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Lexical- and perceptual-based object effects in the two-rectangle cueing paradigm

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ABSTRACT

Previous studies demonstrate that attentional selection can be object-based, in which the object is defined in terms of Gestalt principles or lexical organizations. Here we investigate how attentional selection functions when the two types of objects are manipulated jointly. Experiment 1 replicated Li and Logan (2008) by showing that attentional shift between two Chinese characters is more efficient when they form a compound word than when they form a nonword. Experiment 2A presented characters either alone or within rectangles (Egly, Driver, & Rafal, 1994) and the characters in a rectangle formed either a word or a nonword. Experiment 2B differed from Experiment 2A in that the two characters forming a word were in different rectangles. Experiment 3A presented the two characters of a word either within a rectangle or in different rectangles. Experiment 3B used the same design as Experiment 3A but presented stimuli of different types in random orders, rather than in blocks as in Experiments 2A, 2B and 3A. In blocked presentation, detection responses to the target color on a character were faster when this character and the cue character formed a word than when they did not, and the size of this lexical-based object effect did not vary according to whether the two characters were presented alone or within or between rectangles. In random presentation, however, the lexical-based object effect was diminished when the two characters of a word were presented in different rectangles. Overall, these findings suggest that the processes that constrain attention deployment over conjoined objects can be strategically adjusted.

1. Introduction

Attentional selection of visual information can be both space-based and object-based. Space-based selection is conducted by moving attentional focus, which is analogous to either a spotlight (Posner, 1980) or zoom lens (Eriksen & St. James, 1986; Eriksen & Yeh, 1985), to a particular location in the visual space. Processing of information at that location is hence enhanced. Object-based selection is conducted by focusing attention on a particular object, which is formed through early preattentive processes that segment the visual scene according to the Gestalt principles of perceptual organization (e.g., Baylis & Driver, 1992, 1993; Behrmann, Zemel, & Mozer, 1998; Duncan, 1984; Egly, Driver, & Rafal, 1994; Kahneman & Henik, 1981; Kramer & Jacobson, 1991; Treisman, Kahneman, & Burkell, 1983; Vecera & Farah, 1994; see Scholl, 2001 for a review). Processing of properties belonging to the selected object is thus enhanced.

Experimental evidence in support of object-based attentional selection comes from a variety of paradigms, among which the two-rectangle cuing paradigm (Egly et al., 1994) stands in a prominent position. Egly et al. (1994) presented two parallel rectangles (objects) to participants and asked them to detect as quickly as possible a target flash, which appeared at one end of a rectangle. Before the target was presented, however, there was an informative cue presented at one of the four ends of the rectangles. On most trials, the cue validly indicated the location of the subsequent target. On some trials, however, the cue was presented at the opposite end of the same rectangle where the target appeared, or at the equidistant end of the alternative rectangle. It was found that reaction times (RTs) to the target were the shortest at the validly cued location, reflecting an endogenous cueing effect. More importantly, RTs for invalidly cued trials were shorter when the target appeared on the cued object than when it appeared on the uncued object, despite the fact that the target was equally likely to appear at either location and that the two uncued locations were at the same distance from the cued location. This same-object advantage (or different-object disadvantage) suggests that allocation of attention is not only constrained by the relative spatial positions of the cue and the target, but also by the perceived object structure of the display. The object structure in the visual field guides the definition and selection of a region of space (Arrington, Carr, Mayer, & Rao, 2000).

Since the seminal work of Egly et al. (1994), a large number of studies on object-based attention have employed this two-rectangle

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cuing paradigm and the original findings have been replicated and extended (e.g., Abrams & Law, 2000; Kliegl, Wei, Dambacher, Yan, & Zhou, 2011; Lamy & Egeth, 2002; Lamy & Tsal, 2000; Marrara & Moore, 2003; McCarley, Kramer, & Peterson, 2002; Moore & Fulton, 2005; Moore, Yantis, & Vaughan, 1998; Mortier, Donk, & Theeuwes, 2003; Pratt & Sekuler, 2001; Shomstein & Yantis, 2004). An important extension was made by Li and Logan (2008) who presented four Chinese characters around the fixation and cued one position with a color on a character. In the invalid cue conditions, responses were faster when the target character and the cue character formed a compound word than whey they did not. This effect was interpreted as indicating that objects can be defined in a top-down fashion based on lexical organization and these lexical-based objects can constrain attention deployment in the same way as perceptual-based objects. A recent study by Chen and Zhou (2011) also showed that perception of visual apparent motion can be modulated by a task-irrelevant, lexical-based object. The authors presented participants with two successive stimulus frames of a visual Ternus display (Petersik & Rice, 2006; Ternus, 1926), in which each frame had two discs, with the second disc of the first frame and the first disc of the second frame being presented at the same location. Depending on the stimulus onset asynchrony (SOA) between the two frames, observers could perceive either "element motion", in which the endmost disc is seen as moving back and forth while the middle disc at the overlapping or central position remains stationary, or "group motion", in which both discs appear to move in a manner of lateral displacement as a whole. When each disc was embedded with a Chinese character, more reports of group motion, as opposite to element motion, were obtained when the embedded characters formed two-character compound words than when they formed nonwords, suggesting that Chinese compound words are represented as wholes in the lexicon (Zhou & Marslen-Wilson, 2009; Zhou, Marslen-Wilson, Taft, & Shu, 1999) and this lexical information is used in a top-down fashion to group Chinese characters into objects and to affect visual perception.

An interesting question is how the two types of objects, the lexical (top-down) and perceptual (bottom-up) defined objects, would work in concert to constrain attention deployment when they are manipulated jointly. This question is important because the pattern of effects would allow us to infer how the cognitive processes underlying the two types of object effects would work together in constraining attentional shift and to what extent the functioning of the cognitive processes is affected by task demand or contextual factors. One can image that a lexically defined object (e.g., a two-character Chinese compound word) can be arrayed either congruently or incongruently with a perceptually defined object (i.e., the two characters forming a compound word are displayed within a rectangle or in different rectangles). In the congruent condition, the processes underlying the two types of object effects might work together, either interactively or independently, to facilitate attentional shift and to augment the overall object effect; in the incongruent condition, the processes subserved by the two types of object structures might work against each other, putting attentional shift in limbo and hence reducing or eliminating the overall object effect. On the other hand, if the processing system can be strategically adjusted and if it relies on one type of object structure (e.g., the lexically defined) under certain circumstances to constrain attentional shift, then the overall object effect might not be affected by the congruency between the two types of object structures.

To test these possibilities, we conducted experiments in which the two characters forming a Chinese compound word were presented either within a rectangle (the congruent condition; Experiment 2A) or in two different rectangles (the incongruent condition; Experiment 2B). These critical manipulations were compared with the condition in which characters forming compound words were presented alone, as in Li and Logan (2008), and with the condition in which characters forming nonwords were presented within rectangles. To test further whether the congruency between the arrays of lexically and perceptually defined objects affect the overall object effect, Experiment 3A included both the congruent and the incongruent conditions. In both Experiments 2A, 2B and Experiment 3A, trials of different conditions were blocked according to stimulus type (e.g., congruent, incongruent, or word only). This blocked presentation might make it easy for the processing system to focus on one type of object structure and ignore the other during attention deployment. If so, the overall object effect might not vary as a function of stimulus type. In Experiment 3B, we used the same stimuli as Experiment 3A but randomly mixed trials of different conditions. The potential strategic modulation of the object effect would be minimized in this situation and the contribution of each type of objects to attentional shift and to the overall object effect would be more easily revealed. But before we report the results of these experiments, we first report the results of an experiment designed to replicate Li and Logan (2008).

2. Experiment 1

As described earlier, Li and Logan (2008) presented four Chinese characters, forming two compound words, around a fixation point, and cued one character with green color. Detection responses to the target red color on a character were faster when this character and the cue character formed a compound word than when they formed a nonword. This lexical-based object effect, however, could be contingent upon task demand as Li and Logan asked participants to decide, in one fourth of the trials, which compound word (out of four) was presented earlier in the visual display. As the authors suggested, this explicit, intentional memory test might have made it necessary to group the characters into words and to affect attentional selection. By discarding this memory test, Experiment 1 could examine to what extent the activation of lexical knowledge and its top-down guidance on attentional selection are automatic.

2.1. Method

2.1.1. Participants

Twenty native speakers of Chinese from Peking University were paid to participate in Experiment 1. All of them were right-handed and had normal or corrected-to-normal vision.

2.1.2. Design and materials

Consistent with Li and Logan (2008), this experiment had a 4 (target location: upper left, upper right, lower left, lower right) $\times$ 2 (word orientation: horizontal, vertical) $\times$ 3 (cue validity: valid, invalid same word, invalid different words) within-subjects factorial design. Each trial had four characters, forming two compound words, with the initial characters of the compounds either at the top (for top-down presentations of compounds) or at the left (for left-right presentations of compounds). There were 768 trials in total, with 640 critical trials having a red color target and 128 catch trials without the target. For the critical trials, there were 480 (75%) trials for valid cueing and 80 (12.5%) trials for each of the two invalid conditions. These trials were randomly mixed and were divided into 8 blocks of 96 trials each.

Each trial had a pair of Chinese two-character words, which had characters differing both in orthographic and phonological forms. We made an effort to make sure that the two words were not semantically related. All the words were used only once, so the experiment included 1536 words overall. The frequencies of these words were from 18 to 860 per million words, with the average of 80 per million (Cai & Brysbaert, 2010). Each character had 3 to 12 strokes in writing, indicating that each character was of relatively low visual complexity.

2.1.3. Procedures

Stimuli were presented on a 21-in. CRT monitor (1024 $\times$ 768 resolution; frame rate 100 Hz) controlled by a Dell PC. The font *Song-24* was used, with one character subtending $0.8 \times 0.8°$ of visual angle.

The distance between the centers of two adjacent characters was 1.6° of visual angle. The distance between the center of a character and the fixation sign was 1.13° of visual angle. For the purpose of rejecting trials on which participants looked away from the fixation cross, eye movements were recorded (at a 2000 Hz sampling rate) using an EyeLink 2K system. All the characters were shown in black against a gray background. The fixation was a plus sign (+), subtending 0.1°×0.1° of visual angle.

Each trial began with the display of a stimulus set consisting of four Chinese characters for 1500 ms (Fig. 1), followed by a plus sign, in addition to the characters, at the center of the display for 300 ms. Participants were asked to maintain fixation on the plus sign from then on. One character turned green as a cue for 100 ms and turned black after the cue for another 100 ms. After this SOA of 200 ms, a character was colored in red and participants were asked to press a button on a joystick as soon as they detected the presence of red color, or to do nothing when no character turned red. After the button press (or after 1500 ms when there was no response), the eye tracking system performed drift correction and the experimenter pressed the space bar connected with the control computer to start the next trial. A trial was aborted and a text line ("you moved your eyes") was shown on the screen for 1000 ms if participants did not maintain fixation on the plus sign. A text line reading "incorrect response" would be shown on the screen for 1000 ms when participants made a false response to the catch trial or did not respond to the target within 1500 ms. Participants underwent a training block of 48 trials before being formally tested.

2.2. Results

2.2.1. Eye movements

Participants made eye movements (leaving fixation area, which was 0.8×0.8° in visual angle) in 4.9% (ranging between 0.8% and 11.1%) of all the trails. These trials were excluded from further analysis. The percentage of excluded trials did not vary between conditions.

2.2.2. Manual responses

The hit rate (for critical trials) and the false alarm rate (for catch trials) were 99.9% and 4.6% respectively. Reaction times (RTs) shorter than 150 ms were removed, accounting for 0.2% of the total critical trials. RTs that were more than three standard deviations away from the overall mean across conditions for that participant were also discarded, accounting for another 1.3% of the critical trials.

A three-way repeated-measures analysis of variance (ANOVA) was conducted on mean RTs, with target location, word orientation and cue validity as three within-subjects factors. The only significant effect was cue validity, $F(2, 38) = 17.34$, $p < 0.001$, $\eta_p^2 = 0.48$, indicating that, collapsing over other conditions, RTs were faster for valid trials (M = 383 ms; SE = 12 ms) than for "invalid same word" trials (M = 409 ms; SE = 17 ms) and "invalid different words" trials (M = 418 ms; SE = 17 ms). A planned test showed that the difference of 9 ms between "invalid same word" and "invalid different words" trials was significant, $F(1, 19) = 10.09$, $p < 0.01$, $\eta_p^2 = 0.35$, demonstrating a lexical-based object effect. No other effects or interactions reached significance.

2.3. Discussion

Experiment 1, without a memory test, replicated Li and Logan (2008), who obtained an 8-ms lexical-based object effect. Also consistent with Li and Logan (2008), this experiment did not observe an interaction between this effect and other variables, such as the target location or the orientation of the compound words. Given that in some of the conditions, the cue character was the second constituent of a compound and the target character was the first constituent (for

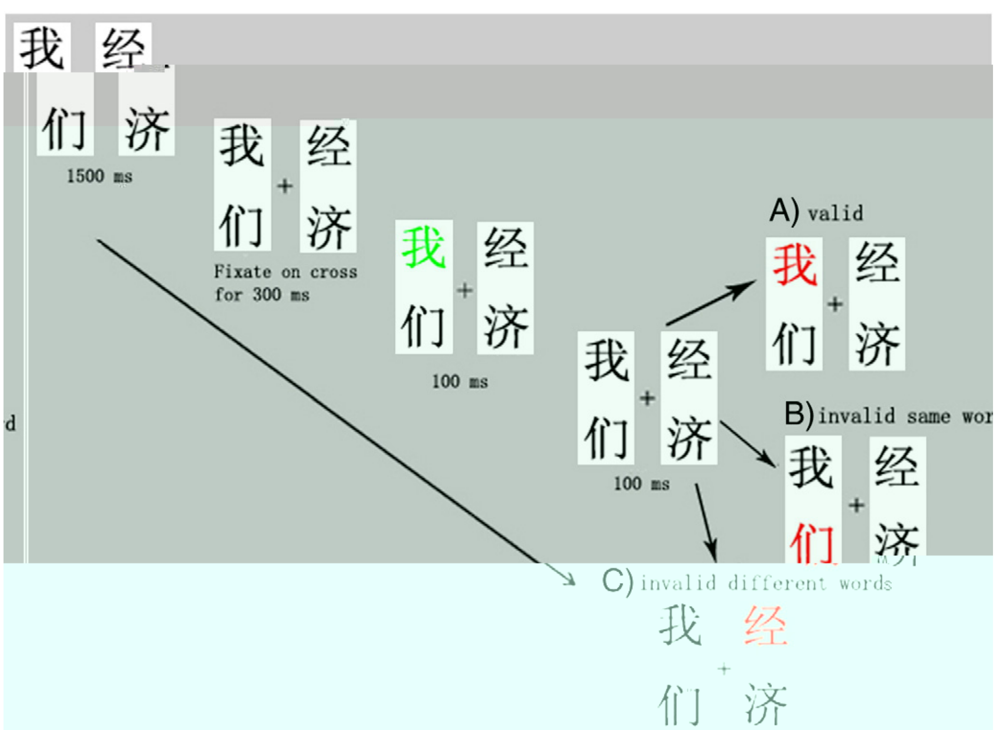

Fig. 1. Sequence of events in a single trial in Experiment 1. Four Chinese characters forming two compound words ("we" and "economic" in the example) were presented, and the participants were asked to press a response key when they detected the presence of a red color target after having seen a green color cue. (A) A valid trial: the color cue and the color target were on the same character. (B) An "invalid same word" trial: the cue character and the target character formed a compound word ("we"). (C) An "invalid different words" trial: the target was another character adjacent to the cue character, but these two characters formed a nonword. Note that the white background indicates which two characters formed a compound word in the figure, but it did not exist in the actual experiment. The background of display was completely in gray.

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characters forming the set of compounds were randomly combined to form nonwords, with the restriction that the four characters for a given trial were pronounced differently and were orthographically different.

Frequencies of the compound words were from 16 to 860 per million words, with an average of 77 per million. Each character had 3 to 12 strokes in writing, indicating that each character was of relatively low visual complexity. The same sets of words were used for Experiments 2A and 2B.

3.1.3. Procedures

The presentation of stimuli to participants in Experiment 2A or 2B was arranged in blocks such that each participant received trials for one stimulus type (4 blocks) and then another. The order of stimulus group was counter-balanced across participants. For each trial, the presentation of stimulus frames and the timing of each frame were the same as those in Experiment 1, except that when a display had two rectangles, they appeared simultaneously with characters and the outlines at one end of the rectangle surrounding the cue or the target character were also turned into green or red during the presentation of the cue or the target color. The latter manipulation was essential because if we had only highlighted characters, the rectangles could be treated as task-irrelevant objects and might not play a role in constraining attentional shift (but see the later discussion). When the two rectangles were shown, each rectangle subtended 0.9° in width and 2.5° in length. The width of the rectangle outlines was approximately 0.05° of visual angle.

3.2. Results

3.2.1. Eye movements

Participants made eye movements (leaving the fixation area, which was 0.8 × 0.8° of visual angle) in 4.2% (ranging between 0.7 and 10.4%) of all the trails in Experiment 2A and in 5.5% (1.5–10.9%) of the trails in Experiment 2B. These trials were excluded from further analysis. The percentage of excluded trials did not vary between conditions in either of the experiments.

3.2.2. Manual responses

The hit rate and the false alarm rate were 99.9% and 3.7% respectively in Experiment 2A and were 99.9% and 4.6% respectively in Experiment 2B. RTs shorter than 150 ms were removed, accounting for 0.04% and 0.2% of the total critical trials in Experiments 2A and 2B, respectively. RTs that were more than three standard deviations away from the grand mean for each participant were also discarded, accounting for another 0.9% and 1.2% of the trials in Experiments 2A and 2B, respectively. Mean RTs for different conditions are presented in Fig. 3.

A two-way repeated-measures ANOVA was conducted for Experiment 2A (and Experiment 2B), with stimulus type and cue validity as two within-subjects factors. In Experiment 2A, there was a significant main effect of stimulus type, $F(2, 40) = 5.40$, $p < 0.01$, $\eta_p^2 = 0.21$, with the RTs increasingly slower to the "rectangle with nonwords" trials (400 ms), the "congruent" trials (416 ms) and the "compounds only" trials (432 ms). The main effect of cue validity also was significant, $F(2, 40) = 20.20$, $p < 0.001$, $\eta_p^2 = 0.50$. Planned tests showed not only a cue validity effect, with faster RTs for valid trials (M = 402 ms; SE = 10 ms) than for "invalid same object" trials (M = 419 ms; SE = 13 ms), $F(1, 20) = 13.63$, $p < 0.005$, $\eta_p^2 = 0.41$, and than for "invalid different object" trials (M = 427 ms; SE = 13 ms), $F(1, 20) = 27.28$, $p <$ 0.001, $\eta_p^2 =$ [illegible] object than on a perceptual-based object. Both experiments also found an object effect, with faster responses to the "invalid same object" trials than to the "invalid different objects" trials. Importantly, in both experiments this object effect was of equivalent magnitude for the three types of stimuli: it was all of equal size to the effect for compound words presented alone.

The finding of object effects for all the types of stimuli suggests that attention shift is more efficient within an object than between objects, whether the object is defined in terms of lexical organization or in terms of Gestalt principles. However, the finding of equivalent effects for both the congruent and incongruent trials is perhaps surprising, given that the lexical-based and perceptual-based objects can independently produce effects during attention deployment. Intuitively, these effects should be able to cancel each other when they are in conflict and should be added up when they are congruent. A possible account for the overall pattern of the effects is that the cognitive processes underlying the two types of object effects interact with each other and this interaction does not produce an effect larger or smaller than the effect produced by the lexically or perceptually defined object alone.

An alternative account is that the processing system may rely on one type of object structure to constrain attention deployment while ignoring the other type. Thus for the "compound only" trials, the lexically defined object guided attentional shift; for the "rectangle with nonwords" trials, the perceptually defined object guided attentional shift. For the "congruent" and "incongruent" trials, however, it was the lexically rather than perceptually defined object that played an upper hand in constraining attentional shift.

One might wonder why the system should or could ignore the constraints from the rectangles, especially for the congruent trials. Note that we were careful to color the end of the rectangle surrounding the cue or target character simultaneously and the representations for both the lexical object and the perceptual object should be activated by the cue or the target. We suspect that the absence of modulation by the congruency between the two types of objects was due to the blocked presentation of different types of stimuli. In blocked presentation, the system could actively keep the activated lexical representations of compound words in working memory and use them to guide subsequent attentional shift. However, lexical representations and the rectangles were perceived as separate objects even though they were activated simultaneously. Constraints from the perceptual structure of the rectangles were strategically and actively suppressed during the shift of attentional focus from the cue character to the target character. This suppression was relatively easy given that in a test block the displays of characters and rectangles were essentially the same across trials and the same strategy can be applied to different trials.

If, however, different types of stimuli are randomly mixed, the system may be less able to suppress the constraints of rectangles on attentional shift and the overall object effect could be modulated by the congruency between the two types of objects. This possibility was tested in Experiment 3B.

4. Experiments 3A and 3B

In Experiments 2A and 2B, congruent trials and incongruent trials were tested separately. In Experiment 3A, we included the two types of stimuli in the same experiment to replicate the absence of congruency modulation in blocked presentation. Experiment 3B used the stimuli as Experiment 3A but with different types of stimuli randomly mixed. If the absence of modulation by the congruency between the two types of objects was indeed due to strategic adjustment of the processing system in face of blocked presentation, mixing stimuli randomly could effectively reduce the active suppression of the perceptual object, and the impact of congruency on the overall object effect could then be revealed.

4.1. Method

4.1.1. Participants

Twenty graduate and undergraduate students from Peking University and 20 students from Shaanxi Normal University were tested respectively for Experiments 3A and 3B. All of them were right-handed and had normal or corrected-to-normal vision. None of them had taken part in the previous experiments.

4.1.2. Design and materials

In each experiment, a 2 (stimulus type: congruent, incongruent) $\times$ 3 (cue validity: valid, invalid same object, invalid different objects) within-subjects factorial design was used. The definitions of stimulus type and cue validity were the same as in Experiments 2A and 2B. The word pairs were taken from those used in Experiments 2A and 2B. The assignment of stimuli into the congruent and incongruent conditions was counter-balanced over participants. There were 592 trials in total, with 512 critical trials having a color target and 80 catch trials without the target. For the critical trials, there were 256 (50%) valid trials and 128 trials (25%) for each of the two invalid conditions. Half of the trials were for the congruent condition and another half for the incongruent condition. The congruent and incongruent trials were presented in different blocks in Experiment 3A and were counter-balanced in order over participants, with the valid, "invalid same object", and "invalid different objects" trials being randomly mixed and being divided into 4 blocks of 74 trials each. In Experiment 3B, the "congruent" and "incongruent" trials were randomly mixed. Other aspects of stimulus preparation and experimental procedures were the same as in Experiments 2A and 2B.

4.2. Results

4.2.1. Eye movements

Participants made eye movements in 5.3% (ranging between 1.4 and 13.2%) of trails in Experiment 3A and in 7.1% (ranging between 1.0 and 13.2%) of trails in Experiment 3B. These trials were excluded from further analysis. The percentage of excluded trials did not vary between conditions.

4.2.2. Manual responses

The hit rate and the false alarm rate were 99.9% and 2.8% respectively in Experiment 3A and were 99.9% and 3.9% respectively in Experiment 3B. RTs shorter than 150 ms were removed, accounting for 0.06% of the critical trials in Experiment 3A and for 0.21% of the critical trials in Experiment 3B. RTs that were more than three standard deviations away from the grand mean for each participant were also discarded, accounting for another 1.2% of the critical trials in Experiment 3A and 1.0% in Experiment 3B. Mean RTs for different conditions are presented in Fig. 4.

A two-way repeated-measures ANOVA was conducted for RTs in Experiment 3A, with stimulus type and cue validity as two within-subjects factors. The main effect of stimulus type did not reach significance, $F(1, 19) = 1.28$, $p = 0.27$, $\eta_p^2 = 0.06$, although it is clear on the left panel of Fig. 4 that responses were generally faster (by about 10 ms) to the congruent stimuli than to the incongruent stimuli. The main effect of cue validity was significant, $F(2, 38) = 10.71$, $p < 0.001$, $\eta_p^2 = 0.36$, with the mean RTs increasingly longer over the valid (M = 416 ms; SE = 12 ms), "invalid same object" (M = 425 ms; SE = 14 ms), and "invalid different objects" (M = 431 ms; SE = 15 ms) conditions. Planned test showed not only the cue validity effect but more importantly the object effect: the difference of 6 ms between "invalid same object" and "invalid different objects" trials was significant, $F(1, 19) = 4.96$, $p < 0.05$, $\eta_p^2 = 0.21$. The interaction between cue validity and stimulus type was not significant, $F(2, 38) = 0.31$, $p = 0.74$, $\eta_p^2 = 0.02$, indicating that the object effect did not differ between the congruent and incongruent conditions.

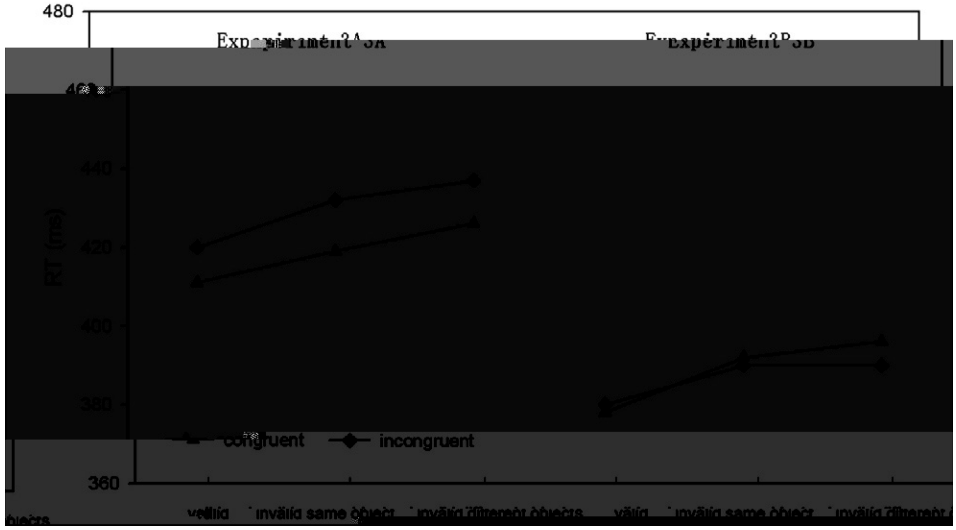

Fig. 4. Mean reaction times (RTs) in Experiments 3A and 3B, plotted as a function of stimulus types and cue condition.

A similar ANOVA for RTs in Experiment 3B did not find a significant main effect of stimulus type, F(1,19) = 0.73, p = 0.40, $\eta_p^2 = 0.04$. However, it did find a significant main effect of cue validity, F(2, 38) = 11.94, p < 0.001, $\eta_p^2 = 0.39$, with the mean RTs increasingly longer over the valid (M = 379 ms; SE = 10 ms), "invalid same object" (M = 391 ms; SE = 12 ms), and "invalid different objects" (M = 393 ms; SE = 12 ms) conditions. Planned test showed only the cue validity effect but not the object effect: the difference of 2 ms between "invalid same object" and "invalid different objects" trials was only approaching significance, F(1, 19) = 3.10, p = 0.09, $\eta_p^2 = 0.14$. Given that the interaction between cue validity and stimulus type was significant, F(2, 38) = 3.86, p = 0.03, $\eta_p^2 = 0.17$, further analyses was conducted. The object effect reached significance for the congruent trials (5 ms), F(1,19) = 5.25, p = 0.03, $\eta_p^2 = 0.22$, but not for the incongruent trials (−1 ms), F(1,19) = 0.11, p = 0.75, $\eta_p^2 = 0.01$.

4.3. Discussion

Experiment 3A replicated the general findings in Experiment 2A and 2B. Although the overall object effect was significant for both congruent and incongruent trials, this effect was not modulated by the congruency between the two types of objects. More importantly, when different types of stimuli were randomly mixed in Experiment 3B, we did observe the modulation of the object effect by the congruency: the object effect was present for the congruent trials but not for the incongruent trials. Random presentation of different types of stimuli might have prevented the participants from forming response strategies that ignore or suppress the constraints of perceptual structure during attention deployment.

To consider how this happened, let's recall that we defined the "invalid same object" and "invalid different object" trials according to whether the cue and the target characters formed a compound word. That is, the "object" here was lexically defined. For the congruent trials (Fig. 2B), in the "invalid different object" condition, attention had to cross the perceptual boundary of the rectangles in order to shift from a cue character (e.g., 我, /wo/) to the target character (e.g., 经, /jing/). For the incongruent trials (Fig. 2C), however, attentional shift could be actually facilitated by the perceptual structure of the rectangles in the "invalid different object" condition. It is clear from Fig. 3 (right panel) that responses in the "invalid different object" condition were indeed faster (6 ms) for the incongruent trials than for the congruent trials, *t*(19) = 1.91, p = 0.07. These faster responses could be the reason for the absence of an object effect for the incongruent trials. Note that, this use of perceptual structure of rectangles to guide attentional shift appeared to be suppressed in blocked presentation of congruent and incongruent trials, as these trials showed the same pattern of responses in Experiment 3A (also see Experiments 2A and 2B).

5. General discussion

The present study investigated how attention deployment is jointly affected by objects formed through top-down lexical organization (the compound words) and objects formed through Gestalt principles (the rectangles). Experiment 1 replicated Li and Logan (2008) by showing that attentional shift between Chinese characters is influenced by whether the two characters form a compound word. Experiments 2A, 2B and 3A demonstrated that regardless of whether the compound word was presented within a rectangle (the congruent condition) or between rectangles (the incongruent condition), the size of the object effect did not change significantly, as compared with the effect based purely on lexical organization or with the effect produced by rectangles containing characters forming nonwords. With random presentation of different types of stimuli, Experiment 3B, however, found that the object effect could be affected by the congruency between the two types of objects: the object effect was significant for the congruent trials, but was completely absent for the incongruent trials. This absence of the object effect seemed to be due to faster responses in the "invalid different object" condition in which the perceptual structure of the rectangles guided attentional shift. Overall, these findings suggest that when lexical- and perceptual-based objects are jointly manipulated, the processes that constrain attention deployment over conjoined objects can be strategically adjusted, depending on how different types of stimuli are presented.

A simple account for the equivalent object effects across different types of stimuli in Experiments 2A, 2B, and 3A assumes that in blocked presentation of different types of stimuli, constraints of the perceptual structure of rectangles on attention deployment are actively suppressed, even though the participants did process the perceptual structure of the rectangles and this processing speeded up the overall responses (see later discussion). Because of the block presentation of stimulus type and because the participants were allowed to preview the visual display before the cue appeared in each trial, the participants could focus attention more on objects formed through lexical organization than on objects formed through Gestalt principles. That the color patch on the character was perceptually more salient than the color information on the outlines of one end of the rectangle helped the system to focus on characters than on the outlines of rectangles. Moreover, the activated semantic representations of compound words help to keep the visual structure (the layout) of the compounds in working memory, guiding subsequent attentional shift from the cue character to the target character. It is no wonder that the processing system is predominantly influenced by constraints of the lexically defined object in shifting attentional focus: the shift of attention was more efficient along characters forming a compound (i.e., in the "invalid same object" condition) than along the rectangle (i.e., in the "invalid different objects" condition), producing faster responses to the color target in the former than in the latter. Indeed, the functioning of the lexically defined object overshadowed the potential impact of the perceptually defined object not only when the object structures were incongruent but also when they were congruent: even when the perceptual structure of the rectangles could help to facilitate attentional shift, the object effect was still of the same magnitude as the effect for compound words alone (Experiment 2A).

The suggestion that constraints from the perceptual structure of the rectangles can be strategically suppressed during attentional shift was further supported by the finding that in random presentation of different types of stimuli, the object effect *was* modulated by the congruency between the two types of objects. Here the strategy of suppressing constraints from the perceptual structure of the rectangles, which can be formed relatively easily and can be applied to different trials in blocked presentation, would be costly to be applied because the congruency between the two types of objects varied constantly over trials, even though the participants could preview the arrays of characters and rectangles before seeing the cue and the target (c.f., Fig. 1). Thus in random presentation, the system is susceptible to the impact of constraints from both lexically and perceptually defined objects during attentional shift from the cue to the target. How the two types of constraints work together is a question for further research.

In Experiments 2A and 2B, we also found that the overall RTs were the slowest to characters forming compounds but presented alone, the fastest to characters forming nonwords and presented in rectangles, and intermediate to characters forming compounds and presented congruently or incongruently with the rectangles. We suggest that this pattern of the overall RTs is mainly due to visual structure of rectangles helping the processing system to group characters into compounds. It is relatively difficult for the representations of two compound words in the lexicon, activated by the four characters in a visual display, to be used in segmenting the four characters into two objects and in guiding attentional shift on these objects. However, when these words are accompanied by rectangles and when different types of stimuli were blocked, participants could use the rectangle as clue to the orientation of compound words. This in turn would speed up attentional shift between characters in general. Nevertheless, it should be noted that this use of visual information in rectangles is workable only when different types of stimuli were presented in blocks.

In summary, by using the two-rectangle cueing paradigm (Egly et al., 1994) and by presenting Chinese characters forming compounds within or between rectangles, the present study demonstrated that attentional shift between characters is constrained by top-down lexical organization (Li & Logan, 2008) and that the processes underlying the lexical- and perceptual-based object attention can be strategically adjusted for the deployment of attention over conjoined objects.

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