cues and color targets to examine effects on spatial attention shifts. Results showed that cues captured attention only when semantically congruent with targets, but lost capture ability when incongruent or unrelated. This demonstrates that when attentional control settings are established by feature attributes, semantically congruent meaning cues can also be activated to attract attention, with capture patterns and magnitudes comparable to feature cue-semantic target conditions, again supporting the contingent orienting hypothesis.

Experiments 1 and 3 suggest that although feature attributes and semantic concepts belong to different levels, their activation appears interconnected or bidirectional—activation at either level triggers activation at the other level to guide attention shifts, and both show consistent patterns in modulating visual spatial attention allocation.

General Discussion

Through three experiments using a cuing paradigm, this study investigated how semantic contingency affects attentional capture. Experiment 1 used feature cues and semantic targets, finding that when participants maintained only one semantic-level attentional control setting, only meaning-congruent cues captured attention. Experiment 2 maintained stimuli while adjusting attentional control settings to include two semantic concepts, finding that all features consistent with the current semantic setting captured attention regardless of specific trial-by-trial relationships. Experiment 3 swapped cue and target attributes, revealing identical patterns and magnitudes of attentional capture for semantic cue-feature target conditions as in Experiment 1.

Similarities Between Semantic and Perceptual Contingency in Attentional Capture

Our results support Folk et al.' s (1992) contingent attentional orienting hypothesis: whether stimuli capture attention depends on current attentional control settings, with only setting-congruent stimuli attracting attention and guiding visual spatial attention allocation. This study robustly demonstrates that human attentional control settings can operate not only at the feature level but also at the semantic concept level. Whether feature attributes or semantic concepts, when one establishes an attentional control setting, the other becomes activated and gains attention modulation ability. Specifically, with feature cues and semantic targets, results supported Goodhew et al. (2014) while eliminating non-systematic advantages of particular feature values through stricter controls, showing that semantic concept-guided attentional control settings can activate corresponding feature attributes to guide attention shifts. With swapped cue-target attributes, consistent results showed that feature-guided attentional control settings can also activate corresponding semantic concepts to guide attention shifts.

Previous feature-level attentional capture research found that for attentional control settings based on a specific feature value, only matching feature cues captured attention (e.g., only red cues when searching for red targets; only green cues when searching for green targets), with equivalent capture magnitudes across colors. When participants adopted non-specific, general feature-based attentional control settings (i.e., uncertain target color), all color cues captured attention equivalently (Folk & Remington, 1998, 2008; Folk & Anderson, 2010). The present study shows that after defining targets with semantic concepts, color cues guide attention shifts in the same pattern (Experiments 1 and 2). Research indicates that conceptual understanding and sensorimotor systems share common neural circuits because semantic comprehension is based (at least partially) on sensorimotor system representations associated with sensory (e.g., visual, auditory, tactile) and motor experiences depicted by semantics (Gallese & Lakoff, 2005; Bottini, Bucur, & Crepaldi, 2016). Therefore, when responding to meaning-defined targets, their meaning activates consistent sensory (visual) representations sufficient to modulate spatial attention allocation. This activation appears automatic, as participants did not need to attend to color cues and thus had no reason to actively activate their representations.

Differences in Capture Magnitude Between Semantic and Perceptual Contingency

In terms of capture magnitude, semantic concept-activated feature attributes produce cuing effects of approximately 20-40 ms (Wang, 2009; Wang et al., 2014; Goodhew et al., 2014; present study), whereas feature-activated attributes produce effects of 40+ ms, even exceeding 100 ms (Folk et al., 1992; Folk & Remington, 2008; Eimer & Kiss, 2008, 2010; Wang et al., 2014; Goodhew et al., 2014; Liu & Bai, 2016). Thus, although perceptual representations activated by abstract semantic concepts modulate visual spatial attention in the same pattern as representations activated by their own features, the former shows clearly reduced modulation magnitude. This may reflect different attentional disengagement patterns. According to Theeuwes' rapid disengagement hypothesis, all salient stimuli automatically attract attention, but subsequent responses adjust according to current tasks. When a stimulus matches the current attentional control setting or is the search target, attention remains at that location; when it mismatches the setting or is a distractor, attention rapidly disengages and moves to the target location (Theeuwes, 1991, 2004). In unrelated conditions, zero results prevent determining whether cues attracted attention, but in association conditions, cues must have attracted attention to produce capture effects. Therefore, differences between semantic and perceptual contingency may stem from different disengagement patterns from non-cued locations.

Specifically, this process may involve two time components: disengagement time from non-target locations (reflecting disengagement difficulty) and movement time from non-target to target locations (reflecting disengagement speed). Their sum constitutes the capture magnitude. For semantic versus perceptual associations, do differences lie in difficulty, speed, or both? This can be derived through calculation. If disengagement time from non-target locations is t, capture magnitude is CE, average movement speed is v, and displacement distance is s, then $s/v = CE - t$. Based on experimental parameters and results, we can calculate capture magnitudes and attention displacements (distance from non-target to target). Solving simultaneous equations yields disengagement time and movement speed. In this study, attention displacement had two cases: from one location to the opposite location (87.3 mm) and to an adjacent location (61.7 mm), with corresponding capture magnitudes of 59.9 ms and 44.1 ms (using only red cue data for comparison with perceptual conditions). This yields the simultaneous equations for semantic conditions:

$87.3/v = 59.9 - t$
$61.7/v = 44.1 - t$

Solving yields $t = 13.2$ ms and $v = 1.6$ mm/ms.

Using the same method with data from Wang et al. (2014) for local perceptual association + feature search mode yields for perceptual conditions:

$87.3/v = 103.8 - t$

$61.7/v = 94.3 - t$

Solving yields $t = 71.4$ ms and $v = 2.7$ mm/ms.

Thus, although attention movement speed in semantic contingency is slightly slower than in perceptual contingency, its disengagement time is much shorter and easier, resulting in smaller overall cuing effects. Of course, these parameters are derived from only these experiments and require more precise future research.

Similarities in Bidirectional Activation Between Perceptual and Semantic Representations

Experiments 1 and 2 showed that semantic concept-level attentional control settings can activate consistent perceptual feature attributes, and these attributes are sufficient to shift attention and modulate allocation. Is this semantic-to-perceptual activation unidirectional or reversible? Experiment 3 addressed this by swapping cue and target attributes, using semantic-defined cues and color-defined targets. Results again showed attentional capture only with semantic congruency, with patterns and magnitudes identical to feature cue-semantic target conditions. This indicates that perceptual feature-level attentional control settings can also activate corresponding semantic concepts to attract attention and modulate spatial attention allocation. Componential theories of semantic vocabulary propose that concepts are represented by many features or attributes that are simple or basic meaning components, manifested at least partially in perceptual, motor, and other neural systems through experience with the concept (Binder et al., 2016). The results from Experiments 1 and 3 suggest that activation between perceptual representations and semantic concepts may be bidirectional with equivalent strength, showing identical characteristics in guiding attention shifts after activation. This implies they may share common cognitive neural mechanisms and brain regions.

Additionally, researchers have constructed a two-dimensional intensionalist model of stimulus salience distribution, proposing that current task categories occupy central positions in spatial distributions, with higher stimulus salience moving toward the center (Su, Bowman, & Barnard, 2007). We can speculate that when stimuli share features with targets, they occupy the center of the current task category, producing larger attentional modulation and capture effects (Folk et al., 1992; Folk & Remington, 2008; Eimer & Kiss, 2008, 2010; Liu & Bai, 2016). Semantically associated stimuli, while belonging to the current task category, are relatively peripheral, producing smaller modulation and capture effects (Wang, 2009; Wang et al., 2014, 2016; Goodhew et al., 2014). In this study, the salience of perceptual and semantic stimuli used to build semantic associations may be similar, placing them at comparable distances from the task category center and producing equivalent capture abilities.

Similarly, inattentional blindness research shows that unexpected stimuli in the same semantic category as target objects are detected more than semantically unrelated stimuli, and effects are larger for English words or Chinese characters than pictures when unexpected stimuli are semantically congruent with targets. This indicates individuals can establish attentional sets based on higher-level semantic categories to adjust attention allocation, prioritizing semantic concept processing—whether a stimulus is perceived depends on its meaning (Koivisto & Revonsuo, 2007; Guo, You, & Li, 2016). Comparing different stimulus levels, researchers have examined brain activation differences in semantic processing of Chinese characters, English words, and pictures (Chee et al., 2000). Results showed that Chinese character and picture semantic tasks co-activated left prefrontal cortex, left posterior temporal lobe, left fusiform gyrus, and left parietal lobe. English word semantic processing showed similar but weaker activation patterns. These findings suggest that Chinese characters, English words, and pictures activate a common semantic system, differing only in specific modality.

Summary and Future Directions

Thus, when stimuli carry meaningful color, they gain attention-attracting ability to some degree, with social meaning being the most typical manifestation. Whether for emotional words or faces, semantic processing modulates attention (Huang, Baddeley, & Young, 2008; Preston & Stansfield, 2008). Both real emotional faces and schematic graphics show dependence on attentional control settings (Barratt & Bundesen, 2012; Glickman & Lamy, 2018). Both direct threat expressions and learned fear associations show attentional selection priority (Schmidt, Belopolsky, & Theeuwes, 2015; Burra, Barras, Coll, & Kerzel, 2016). Humans show preferences for social stimuli from infancy, such as attending more to faces, body parts, and animal pictures (Gluckman & Johnson, 2013). In laboratory controls, objects with meaningful associations to targets affect selective attention even when task-irrelevant (Malcolm, Rattinger, & Shomstein, 2016). Real-world scenes involve more uncertainty factors—a recent study found that reducing distractor frequency and increasing task quantity in driving simulator scenes caused greater attentional dispersion, becoming risk factors from improper attention allocation (Arexis, Maquestiaux, Gaspelin, Ruthruff, & Didierjean, 2017). How meaningful color influences real-life attention shifts represents a future research direction.

Conclusions

1. Semantic contingency in attentional capture conforms to the contingent attentional orienting hypothesis, with stimulus capture ability modulated by current attentional control settings.
2. Perceptual representations activated by semantic concepts regulate spatial attention allocation in the same pattern as, but to a lesser degree than, the representations themselves.
3. Attentional control settings at the perceptual feature level can activate corresponding semantic concepts, enabling them to guide attention shifts

and modulate spatial attention allocation.
4. Activation between perceptual representations and semantic concepts may be bidirectional, exhibiting identical characteristics in guiding attentional shifts after activation.

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Note: Figure translations are in progress. See original paper for figures.