RESEARCH ARTICLE

Attentional selection within and across hemispheres: implications for the perceptual load theory

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Abstract The perceptual load of a given task affects attentional selection, with the selection occurring earlier when the load is high and later when the load is low. Recent evidence suggests that local competitive interaction may underlie the perceptual load effect and determine to what extent a task-irrelevant distractor is processed. Here, we asked participants to search for a target bar among homogeneously oriented bars (the low load conditions) or heterogeneously oriented bars (the high load conditions) in the central display, while ignoring a congruent or incongruent flanker bar presented to the left or right side of the central display, or a bar presented at one of the six positions outer to the central display. Importantly, we differentiated conditions in which the target in the central display and the peripheral flanker was presented within the same hemifield or across different hemifields. Results showed a significant flanker effect for the low load condition, but not for the high load condition, when the target and the flanker were across hemifields. However, when the target and the flanker were presented within the same hemifield, there was no flanker effect for either low or high load conditions. These findings demonstrate that the ability to ignore the task-irrelevant distractor is affected by local competition within hemisphere and that the perceptual load theory needs to be supplemented with detailed analysis of cognitive processes and mechanisms underlying the consumption of attentional resources.

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Introduction

The ability to focus on a given task in face of irrelevant distracting information is vital for human cognitive functions. Studies have been conducted to investigate how and when the attentional process selects relevant information for further processing and prevents interference from irrelevant information (e.g., Lavie 2005; Mangun 1993; Moran and Desimone 1985; Pashler 1998; Yantis and Johnston 1990). The perceptual load theory of attention and cognitive control (Lavie 1995, 2005, 2010; Lavie et al. 2004; Lavie and Tsal 1994) resolves the classic debate between the *early* selection theory (e.g., Broadbent 1958) and the *late* selection theory (e.g., Deutsch and Deutsch 1963) by assuming that attentional resources are limited, and the perceptual load imposed by searching for and identifying the target among distracting information determines the extent to which the irrelevant information is processed. According to this theory, early selection occurs under situations of high perceptual load that exhausts available capacity in the processing of task-relevant information; late selection occurs under situations of low perceptual load in which spare attentional resources left from the processing of the relevant information automatically "spill over" to distractors, resulting in the processing of these distractors and its interference with the processing of the task-relevant information.

The perceptual load theory has received much empirical support (see Lavie 2005, 2010 for reviews). Typically in

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

A $2 \times 2 \times 2$ within-participant factorial design was used for each experiment, with the first factor referring to the perceptual load of the central display, the second factor referring to the flanker congruency, and the third factor referring to the relative location of the target and the flanker. A central search display consisted of six bars presented on an imagery circle around the central fixation, with one horizontally or vertically oriented target bar and five homogeneously or heterogeneously oriented distractor bars (Fig. 1). Three items in the central display were in the left hemifield and another three in the right hemifield in Experiments 1 and 2; three items in the central display were in the upper visual field and another three in the lower visual field in Experiment 3. The flanker bar, which was presented

at periphery outer to the display, was either horizontally or vertically oriented. It was congruent or incongruent with the target in the central display (i.e., potentially linking to the same or opposite response code). The flanker was presented at the same location in the left or right hemifield in Experiment 1, at one of the three locations in the left or right hemifield in Experiment 2, and at the same location in the upper or lower visual field in Experiment 3. The flanker and the target were either in the same visual field or across different visual fields. Participants were required to search for a vertically or a horizontally oriented bar in the central search display before making a discriminative response.
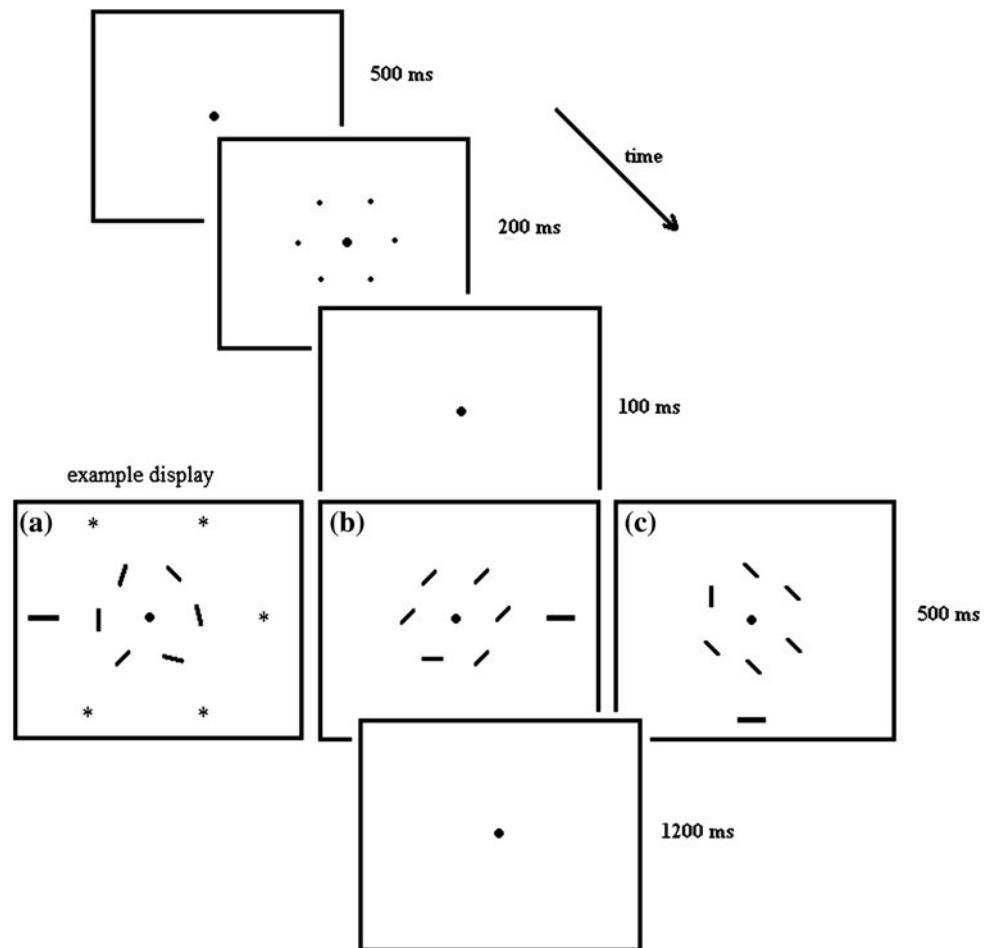
Each experiment had 768 trials in total, with each experimental condition having 96 trials. The target and the flanker were presented at their possible locations with equal probability. Each distractor bar in the central display could have an orientation of either left or right 22.5°, 45°, or 67.5°. For the high load conditions, the five distractor bars always had different orientations. For the low load conditions, although the distractor bars in each trial had the same orientation, bars with different orientations were equally likely used over different trials.

Procedures

The presenting of stimuli and recording of response times and error rates were controlled by Presentation software (http://nbs.neuro-bs.com/). Each trial lasted for 2,500 ms. At the start of each trial, a white fixation point measuring 0.10° in visual angle appeared at the center of the black screen for 500 ms, followed by the fixation point together with six dots surrounding the fixation for 200 ms. These dots formed an imaginary circle and indicated the locations of bars to be searched. After an interval of 100 ms during which the fixation point remained on the screen but the six dots disappeared, six bars appeared at the locations previously indicated by the six dots, together with a flanker bar outer to the central display. The center-to-center distance between central fixation and each bar around the fixation was 1.3° in visual angle, and the center-to-center distance between central fixation and the peripheral flanker was 3.2°. Each bar in the central display subtended 0.9° × 0.15° in visual angle, with equal distance between adjacent bars. The flanker bar also subtended 0.9° × 0.15° in visual angle. The viewing distance was held at 65 cm with a chinrest.

The search display and the flanker were presented for 500 ms, followed by the presentation of fixation point again for 1,200 ms. Participants were instructed to respond as quickly and as accurately as possible upon the presentation of the search display by pressing the left button of the computer mouse for horizontal bar and the right button for vertical bar. The assignment of response buttons to the target bars was counter-balanced over participants.

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.

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

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

When the target and the flanker were presented across left and right hemifields, however, both the main effect of the perceptual load and the main effect of the flanker

congruency were significant, $F(1, 19) = 19.15$, $p < .001$, 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 significant, $F(1, 19) = 6.69$, $p < .05$. 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 significant 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 significant, $F(1, 19) = 6.28$, $p < .05$, with more errors on incongruent trials (14.1 %) than on congruent trials (12.5 %). No other effects or interactions reached significance.

Experiment 2

ANOVA conducted on RTs revealed a significant 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 flanker congruency did not reach significance, $F(1, 20) < 1$. However, the interaction between flanker congruency and the relative location of the flanker and the target was marginally significant, $F(1, 20) = 3.85$, $p = .06$; the three-way interaction between flanker congruency, perceptual load, and relative location was significant, $F(1, 20) = 5.35$, $p < .05$. These interactions indicated that the flanker congruency effect appeared only in specific conditions (i.e., the low load condition in which the flanker and the target appeared in different hemifields). Separate ANOVAs for trials with the target and the flanker in the same hemifield and for trials with the.Sme SCogruent

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 perceptualf (10(12 TD[ftwere(1, 20)

in the low perceptual load trials, but only when the flanker and the target were presented across left and right hemi-fields. 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,

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.

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

Müller 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

Müller 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, Lü J, Müller 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