Exp Brain Res (2013) 225:37 45
DOI 10.1007/s00221-012-3346-7

P. Wei (✉) · G. Kang
Beijing Key Laboratory of Learning and Cognition,
Department of Psychology, Capital Normal University,
Beijing 100048, China
e-mail: aweiping@gmail.com

X. Zhou (✉)
Department of Psychology, Center for Brain and Cognition
Sciences, Peking University, Beijing 100871, China
e-mail: xz104@pku.edu.cn

these studies, a target is mixed with a number of to-be-searched items in the central search display around the fixation point, and a to-be-ignored flanker item, either congruent or incongruent with the target, is presented at left or right periphery. The perceptual load in the central search display is manipulated in different ways, including mixing the target with fewer or more distractors (e.g., Lavie and de Fockert 2003), presenting visually homogeneous or heterogeneous distractors (e.g., Johnson et al. 2002; Lavie and Cox 1997; Wei and Zhou 2006), or varying the processing requirement such that the target identification requires either the registration of a simple feature or the integration of two or more features (e.g., Lavie 1995; Chen 2003). The flanker congruency is manipulated by varying the peripheral flanker which potentially requires either the same response as the target (the congruent condition) or the opposite response (the incongruent condition). The differences between response times (RTs) to the incongruent stimuli and congruent stimuli are denoted as the flanker congruency effects (Eriksen and Eriksen 1974). It is found that the congruency effect is larger when the processing of the central display and identifying the target are of low perceptual load, and smaller or null when the processing of the central display and identifying the target are of high perceptual load (Lavie 2005). The absence or presence of the congruency effect is taken as an indicator of whether or not early attentional selection has taken place.

However, the perceptual load theory of selective attention has been accused of "using general terms without implicating proximity or salience… the functional role of perceptual load becomes void and the theory becomes unfalsifiable" (Tsal and Benoni 2010, pp. 1665–1666). This theory has to be supplemented with detailed analysis of cognitive processes and mechanisms underlying the consumption of resources by central perceptual load and the spillover of spare resources to the periphery (i.e., the processing of the flanker). It is possible, for example, that the appearance or absence of the flanker congruency effect in the manipulation of perceptual load is a result of local competitive interactions in visual cortex, not the consequence of whether the overall capacity per se is exhausted (Torralbo and Beck 2008). According to Luck et al. (1997), the simultaneous processing of multiple objects, in particular, objects falling within the relatively large receptive fields of the same populations of neurons in extrastriate cortex, may lead to ambiguity in neural coding for individual objects. The ambiguity becomes severe when the distance between simultaneously presented items is smaller (Hopf et al. 2006; Torralbo and Beck 2008), when more items are presented (Wei et al. 2008), or when distracting stimuli share features with the target (Wei et al. 2008). As a result, the neural representation (and the bottom-up perceptual salience) of a target stimulus is diminished by the presence of nearby items (Kastner et al. 1998; Mounts and Gavett 2004; Mounts and Tomaselli 2005; Petrov et al. 2005; Reynolds et al. 1999).

Moreover, the perceptual load theory of attentional selection needs to take into other factors that may modulate the distribution and consumption of attentional resources. Laterality studies suggest that the competition between the target representation and distractor representations becomes severe when critical items are presented within a hemisphere rather than across hemispheres (Banich 1998; Nishimura and Yoshizaki 2010; Nishimura et al. 2009; Torralbo and Beck 2008). For example, Torralbo and Beck (2008) asked participants to search for a target letter among an array of letters arranged in an arc around a 'flanker' centered at fixation. The target was either within the same hemifield as two distractor letters or it appeared alone in one hemifield and the distractors appeared in another hemifield. The central flanker could be congruent or incongruent with the target. Results showed a greater flanker effect when the target and the distractors were presented in different hemifields than when they were in the same hemifield. Similarly, Nishimura and Yoshizaki (2010) found that a flanker was excluded from processing if it was presented to a high-loaded visual hemisphere; however, if it was presented to a low-loaded hemisphere, the flanker was processed and caused flanker interference. These findings suggest that competition for representation in each visual hemisphere may underlie the perceptual load effect and determine the degree to which the task-irrelevant information is processed.

Given these findings and given that the previous research on the role of perceptual load in attentional selection has generally mixed trials in which the flanker and the target are presented in the same or different visual fields, it is important to manipulate the perceptual load and flanker congruency as a function of hemifield. In the conditions where the target is intermixed with several non-targets in the central display, with the flanker being presented to the left or right side of the central display, the target and the flanker are essentially presented within the same hemifield for half of trials and are presented across different hemifields for the other half of trials. When the flanker and the target are presented within the same hemifield, the peripheral flanker is close to the target and thus may have more ambiguity in representation as compared to the condition in which the flanker and the target are presented across different hemifields. The interference from the peripheral flanker on the selection of the central target and the flanker congruency effect may thus be affected by both the perceptual load of the central display and the relative location of the flanker and the target.

To test this hypothesis, we conducted two experiments in which participants were asked to search for a target bar in the central display (six positions around the fixation point, with three at the left hemifield and another three at the right hemifield) while ignoring the congruent or incongruent flanker bar presented to the left or right side of the central display (Experiment 1) or at one of the six positions outer to the central display (Experiment 2). In the two experiments, the position of the peripheral flanker was different: in Experiment 1, the peripheral flanker was relatively fixed at the left or right hemifield, while in Experiment 2, the peripheral flanker location was randomly selected. For the low perceptual load conditions, the distractor bars in the central display were oriented homogeneously (i.e., in the same direction); for the high perceptual load conditions, these distractor bars were oriented heterogeneously (i.e., in different directions). Importantly, the target and the flanker could be presented either within the same hemifield or across left and right hemifields. To rule out an alternative account for the findings in Experiments 1 and 2, we conducted Experiment 3 which employed essentially the same design as Experiment 1 but presented the central target and the peripheral flanker at the upper and/or lower visual field.

Method

Participants

Twenty undergraduate or graduate students (14 females, 18–27 years of age), another twenty-one students (17 females, 17–25 years of age), and a third group of sixteen students (9 females, 19–27 years of age) participated in Experiments 1, 2 and 3, respectively. They were all right-handed, had normal or corrected-to-normal vision and had no known cognitive or neurological disorders. They gave informed consent to take part in the study and were paid for their participation.

Design and materials

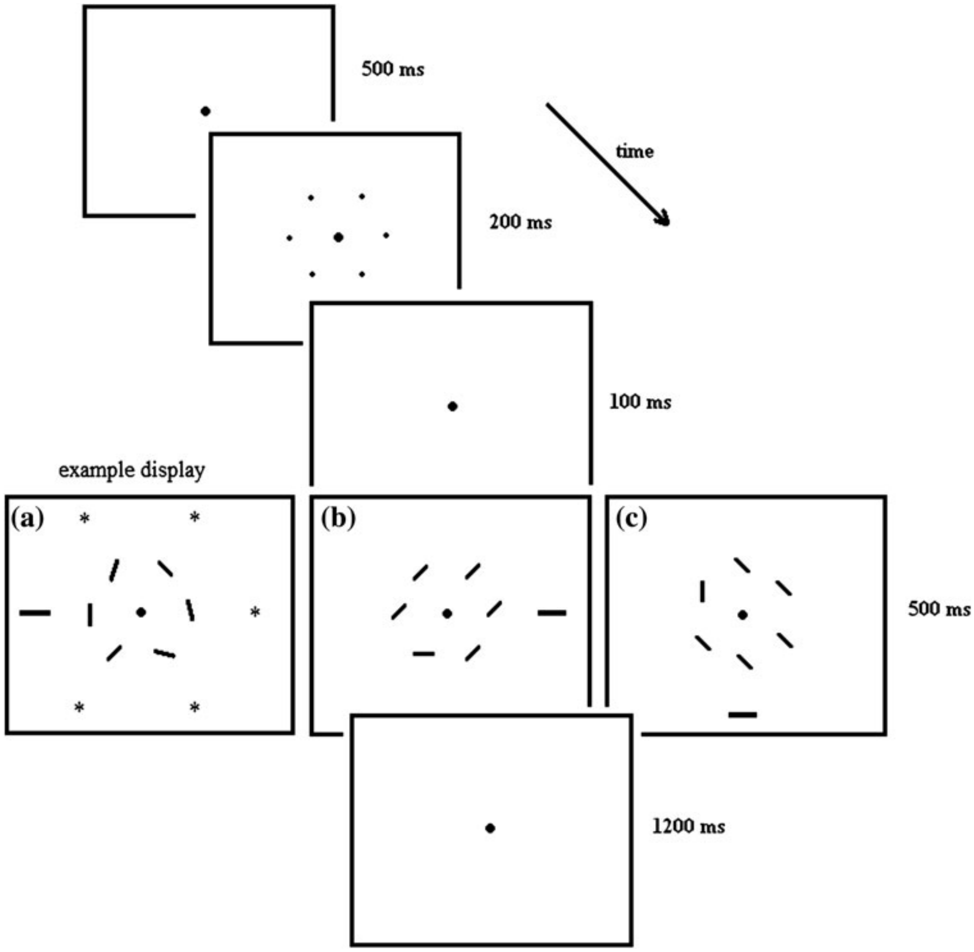

Fig. 1 Example of trial sequence. Example display **a** simulates high perceptual load condition; the target and the flanker are incongruent and are presented to the same visual field. *Stars* (not shown in the real search display) are referring to the other possible positions of the peripheral flanker in Experiment 2. Example display **b** simulates low perceptual load condition; the target and the flanker are congruent and are presented across left and right hemifields. Example display **c** simulates low perceptual load; the target and the flanker are incongruent and are presented across upper and lower visual fields in Experiment 3. The second frame in which dots indicating the positions of to-be-searched items in the central display were changed accordingly in Experiment 3

The total 768 experiment trials were divided into four sessions, with each experimental condition having 24 trials in each session. Trials in each session were pseudo-randomized. Participants practiced 96 trials before the formal experiment. There was a 2-min break between sessions.

Results

Incorrect responses were excluded from the analyses of RTs. Moreover, RTs more than three standard deviations above or below the mean in each experimental condition for each participant were discarded as "outliers" (0.50, 0.47 and 1.08 % of the total data point in Experiments 1, 2 and 3, respectively). Mean RTs and response error percentages are reported in Table 1 for each experimental condition. Flanker congruency effects, collapsed over Experiment 1 and 2, are reported in Fig. 2.

Experiment 1

An analysis of variance (ANOVA) was conducted on RTs, with the perceptual load of the central search display (high vs. low load), the congruency between the target and the flanker (congruent vs. incongruent), and the relative location of the target and the flanker (same vs. different hemifields) as three within-participant factors. Results showed a significant main effect of central search load, $F(1, 19) = 24.67$, $p < .001$, suggesting that the overall RTs were slower to displays of high load (834 ms) than to displays of low load (778 ms). Although the main effect of flanker congruency was not significant, $F(1, 19) = 1.10$, $p > .1$, it nevertheless interacted with the central perceptual load, $F(1, 19) = 8.81$, $p < .01$. Planned pairwise comparisons showed that RTs did not differ between the congruent and incongruent trials in the high load conditions (838 vs. 830 ms), $t(19) = 1.48$, $p > .1$, but did differ in the low load conditions (771 vs. 789 ms), $t(19) = 3.89$, $p < .005$. The flanker congruency was also interacted with the relative location of the target and the flanker, $F(1, 19) = 14.71$, $p < .005$. Planned pairwise comparisons showed that RTs did not differ between the congruent and incongruent trials when the target and the flanker were presented within the same hemifield (806 vs. 799 ms), $t(19) = 1.74$, $p = .1$, but differed when the target and the flanker were presented across different hemifields (802 vs.

Table 1 Mean reaction times (ms), standard errors (in parentheses) and error percentages in Experiments 1, 2 and 3

		Relative location between the target and the anker							
		Same visual eld				Different visual elds			
		Congruent		Incongruent		Congruent		Incongruent	
		RT (SE)	Error	RT (SE)	Error	RT (SE)	Error	RT (SE)	Error
Exp. 1	High load	840 (49)	15.1	823 (46)	15.1	837 (48)	16.1	837 (46)	17.8
	Low load	773 (42)	9.5	776 (40)	11.6	768 (41)	9.4	796 (41)	11.9
Exp. 2	High load	900 (33)	16.0	900 (34)	16.2	913 (35)	16.2	911 (34)	17.2
	Low load	867 (35)	10.6	858 (34)	9.9	856 (33)	9.3	878 (33)	11.3
Exp. 3	High load	839 (34)	10.0	843 (37)	10.3	858 (36)	12.8	869 (34)	12.2
	Low load	809 (39)	6.1	812 (41)	7.4	833 (41)	8.6	836 (41)	8.0

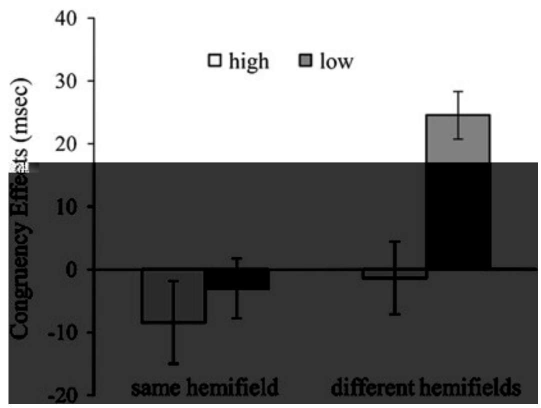

Fig. 2 Flanker congruency effects, collapsed over Experiment 1 and 2, are reported as functions of perceptual load and the relative location between the target and the anker

816 ms), $t(19) = 3.42$, $p < .005$. These interactions suggested that the magnitude of the anker congruency effect was affected by both the central perceptual load and by the relative location between the target and the anker. No other main effects or interactions reached signi cance.

Separate ANOVAs, with the central perceptual load and the anker congruency as two within-participant factors, were conducted for trials in which the target and the anker were in the same hemi eld and for trials in which the target and the anker were across different hemi elds. When the target and the anker were in the same hemi eld, only the main effect of perceptual load was signi cant, $F(1, 19) = 23.88$, $p < .001$, with longer RTs for the high load conditions (831 ms) than for the low load conditions (775 ms). The main effect of anker congruency was not signi cant, $F(1, 19) = 3.06$, $p = .096$, nor was the interaction between anker congruency and perceptual load, $F(1, 19) = 2.54$, $p > .1$.

When the target and the anker were presented across left and right hemi elds, however, both the main effect of the perceptual load and the main effect of the anker congruency were signi cant, $F(1, 19) = 19.15$, $p < .001$, and $F(1, 19) = 11.86$, $p < .005$, respectively. RTs were longer for the high load conditions (837 ms) than for the low perceptual conditions (782 ms) and were longer for the incongruent conditions (816 ms) than for the congruent conditions (803 ms). Importantly, the interaction between the two factors was signi cant, $F(1, 19) = 6.69$, $p < .05$. Planned pairwise comparisons showed that RTs did not differ between the incongruent and congruent trials in the high load conditions (837 vs. 837 ms), $t(19) < 1$, but they did differ in the low load conditions (796 vs. 768 ms), $t(19) = 4.92$, $p < .001$.

Analyses of error rates revealed a signi cant main effect of perceptual load, $F(1, 19) = 29.59$, $p < .001$, with more errors committed to high load trials (16.0 %) than to low load trials (10.6 %). The main effect of congruency was also signi cant, $F(1, 19) = 6.28$, $p < .05$, with more errors on incongruent trials (14.1 %) than on congruent trials (12.5 %). No other effects or interactions reached signi cance.

Experiment 2

ANOVA conducted on RTs revealed a signi cant main effect of perceptual load, $F(1, 20) = 35.43$, $p < .001$, with overall RTs being slower to trials of high load (906 ms) than to trials of low load display (865 ms). The main effect of anker congruency did not reach signi cance, $F(1, 20) < 1$. However, the interaction between anker congruency and the relative location of the anker and the target was marginally signi cant, $F(1, 20) = 3.85$, $p = .06$; the three-way interaction between anker congruency, perceptual load, and relative location was signi cant, $F(1, 20) = 5.35$, $p < .05$. These interactions indicated that the anker congruency effect appeared only in speci c conditions (i.e., the low load condition in which the anker and the target appeared in different hemi elds). Separate ANOVAs for trials with the target and the anker in the same hemi eld and for trials with the target and the flanker across left and right hemifields confirmed this observation.

When the target and the flanker were in the same hemifield, only the main effect of perceptual load was significant, $F(1, 20) = 18.35$, $p < .001$, with longer RTs for high perceptual load conditions (900 ms) than for low perceptual load conditions (862 ms). However, when the target and the flanker were across left and right hemifields, not only the main effect of perceptual load was significant (912 vs. 867 ms), $F(1, 20) = 36.14$, $p < .001$, the interaction between flanker congruency and perceptual load was also significant, $F(1, 20) = 6.03$, $p < .05$. Planned pairwise comparisons then showed that RTs did not differ between incongruent and congruent trials in the high load conditions (911 vs. 913 ms), $t(20) < 1$, but they did differ in the low load conditions (878 vs. 856 ms), $t(20) = 4.15$, $p < .005$.

Analyses of error rates revealed a significant main effect of central search load, $F(1, 20) = 37.72$, $p < .001$, with more errors committed to high load stimuli (16.4 %) than to low load stimuli (10.3 %). The interaction between the location factor and the flanker congruency was significant, $F(1, 20) = 5.04$, $p < .05$. When the target and the flanker were presented within the same hemifield, the error rates did not differ between the congruent (13.3 %) and incongruent (13.1 %) conditions, $t(20) < 1$. However, when the target and the flanker were presented across left and right hemifields, participants made more errors in the incongruent condition (14.2 %) than in the congruent condition (12.7 %), $t(20) = 3.12$, $p < .01$. No other main effects or interactions reached significance.

Overall analysis of RTs across Experiments 1 and 2

ANOVA was conducted on RTs, with the perceptual load of the central search display (high vs. low load), the congruency between the target and the flanker (congruent vs. incongruent), and the relative location of the target and the flanker (same vs. different hemifields) as the three within-participant factors, and the experiment as the between-participant factors. There was a significant main effect of perceptual load, $F(1, 39) = 55.26$, $p < .001$, and a significant main effect of the relative location of the flanker and the target, $F(1, 39) = 5.45$, $p < .05$, with RTs slower to trials of high load than to trials of low load (870 vs. 821 ms), and slower to trials with the flanker and the target in different hemifields than to trials with the flanker and the target in the same hemifield (850 vs. 842 ms). Importantly, although the main effect of flanker congruency was not significant, $F(1, 39) < 1$, it interacted with perceptual load, $F(1, 39) = 9.27$, $p < .005$, with relative location, $F(1, 39) = 14.91$, $p < .001$, and with both perceptual load and relative location, $F(1, 39) = 3.48$, $p = .07$. The experiment as the between-participant factor did not interact with any factors, indicating that the two experiments obtained essentially the same pattern of effects.

Separate analysis for trials with the flanker and the target in the same hemifield did not find any significant effects or interactions apart from the main effect of perceptual load, $F(1, 39) = 42.54$, $p < .001$. However, analysis for trials with the flanker and the target in different hemifields found not only a significant main effect of flanker congruency, $F(1, 39) = 12.05$, $p < .005$, but also an interaction between flanker congruency and relative location, $F(1, 39) = 12.76$, $p < .005$. It is clear from Fig. 2 that the flanker congruency effect appeared only when the flanker and the target appeared across left and right hemifields (837 vs. 812 ms), as confirmed by the planned test, $F(1, 39) = 41.28$, $p < .001$.

Experiment 3

ANOVA conducted on RTs showed a significant main effect of perceptual load, $F(1, 15) = 9.28$, $p < .01$, suggesting that RTs were slower to displays of high load (852 ms) than to displays of low load (822 ms). The main effect of the relative location of the flanker and the target was significant, $F(1, 15) = 25.68$, $p < .001$, such that the overall RTs were slower when the target and the flanker were presented across visual fields (849 ms) than when they were presented within the same visual field (826 ms). However, the main effect of flanker congruency was not significant, $F(1, 15) = 1.21$, $p > .1$, nor the interaction between flanker congruency, perceptual load or the relative location, $Fs(1, 15) < 1$.

Analyses of error rates revealed a significant main effect of perceptual load, $F(1, 15) = 22.75$, $p < .001$, with more errors committed to high load stimuli (11.3 %) than to low load stimuli (7.5 %). The main effect of relative location was significant, with more errors committed when the target and the flanker were presented across visual fields (10.4 %) than when they were presented within the same visual field (8.4 %). No other main effects or interactions reached significance.

Discussion

Experiments 1 and 2 obtained essentially the same pattern of effects. While the perceptual load of the central display affected RTs to the target, the appearance of the flanker congruency effects depended not only on the perceptual load, but also on the relative location of the flanker and the target. There was no flanker congruency effect for trials with high perceptual load, regardless of the flanker positions in the visual fields. The congruency effect did appear in the low perceptual load trials, but only when the flanker and the target were presented across left and right hemifields. Moreover, when the target and the flanker were presented in the same or different upper-lower visual fields as in Experiment 3, there was no main effect of flanker congruency effect, nor its modulation by perceptual load or the relative location between the target and the flanker.

Clearly, the pattern of effects obtained in Experiments 1 and 2 is not wholly compatible with the perceptual load theory of attentional selection in its current form (Lavie 1995, 2005; Lavie et al. 2004; Lavie and Tsal 1994). Although this theory does predict the absence of the flanker congruency effect when the perceptual load of the central display was high, it does not predict the interaction between the congruency effect and the relative location of the flanker and the central target.

Recent evidence suggests that competitive interaction in the visual cortex within each hemisphere underlies the modulation of perceptual load on attentional selection (Torralbo and Beck 2008; Nishimura and Yoshizaki 2010). When multiple objects fall within the relatively large receptive fields of the same groupings of neurons in the extrastriate cortex, the simultaneous processing may lead to ambiguity in neural coding for individual objects (the ambiguity resolution account, Luck et al. 1997) and lead to competition between representations for different items (Bahcall and Kowler 1999; Caputo and Guerra 1998; Mounts 2000a, b; Mounts and Gavett 2004; Mounts and Tomaselli 2005; Wei et al. 2008). This competition can be modulated by both the top-down task set (Benoni and Tsal 2010) and the relative bottom-up perceptual saliency between items (Lavie and Torralbo 2010; Marcianoa and Yeshuruna 2011; Wei and Zhou 2006; Wei et al. 2008).

According to the salience-based models of attention, such as Guided Search (Wolfe 1994), feature contrast values, signaling the extent to which an item differs from other items in its vicinity, are computed not only for the target, but also, in parallel, for the distractors and the flanker. In the present low perceptual load conditions, when the target and the flanker were projected to different hemifields, the flanker would have high perceptual salience since the nearby items (the three central distractors in the same hemifield) were homogenous; in contrast, when the target and the flanker were projected to the same hemifield, the flanker would have lower perceptual salience since now the flanker, the target, and the two distractors in this hemifield could have different orientations. Thus, the flanker could be more likely to win competition within its vicinity and interfere with the selection of the target in the different-hemifield condition than in the same hemifield condition. The absence of a significant flanker congruency effect for the low load, same hemifield condition could be due to the fact that the flanker with the lower perceptual salience was completely inhibited by the representation of the nearby target, which was supported by the top-down task set.

In the above arguments, we have implicitly assumed that there is a common pool of attentional resources for attentional selection across different hemifields. However, behavioral and neuroimaging studies of visual selective attention (Alvarez and Cavanagh 2005; Banich 1998; Pollmann et al. 2003; Torralbo and Beck 2008) and visual short-term memory (Delvenne 2005) have also found that parallel processing taking place in each hemisphere can lead to the most efficient processing of visual information, suggesting that each hemisphere may have a separate attentional resource pool (Nishimura and Yoshizaki 2010; Nishimura et al. 2009). If this suggestion is applied to the traditional perceptual load theory, the absence of a flanker congruency effect in the low load, same hemifield condition may be attributed to the exhausting of attentional resources in the particular hemifield. It is possible that processing the target and the two distractors in the central display had already used up available resources for the particular hemifield, leaving no spare resources for the processing of the flanker within this hemifield. Indeed, when the target and the flanker were presented to the same hemifield but without the company of distractors, as in Nishimura and Yoshizaki (2010), the flanker congruency effect *was* evident. When the target and the flanker were presented to separate hemispheres, however, given that the homogeneously oriented distractors could be rejected "in group" (Muller and Humphreys 1993; Muller et al. 1998), there would be sufficient resources for the processing of the flanker within its hemifield. Thus, the target in one hemifield and the flanker in the other hemifield may activate two competing response codes, and this competition, resolved finally by a cognitive control system (Lavie 2005), would delay the response to the target, leading to the flanker congruency effect in the low load, different hemifields condition.

The present study does not allow us to choose between the accounts based on one common resource pool versus separate pools for different hemifields for the interaction between flanker congruency and the relative location between the flanker and the target. However, Experiment 3 does allow us to reject a third, plausible account for this interaction. This account assumes that it is the distance between the flanker and the target rather than hemifield that determines whether the flanker congruency effect would appear in the low load conditions. Previous studies (Bahcall and Kowler 1999; Caputo and Guerra 1998; Mounts 2000a, b; Mounts and Gavett 2004; Mounts and Tomaselli 2005; Wei et al. 2008) have shown that representation ambiguity and hence local competition occurs only for items close to each other in space, not between items distant from each other. It is plausible that the presence of a flanker congruency effect for the low load, different hemifields condition and the absence of this effect for the low load, same hemifield condition were simply due to the fact that the distance between the flanker and the target was longer in the former than in the latter condition. Experiment 3 demonstrated that the distance per se is not the main factor determining the pattern of flanker congruency effects. Indeed, in Experiment 3, there was no flanker congruency effect for either the high or the low perceptual load condition, nor was there an interaction between flanker congruency and perceptual load. The absence of flanker congruency effect in the low load condition was inconsistent with the prediction of perceptual load theory, but replicated Nishimura and Yoshizaki (2010). In our Experiment 3 and in Nishimura and Yoshizaki (2010), the flanker was presented at the midline between the left and the right hemifields and thus could be represented by both hemispheres. Thus, the upper or lower flanker and the central display (including the target) were still represented within the same hemisphere, and this would lead to the same hemifield competition and the absence of the flanker congruency effect. Further studies are needed to investigate in detail the distribution of attentional resources over the upper and lower visual fields.

To conclude, by manipulating perceptual load of attentional selection and by presenting the target and the flanker in the same or different hemifields, we demonstrate that the flanker congruency effect can be modulated by the relative location between the flanker and the target. This finding, while challenging the perceptual load theory in the current form, is better understood in terms of competition between representations in the same or across hemifields.

Acknowledgments This study was supported by grants from the Natural Science Foundation of China (31000502, 30110972, 30970889) and by the National Basic Research Program of the Ministry of Science and Technology of China (973 Program: 2010CB833904). Electronic mail concerning this study should be addressed to Dr. Ping Wei, aweiping@gmail.com or to Dr. Xiaolin Zhou, xz104@pku.edu.cn.

References

Alvarez GA, Cavanagh P (2005) Independent resources for attentional tracking in the left and right visual fields. Psychol Sci 16:637–643
Bahcall DO, Kowler E (1999) Attentional interference at small spatial separations. Vis Res 39:71–86
Banich MT (1998) The missing link: the role of interhemispheric interaction in attentional processing. Brain Cogn 36:128–157
Benoni H, Tsal Y (2010) Where have we gone wrong? Perceptual load does not affect selective attention. Vis Res 50:1292–1298
Broadbent DE (1958) Perception and communication. Pergamon Press, London
Caputo G, Guerra S (1998) Attentional selection by distractor suppression. Vis Res 38:669–689
Chen Z (2003) Attentional focus processing load and Stroop interference. Percept Psychophys 65:888–900
Delvenne JF (2005) The capacity of visual short-term memory within and between visual fields. Cognition 96:79–88
Deutsch JA, Deutsch D (1963) Attention: some theoretical considerations. Psychol Rev 70:80–90
Eriksen BA, Eriksen CW (1974) Effects of noise letters upon the identification of a target in a non-search task. Percept Psychophys 16:143–149
Hopf JM, Boehler CN, Luck SJ, Tsotsos JK, Heinze HJ, Schoenfeld MA (2006) Direct neurophysiological evidence for spatial suppression surrounding the focus of attention in vision. Proc Natl Acad Sci USA 103:1053–1058
Johnson DN, McGrath A, McNeil C (2002) Cuing interacts with perceptual load in visual search. Psychol Sci 13:284–287
Kastner S, de Weerd P, Desimone R, Ungerleider LG (1998) Mechanisms of directed attention to human extrastriate cortex as revealed by functional MRI. Science 282:108–111
Lavie N (1995) Perceptual load as a necessary condition for selective attention. J Exp Psychol 21:451–468
Lavie N (2005) Distracted and confused?: Selective attention under load. Trends Cogn Sci 9:75–82
Lavie N (2010) Attention distraction and cognitive control under load. Curr Direct Psychol Sci 19(3):143–148
Lavie N, Cox S (1997) On the efficiency of visual selective attention: efficient visual search leads to inefficient distractor rejection. Psychol Sci 8:395–398
Lavie N, de Fockert JW (2003) Contrasting effects of sensory limits and capacity limits in visual selective attention. Percept Paychophys 65:202–212
Lavie N, Torralbo A (2010) Dilution: a theoretical burden or just load? A reply to Tsal and Benoni (2010). J Exp Psychol Hum Percept Perform 36:1657–1664
Lavie N, Tsal Y (1994) Perceptual load as a major determinant of the locus of selection in visual attention. Percept Psychophys 56: 183–197
Lavie N, Hirst A, de Fockert JW, Viding E (2004) Load theory of selective attention and cognitive control. J Exp Psychol Gen 133:339–354
Luck SJ, Girelli M, McDermott MT, Ford MA (1997) Bridging the gap between monkey neurophysiology and human perception: an ambiguity resolution theory of visual selective attention. Cogn Psychol 33:64–78
Mangun GR (1993) Neural mechanisms of visual selective attention. Psychophysiol 32:4–18
Marcianoa H, Yeshuruna Y (2011) The effects of perceptual load in central and peripheral regions of the visual field. Vis Cogn 19(3):367–391
Moran J, Desimone R (1985) Selective attention gates visual processing in the extrastriate cortex. Science 229:782–784
Mounts JW (2000a) Evidence for suppressive mechanisms in attentional selection: feature singletons produce inhibitory surrounds. Percept Psychophys 62:969–983
Mounts JW (2000b) Attentional capture by abrupt onsets and feature singletons produce inhibitory surrounds. Percept Psychophys 62:1485–1493
Mounts JW, Gavett BE (2004) The role of salience in localized attentional interference. Vis Res 44:1575–1588
Mounts JW, Tomaselli RG (2005) Competition for representation is mediated by relative attentional salience. Acta Psychol 18: 261–275
Muller HJ, Humphreys GW (1993) A connectionist model of visual search for simple form conjunctions. In: Brogan D, Gale A, Carr K (eds) Visual search 2. Taylor and Francis, London, pp 61–71

Muller HJ, Humphreys GW, Olson AC (1998) SEarch via recursive rejection (SERR). In: Wright RD (ed) Visual attention. Vancouver studies in cognitive science. Oxford University Press, New York, pp 389 416

Nishimura R, Yoshizaki K (2010) A high-loaded hemisphere successfully ignores distractors. Conscious Cogn 19(4):953 961

Nishimura R, Yoshizaki K, Kato K, Hatta T (2009) Hemisphere division and its effect on selective attention: a generality examination of Lavie's load theory. Int J Neurosci 119:1429 1445

Pashler H (1998) Attention. Taylor Francis, Philadelphia

Petrov Y, Carandini M, McKee S (2005) Two distinct mechanisms of suppression in human vision. J Neurosci 25:8704 8707

Pollmann S, Zaidel E, von Cramon DY (2003) The neural basis of the bilateral distribution advantage. Exp Brain Res 221:322 333

Reynolds JH, Chelazzi L, Desimone R (1999) Competitive mechanisms subserve attention in macaque areas V2 and V4. J Neurosci 19:1736 1753

Torralbo A, Beck DM (2008) Perceptual-load-induced selection as a result of local competitive interactions in visual cortex. Psychol Sci 19:1045 1050

Tsal Y, Benoni H (2010) Diluting the burden of load: perceptual load effects are simply dilution effects. J Exp Psychol Hum Percept Perform 36:1645 1656

Wei P, Zhou X (2006) Processing multidimensional objects under different perceptual loads: the priority of bottom-up perceptual saliency. Brain Res 1114:113 124

Wei P, Lu J, Muller HJ, Zhou X (2008) Searching for two feature singletons in the visual scene: the localized attentional interference effect. Exp Brain Res 185:175 188

Wolfe JM (1994) Guided search 2.0: a revised model of visual search. Psychon Bull Rev 1:202 238

Yantis S, Johnston JC (1990) On the locus of visual selection: evidence from focused attention tasks. J Exp Psychol Hum Percept Perform 16:135 149