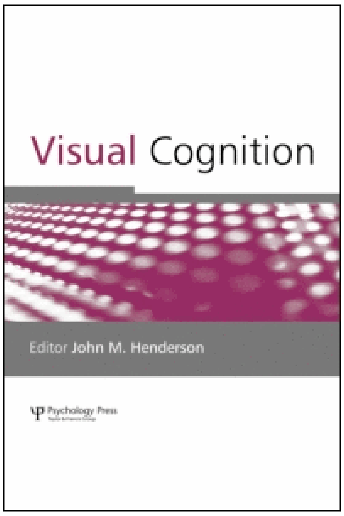

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The effects of perceptual load in central and peripheral regions of the visual field

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The effects of perceptual load in central and peripheral regions of the visual field

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The perceptual load model claims that attentional selectively depends on perceptual load. Selectivity is high with high load, but low with low load. Previous studies only manipulated load levels at task-relevant regions. In this study, perceptual load was orthogonally manipulated in both relevant (central) and nonrelevant (peripheral) regions, by varying the similarity between the target and nontarget letters and the nontarget letters' heterogeneity. The participants had to identify a target-letter appearing in a central circle of letters. A distractor-letter, appearing in a peripheral circle, was compatible, neutral, or incompatible with the target. As expected, increasing peripheral load deteriorated performance, but only with low levels of central load. The pattern of distractor interference did not follow the model's predictions because distractor interference under high load levels was occasionally found. The expected pattern of results emerged only when the spatial uncertainty regarding the distractor position was low, implying that spatial uncertainty plays an important role in attentional selectivity.

Keywords: Attention; Perceptual load; Peripheral load.

The optimal allocation of attention in a given task involves focusing on relevant stimuli and ignoring irrelevant stimuli. In some cases the attentional selectivity seems too high. Several studies have found that observers cannot report the presence of objects appearing outside the focus of attention (e.g., Mack, Pappas, Silverman, & Gay, 2002; Mack & Rock, 1998). In other cases, the attentional selectivity seems too low. For instance, observers often cannot ignore distracting irrelevant stimuli presented outside the regions of interest (e.g., Eriksen & Eriksen, 1974; Theeuwes, 1992). The fact that the

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selectivity of attention can be either high or low may seem contradictory. However, the perceptual load model (e.g., Lavie, 1995; Lavie & Cox, 1997; Maylor & Lavie, 1998) offers a theoretical account for both possibilities. It suggests that perceptual load is the critical factor that determines the extent to which nonattended information is processed. According to the model, as long as capacity limitations were not met, perceptual processing proceeds automatically on all stimuli, relevant or not. Once the capacity exceeds its limitations, irrelevant information can no longer be processed. When the relevant information imposes a high load, it exhausts the available processing capacity and, in turn, the processing of irrelevant information is prevented.

Following the finding that a search for a target appearing among dissimilar homogenous distractors is easier than a search for a target appearing among heterogeneous distractors that are similar to the target (Duncan & Humphreys, 1989), Lavie and Cox (1997) varied the load by changing the similarity between a target and nontarget letters and the heterogeneity of the nontarget letters. The target, “N” or “X”, was presented in one of six positions on an imaginary circle. The other five positions were occupied by either other heterogeneous letters (H, M, K, Z, W) in the high perceptual load condition, or by five homogeneous “Os” in the low perceptual load condition. The task was to indicate whether there was an X or an N in the circle of letters while ignoring a peripheral distractor letter. The distractor was either compatible with the target, incompatible, or neutral. A compatibility effect—incompatible reaction time (RT) minus neutral RT—was found in the low load condition but was absent in the high load condition. Hence, in accordance with the perceptual load model, the low load condition resulted in an inefficient suppression of distractors, while the high load condition resulted in an efficient suppression of distractors. Similar results were found with different stimuli and manipulations of the perceptual load (e.g., Bahrami, Lavie, & Rees, 2007; Brand-D’Abrescia & Lavie, 2007; Handy, Soltani, & Mangun, 2001; Lavie & Fox, 2000; Lavie & Robertson, 2001; Rorden, Guerrini, Swainson, Lazzeri, & Baylis, 2008; but see Khetrepal, 2010).

In these previous studies the load at the nonrelevant, often peripheral, regions of the display was always low or completely absent (i.e., only the distractor was present). Most real-life situations, however, are more complex involving varying degrees of load at both relevant and nonrelevant regions of the visual scene. The goal of this study is to examine the effect of perceptual load at nonrelevant regions on the selectivity of attention. To that end, we varied the levels of perceptual load not only in the centre of the visual field, as was done in the past, but also in the periphery of the visual field. We utilized the paradigm of Lavie and Cox (1997) with a single distractor in the periphery (i.e., no peripheral load) and added two additional peripheral load conditions: Low peripheral load and high peripheral load. Hence, the target was one of six letters appearing on an imaginary inner circle (Figure 1). The other letters on this circle were either all homogenous letters which were dissimilar from the target (five Os; low central load), or heterogeneous letters that share several figural features with the target (X, K, H, Y, V; high central

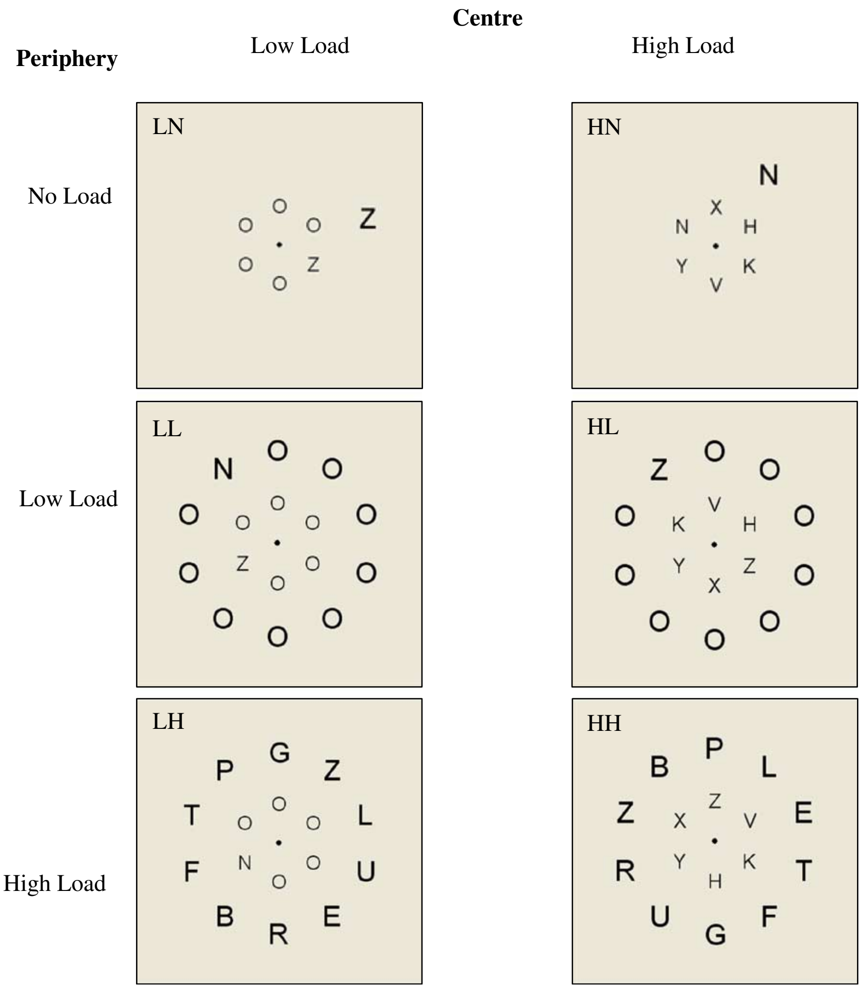

Figure 1. The various load conditions of Experiments 1: LN = low load in the central circle and no load in the peripheral circle (with a compatible distractor); HN = high load in the central circle and no load in the peripheral circle (with a compatible distractor); LL = low load in both central and peripheral circles (with an incompatible distractor); HL = high load in the central circle and low load in the peripheral circle (with a compatible distractor); LH = low load in the central circle and high load in the peripheral circle (with an incompatible distractor); HH = high load in both central and peripheral circles (with a compatible distractor).

load). In the no peripheral load condition there was only a single letter—the critical distractor—appearing in one of 10 possible locations on an imaginary outer circle. In the low peripheral load and high peripheral load conditions the critical distractor appeared with nine other letters following the same load manipulation as in the central load. The combination of the central and peripheral load manipulations resulted in six conditions: Low central load + no peripheral load (LN); high central load + no peripheral load (HN); low central load + low peripheral load (LL); low central load + high peripheral load (LH); high central load + low peripheral load (HL); and high central load + high peripheral load (HH).

In light of the assertion that each element in the display generates response noise, and the more features the target and the nonrelevant items share, the larger the detrimental effect of this noise (e.g., Eckstein, 1998), we expected to find an effect of peripheral load on general performance (mean RT and mean accuracy): Performance should deteriorate as the level of load at the periphery increases. However, according to the perceptual load model, this effect of peripheral load should be modulated by the levels of central load. Specifically, the effect of peripheral load should be present only under low levels of central load when resources for processing of peripheral information are available. When central load is high the load level of peripheral information should not matter as there are no available resources to process anything but the relevant central information. Furthermore, regarding distractor interference, when there is no peripheral load we expected to replicate the findings of previous studies of the perceptual load model (e.g., Lavie & Cox, 1997): Distractor interference should be relatively high with low levels of central load, but it should be relatively low with high levels of load at the centre. However, when the levels of peripheral load are high, we expected to find low distractor interference under both central load conditions, as it is likely that the high peripheral load will render the distractor less visible and therefore less interfering.

Similar predictions also follow from the dilution account. Tsal and Benoni (2010) claim that when the levels of perceptual load are manipulated via a change in set size, the typical lack of interference under high (central) load level is not due to the increase in load level but to an effect of dilution. The addition of neutral letters that share features with the target and distractor dilute the interference effect brought about by the incompatible distractor. In support of this claim they found that when the additional neutral letters were different in colour from the target, ensuring that the search for the target is easy (i.e., low load), there was no distractor interference. Hence, even though in this condition the perceptual load was low, the mere addition of diluting items (i.e., neutral letters) eliminated the interference. Given that the peripheral letters of the high peripheral load condition in the present study are similar to the target and distractor, they can be viewed as diluting items. The dilution account, therefore, also predicts that when the levels of peripheral load are high, low distractor interference should be found under both central load conditions. These predictions are tested in Experiments 1, 2a, and 2b.

The manipulation of peripheral load that was established via the addition of peripheral items to the display also increased the spatial uncertainty regarding the location of the critical distractor. That is, in previous studies of the perceptual load model (e.g., Forster & Lavie, 2007; Lavie & Cox, 1997) there were only two possible distractor positions, whereas with the addition of peripheral items there are 10 such possible positions. Experiments 3 and 4 test the contribution location uncertainty to the degree of distractor interference.

EXPERIMENT 1

Method

Participants. Nineteen students from the University of Haifa took part in the experiment. All had normal or corrected to normal vision and all were naive to the purpose of the study.

Stimuli. The display consisted of two imaginary circles: Inner-central and outer-peripheral. There were six evenly spaced letters (1.7° centre to centre distance of neighbouring letters) on the central imaginary circle. One of these letters was the target, which was the letter N on half of the trials and the letter Z on the rest of the trials. The target appeared equally often at each of the six possible locations. The other five letters were either all Os in the low central load conditions or X, K, H, Y, and V in the high central load conditions (Figure 1). The peripheral circle included 10 evenly spaced locations (2.5° centre to centre distance). In the low and high peripheral load conditions there were 10 additional letters on this circle, one of which was the critical distractor. The other nine letters were either all Os, in the low peripheral load conditions, or B, P, L, E, T, F, G, U, and R in the high peripheral load conditions. In the no peripheral load conditions, only the distractor letter was presented in one of the 10 possible locations on the peripheral circle. In all the conditions, the critical distractor was either the letter Z or N. On half of the trials the critical distractor was incompatible with the target (e.g., the target was the letter N and the distractor was the letter Z) and on the rest of the trials the distractor was compatible (e.g., both the target and the distractor were the letter N). The location of the critical distractor was chosen randomly on each trial. Overall there were six conditions: Low central load + no peripheral load (LN); high central load + no peripheral load (HN); low central load + low peripheral load

(LL); low central load + high peripheral load (LH); high central load + low peripheral load (HL); and high central load + high peripheral load (HH).

The height and width of the letters in the inner central circle were $0.6^\circ \times 0.4^\circ$ of visual angle, and the height and width of the letters in the outer peripheral circle were $0.9^\circ \times 0.5^\circ$ of visual angle. The size difference between the inner and outer circle letters was designed to control for the effect of eccentricity (Maylor & Lavie, 1998). The radius of the inner circle was 2° and the radius of the outer circle was 4°. The black letters were presented against a light grey background.

Procedure. Viewing distance was held fixed at 57 cm with a chinrest. The participants' task was to indicate as quickly and accurately as possible whether the target letter in the central circle was a Z or an N, while ignoring the outer circle of letters. Each trial started with a fixation point presented at the centre of the screen for 1000 ms. In order to prevent eye movements (e.g., Mayfrank, Kimmig & Fischer, 1987), the letter stimuli followed for a short duration of 150 ms, and were replaced with the fixation point until the participant responded but no longer than 3000 ms (Figure 2). After responding, a 500 ms feedback was given: A "+" sign for a correct response, and a "–" sign for an incorrect response.

Overall, each participant performed 864 experimental trials, 144 for each combination of central and peripheral load, in a random mixed design. The experimental trials were preceded by 36 practice trials.

Results and discussion

RT analysis. A three-way repeated measures ANOVA, Central load (low vs. high) $\times$ Peripheral load (none, low, and high) $\times$ Compatibility (incompatible vs. compatible) was conducted on mean correct RT data. RTs shorter than 100 ms or longer than 2000 ms were excluded from the analysis (0.86% from the total number of trials). The main effect of central load was significant, $F(1, 18) = 389.17$, $p < .0001$; RTs were longer with high load than with low load (730 ms vs. 515 ms, respectively), revealing that the manipulation of central load was effective. The main effect of peripheral load was also significant, $F(2, 36) = 7.46$, $p < .002$. Planned comparisons indicated that RTs in the high peripheral load condition (634 ms) were significantly longer than RTs in either the low load condition (616 ms; $p < .0003$) or the no load condition (617 ms; $p < .0006$). The two-way interaction between central load and peripheral load was marginally significant, $F(2, 36) = 2.59$, $p = .0889$. In line with our predictions, the effect of peripheral load was modulated by the manipulation of central load: As can be seen in Figure 3 and confirmed by least significant differences (LSD) post hoc analysis, there was no difference between the various conditions of

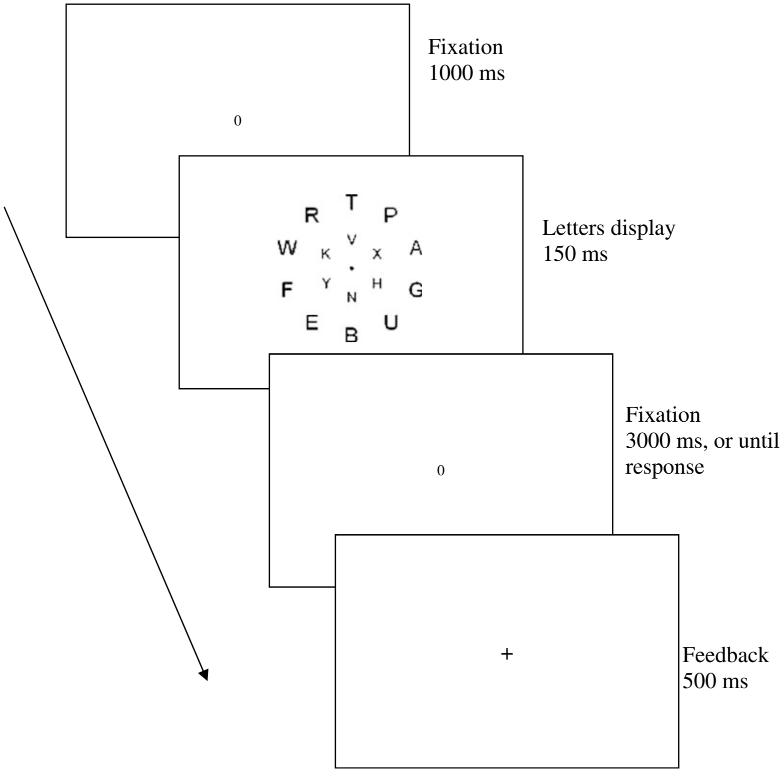

Figure 2. A schematic illustration of a single trial in Experiment 1.

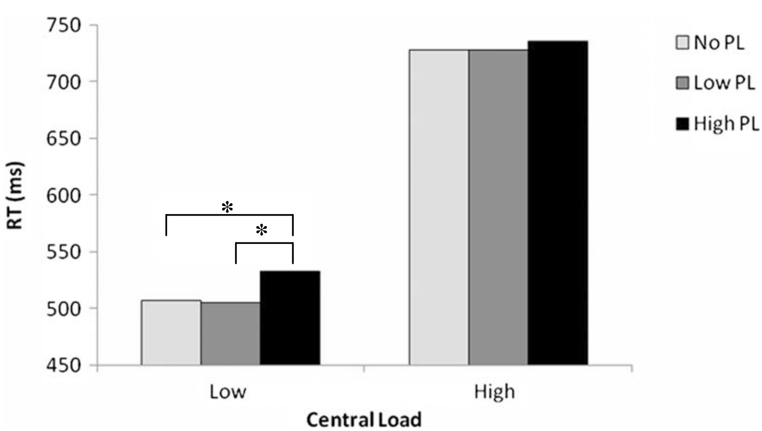

Figure 3. The effects of peripheral load (PL) and central load on mean RTs in Experiment 1. * Significant effect of the simple pairwise comparisons with compatible conditions.

peripheral load in the high central load condition, but when central load was low there were significant differences between the high peripheral load condition (532 ms) and the two other peripheral load conditions: No load (507 ms, $p < .0001$) and low load (504 ms, $p < .0001$).

The two-way interaction between central load and compatibility was significant, $F(1, 18) = 5.18$, $p < .04$. Although there was a significant difference between the mean RT in the incompatible and compatible conditions in the low central load condition (incompatible: 520 ms, compatible: 509 ms; $p < .04$), there was no such significant effect in the high central load condition (incompatible: 727 ms, compatible: 734 ms). The three-way interaction between central load, peripheral load, and compatibility was nearly significant, $F(2, 36) = 3.05$, $p = .0596$ (Figure 4a and Table 1). Planned comparisons indicated that mean RT was significantly longer in the incompatible than compatible trials of the LN condition ($p < .007$), as expected by the perceptual load model. However, in contrast to the model's prediction, mean RT was also significantly different in the incompatible versus the compatible trials of the HN condition ($p < .05$), but this time it was a reversed effect—incompatible RTs were shorter than compatible RTs. In all other conditions there was no significant distractor interference.

Accuracy analysis. A similar analysis was conducted on the mean accuracy data. Trials with RTs shorter than 100 ms or longer than 2000 ms were excluded from the analysis (0.86% from the total number of trials). The main effect of central load was significant, $F(1, 18) = 85.32$, $p < .0001$; accuracy was lower in the high than low load condition (87.17% vs. 97.12%, respectively). The main effect of distractor compatibility was also significant, $F(1, 18) = 5.65$, $p < .03$, with a lower accuracy in the incompatible (92.21%) than compatible condition (93.08%).

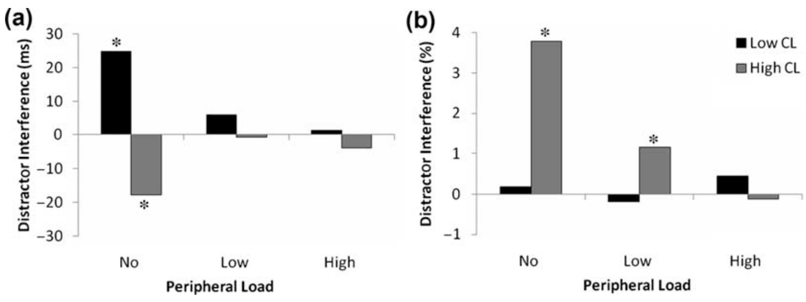

Figure 4. Distractor interference (incompatible minus compatible) in Experiment 1 as a function of central load (CL) and peripheral load. (a) RT; (b) accuracy. * Significant effect of the simple pairwise comparisons with compatible conditions.

TABLE 1
Mean correct RT and accuracy as a function of central load, peripheral load, and distractor compatibility in Experiment 1 (incompatible vs. compatible), 2a (incompatible vs. neutral), and 2b (incompatible vs. neutral)

		Distractor compatibility					
		Incompatible			*Compatible/neutral*		
Load condition		*Exp. 1*	*Exp. 2a*	*Exp. 2b*	*Exp. 1*	*Exp. 2a*	*Exp. 2b*
LN	RT (ms)	521	501	514	498	483	496
	Accuracy (%)	96.5	95.4	94.2	96.7	96.2	97.0
LL	RT (ms)	508	450	501	505	483	492
	Accuracy (%)	97.5	96.2	93.7	97.3	96.7	96.4
LH	RT (ms)	535	521	539	534	509	516
	Accuracy (%)	97.2	94.8	95.9	97.7	95.6	96.2
HN	RT (ms)	756	719	702	766	712	694
	Accuracy (%)	86.5	84.7	86.1	90.3	86.5	89.3
HL	RT (ms)	756	723	696	759	711	685
	Accuracy (%)	87.0	87	86.5	88.2	87.1	87.5
HH	RT (ms)	761	720	688	765	717	690
	Accuracy (%)	88.6	84.4	87.0	88.5	86.1	87.4

The three-way interaction between central load, peripheral load, and compatibility was nearly significant, $F(2,\ 36) = 3.17$, $p = .06$. Planned comparisons indicated that the accuracy in the incompatible condition was significantly lower than the compatible condition in the HN condition ($p < .0001$). A similar effect, though smaller, also emerged in the HL condition: Accuracy in the incompatible condition was significantly lower than the compatible condition ($p < .0001$). In all other conditions there was no significant distractor interference (Figure 4b and Table 1).

Thus, the findings of this experiment follow our predictions regarding the effect of peripheral load. Increasing perceptual load at the periphery had a detrimental effect on overall performance, but the level of load at the centre modulated this effect. When the central load was low RTs were indeed longer with high level of peripheral load. Yet when the central load was high, the level of peripheral load did not affect performance. This interaction between peripheral and central load is expected given the perceptual load model. The model predicts that under the high central load condition there will be no available resources to process the nonrelevant peripheral information and therefore the level of peripheral load should not matter.

In contrast, the findings regarding the effect of distractor interference are not in accord with the expectations of the perceptual load model. In the RT data, there was distractor interference in the LN condition as predicted by the model, but an inverse interference effect was found in the HN condition, in which no interference was expected. This inverse effect is surprising, because it indicates that the participants where faster when an incompatible distractor was present than when a compatible distractor was present. The accuracy data suggest that this inverse effect simply reflects a speed–accuracy tradeoff, because, in this particular condition (HN), the interference effect of the accuracy was opposite to that of RTs: The participants made more errors in the incompatible than the compatible condition.

Another possible explanation for these surprising results is based on the specific comparison between incompatible and compatible trials. Lavie (1995) compared all three types of congruency—incompatible, compatible, and neutral—and found that performance in the compatible condition was inconsistent. She concluded that the compatible effects may reflect processes that arise at the level of physical features, due to the physical identity between the target and distractor, and therefore are not optimally suited to explore the issue of distractor interference.

In order to test the possibility that the outcomes of this experiment only partially matched the predictions of the perceptual load model because we compared the compatible and incompatible conditions, we conducted Experiments 2a and 2b, in which we compared two other congruency conditions: Incompatible versus neutral.

EXPERIMENTS 2A AND 2B

Method

Participants. Forty-four students from the University of Haifa took part in these experiments (24 in Experiment 2a and 20 in Experiment 2b). All had normal or corrected to normal vision and all were naive to the purpose of the study. None of them participated in the previous experiment.

Stimuli and procedure. The stimuli and procedure of both experiments were identical to those of Experiment 1 except for the following: The compatible condition was replaced with a neutral condition. On half of the trials the critical distractor was neutral—either a T or an L. On the rest of the trials the distractor was incompatible. The other nine peripheral letters in the high peripheral load condition were B, E, R, W, U, P, A, F, and G. Additionally, in Experiment 2b the two possible target letters were X or N rather than Z or N.

Results and discussion

Reaction time analysis. A three-way repeated measures ANOVA, Central load (low vs. high) $\times$ Peripheral load (none, low, high) $\times$ Compatibility (incompatible vs. neutral), was conducted on mean correct RT data of both experiments. Trials with RTs shorter than 100 ms or longer than 2000 ms were excluded from the analysis (0.92% and 0.44% of the total number of trials in Experiments 2a and 2b, respectively). In both experiments the main effect of central load was significant: 2a, $F(1, 23) = 177.36$, $p < .0001$; 2b, $F(1, 19) = 270.48$, $p < .0001$; RTs were longer with high central load than with low central load: 2a, 717ms vs. 500 ms; 2b, 692 ms vs. 510 ms, reflecting the effective manipulation of central load. The main effect of distractor compatibility was also significant: 2a, $F(1, 23) = 7.45$, $p < .02$; 2b, $F(1, 19) = 9.69$, $p < .006$, with longer RTs in the incompatible versus the neutral condition: 2a, 614 ms vs. 604 ms; 2b, 607 ms vs. 595 ms.

Importantly, the main effect of peripheral load was significant: 2a, $F(2, 46) = 6.06$, $p < .005$; 2b, $F(2, 38) = 3.88$, $p < .03$. As confirmed by LSD post hoc analysis, RTs with high peripheral load (2a, 617 ms; 2b, 608 ms) were longer than RTs in either the low load condition (2a, 604 ms, $p < .003$; 2b, 593 ms, $p < .009$) or the no load condition (2a, 604 ms, $p < .003$; 2b, 602 ms, $p < .05$). The two-way interaction between central load and peripheral load was also significant: 2a, $F(2, 46) = 5.05$, $p < .02$; 2b, $F(2, 38) = 8.28$, $p < .002$. As in Experiment 1 and in accordance with our predictions, the effect of peripheral load was modulated by the manipulation of central load (Figure 5): In the high central load condition no difference between the various conditions of peripheral load was found (2a, no load 716 ms, low load 717 ms, high load 718 ms; 2b, no load 698 ms, low load 690 ms, high load 689 ms). However, when central load was low there were significant differences between the high peripheral load condition (2a, 516 ms; 2b, 528 ms) and the two other peripheral load conditions: No load (2a, 492 ms, $p = .0002$; 2b, 505 ms, $p < .0005$) and low load (2a, 492 ms, $p < .0001$; 2b, 497 ms, $p < .0001$). All other effects did not attain statistical significance.

Although the three-way interaction between central load, peripheral load, and compatibility was not significant, we nevertheless analysed planned

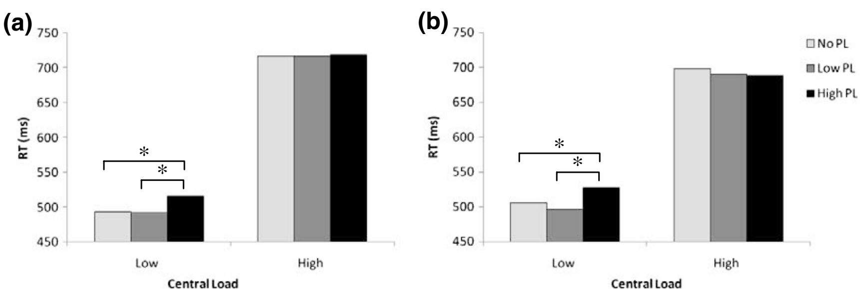

Figure 5. The effects of peripheral load (PL) and central load on mean RTs in (a) Experiment 2a and (b) Experiment 2b. * Significant effect of the simple pairwise comparisons with compatible conditions.

comparisons because the model has clear predictions concerning the simple pairwise comparisons. In line with the model's predications, the RTs in the incompatible condition were significantly different from the neutral condition only when the load at the centre was low. Specifically, in Experiment 2a (Figure 6a and Table 1) such a significant effect was found only in the LN ($p < .04$) and LL conditions ($p < .05$); and in Experiment 2b (Figure 6c and Table 1) this effect was only significant in the LN and LH conditions ($p < .04$ and $p < .008$, respectively).

Accuracy analysis. A similar analysis was conducted on the mean accuracy data. Trials with RTs shorter than 100 ms or longer than 2000 ms were excluded from the analysis (0.92% and 0.44% from the total number of trials in Experiments 2a and 2b, respectively). The main effect of central load was significant: 2a, $F(1, 23) = 70.33$, $p < .0001$; 2b, $F(1, 19) = 72.76$, $p < .0001$; accuracy was lower with high than low central load conditions (2a, 85.93% vs. 95.82%; 2b, 87.31% vs. 95.58%, in the high and low load conditions, respectively). The main effect of peripheral load was significant in Experiment 2a but not 2b: 2a, $F(1, 23) = 3.90$, $p < .03$. The accuracy in the low peripheral load condition (91.74%) was higher than either the high load

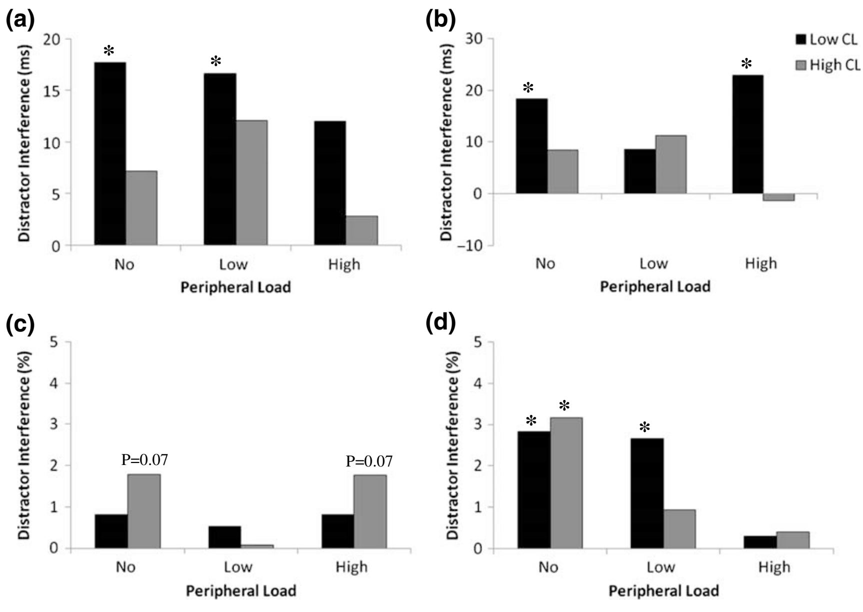

Figure 6. Distractor interference (incompatible minus neutral) as a function of central load (CL) and peripheral load in (a) Experiment 2a—RT; (b) Experiment 2b—RT; (c) Experiment 2a—accuracy; and (d) Experiment 2b—accuracy. * Significant effect of the simple pairwise comparisons with neutral conditions.

condition (90.23%, $p < .003$) or the no load condition (90.68%, $p < .04$). The main effect of distractor compatibility was significant in Experiment 2b, $F(1, 19) = 13.61$, $p < .002$, with lower accuracy in the incompatible than neutral condition (90.58% vs. 92.30%, respectively), but only marginally significant in Experiment 2a, $F(1, 23) = 3.43$, $p = .077$. All other effects did not attain statistical significance ($F < 1$).

The three-way interaction between central load, peripheral load, and compatibility was not significant in both experiments. Still, we conducted planned comparisons to examine the distractor interference effect in the various conditions of central and peripheral load. The pattern of results in both experiments was not consistent with the perceptual load model. In Experiment 2a (Figure 6c and Table 1) the difference between the incompatible and the neutral conditions was marginally significant in the HN condition ($p = .0672$), indicating that more errors occurred in the incompatible compared to the neutral. A similar marginally significant effect also emerged in the HH condition ($p = .0714$). In all other conditions there was no significant distractor interference. In Experiment 2b (Figure 6d and Table 1) the accuracy in the incompatible condition was significantly lower than in the neutral condition in LN and LL conditions ($p < .006$ and $p < .009$, respectively), but also in the HN condition ($p < .003$).

The effect of peripheral load on general performance was replicated in both Experiments 2a and 2b: High peripheral load resulted in longer RTs compared to no peripheral load and low peripheral load, but this effect was seen only in the low central load condition.

The results of the distractor interference effects are inconclusive. The RT data in general follow the predictions of the perceptual load model: Distractor interference was found only when the central load was low, although the fact that distractor interference was found in the LH condition of Experiment 2b but not in the LL condition is hard to explain in terms of the models' logic. In contrast, the accuracy data do not support the model. In both experiments, distractor interference effects were found when the central load was high, though in Experiment 2a these effects were only marginally significant. These results suggest that the incompatible distractor was processed even under conditions of high central load. This finding weakens the assertion of the perceptual load model that with high central load there are no resources available for the processing of the peripheral distractor.

Thus, Experiments 1, 2a, and 2b did not yield the pattern of results expected on the basis of the perceptual load model. The pattern of distractor interference across the various load conditions seems to vary between the different experiments. To test whether these variation are meaningful we performed an additional analysis on data combined from the three experiments. Specifically we performed a four-way ANOVA on both RT and accuracy data with the factor of experiment as a between participants factor and the factors of central load, peripheral load, and compatibility as within participants factors. These analyses indicated that with both measures the relevant interaction with the factor of experiment (Experiment × Central load × Peripheral load × Compatibility) did not reach statistical significance ($p > .1$). In fact, none of the other interactions with the factor experiment reached statistical significance, apart for the Peripheral load × Experiment interaction with the accuracy data ($p < .02$), which was due to the fact that in Experiment 2a accuracy was relatively high in the low peripheral load condition.

One difference between our current paradigm and the one employed in previous studies of the model (e.g., Lavie & Cox, 1997; Maylor & Lavie, 1998), which may explain the discrepancy between our and prior findings, is the manipulation of peripheral load. In previous studies the peripheral load was always minimal consisting of a single letter. Although our paradigm also included conditions with such minimal peripheral load (LN and HN), the mere presence of trials with higher peripheral load might have somehow affected the selection processes rendering some of the conditions more susceptible to distractor interference. Another methodological difference refers to the level of spatial uncertainty regarding the location of the critical distractor. In the current experiments the distractor could appear in one of 10 possible positions, whereas in prior studies (e.g., Forster & Lavie, 2007; Lavie & Cox, 1997) there were only two possible distractor positions. In order to explore the contribution of these two methodological differences to the pattern of results obtained so far, we performed two additional experiments. In both experiments the peripheral load was always minimal but in Experiment 3 the level of spatial uncertainty was high (10 possible distractor positions), whereas in Experiment 4 it was low (two possible positions).

EXPERIMENT 3

This experiment was similar to the previous ones but it included only no peripheral load conditions to test whether the lack of peripheral load will result in outcomes that are more similar to those obtained by previous studies (e.g., Lavie & Cox, 1997; Maylor & Lavie, 1998). Another difference was the addition of a compatible condition. Thus, this experiment includes three compatibility conditions: Compatible, neutral, and incompatible. We added the compatible condition to prevent the adoption of a response strategy in which one utilizes the distractor identity to give a correct response. That is, when there are only two compatibility conditions, incompatible and neutral, some of the participants may figure out that if the distractor is the letter Z then the correct response is N, and vice versa. The fact that in the incompatible condition the identity of the distractor could indicate the correct response might have encouraged the participants to pay attention to the distractor, particularly when the central load is high and it is harder to find the target in the central circle. Finally, the different load conditions were presented in separate blocks to closer resemble prior studies (e.g., Forster & Lavie, 2007; Lavie & Cox, 1997).

Method

Participants. Twenty students from the University of Haifa participated in the experiment. All had normal or corrected to normal vision and all were naive to the purpose of the study. None of them participated in the previous experiments.

Stimuli and procedure. The stimuli and procedure were identical to those of conditions LN and HN in Experiments 2a, apart from the following: On one-third of the trials the distractor was compatible with the target (namely, N when the target is N and Z when the target is Z). The other two-thirds included neutral and incompatible trials. Each participant performed eight blocks of trials—four high load and four low load. The blocks order was fixed for all participants (Forster & Lavie, 2007): LN, HN, HN, LN, LN, HN, HN, LN. In each block there were 144 trials divided equally between the three compatibility conditions presented in random order. Each participant performed 1152 experimental trials, 576 of each condition of central load.

Results and discussion

RT analysis. A two-way repeated measures ANOVA, Central load (low vs. high) $\times$ Compatibility (incompatible, compatible, and neutral), was conducted on mean correct RT data. Trials with RTs shorter than 100 ms or longer than 2000 ms were excluded from the analysis (0.36% from the total number of trials). The main effect of central load was significant, $F(1, 19) = 144.16$, $p < .0001$; RTs were longer with high load than with low load (706 ms vs. 543 ms, respectively). The main effect of distractor compatibility was also significant, $F(2, 38) = 24.81$, $p < .0001$. As confirmed by LSD post hoc analysis, the effect reflects significant differences between the incompatible condition (638 ms) and the two other compatibility conditions (compatible: 616 ms, $p < .0001$; neutral: 620 ms, $p < .0004$).

The two-way interaction between central load and compatibility did not attain statistical significance, $F(2, 38) = 1.98$, $p = .1526$. Planned comparisons examined the differences in the compatibility effects between the various conditions of central load (Figure 7a and Table 2). The pattern of results was not consistent with the perceptual load model: The RTs in the incompatible condition were significantly slower than the neutral condition in the low

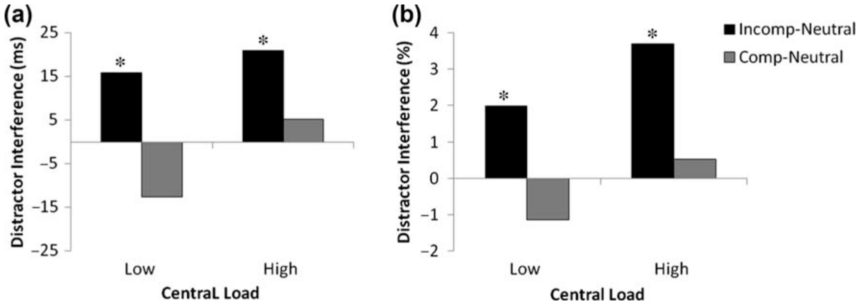

Figure 7. Distractor interference (incompatible minus neutral) and distractor facilitation (compatible minus neutral) as a function of central load in Experiment 3. (a) RT; (b) accuracy. * Significant effect of the simple pairwise comparisons with neutral conditions.

central load condition ($p < .02$), but also in the high central load condition, reflecting even greater differences ($p < .003$). The RT difference between the compatible and neutral conditions was marginally significant in the low load condition ($p = .0620$), but no such effect was found in high load condition.

Accuracy analysis. A similar analysis was conducted on mean accuracy data. Trials with RTs shorter than 100 ms or longer than 2000 ms were excluded from the analysis (0.36% from the total number of trials). The main effect of central load was significant, $F(1, 19) = 59.49$, $p < .0001$; accuracy was lower with high load than with low load (90.36% vs. 95.52%, respectively). The main effect of distractor compatibility was also significant, $F(2, 38) = 30.91$, $p < .0001$. As confirmed by post hoc analysis (LSD), the effect reflects lower mean accuracy in the incompatible condition (90.95%) than the other compatibility conditions (94.09%, $p < .0001$ and 93.79%, $p < .0001$ for the compatible and neutral conditions, respectively).

TABLE 2
Mean correct RT and accuracy as a function of central load and distractor compatibility in Experiment 3 and 4

		Distractor compatibility					
		Incompatible		*Compatible*		*Neutral*	
Load condition		*Exp. 3*	*Exp. 4*	*Exp. 3*	*Exp. 4*	*Exp. 3*	*Exp. 4*
LN	RT (ms)	558	578	529	552	542	559
	Accuracy (%)	93.8	95.2	97.0	97.1	95.8	97.6
HN	RT (ms)	718	737	703	736	697	735
	Accuracy (%)	88.1	89.3	91.3	91.4	91.8	90.4

The two-way interaction between central load and compatibility did not attain statistical significance, $F(2, 38) = 1.86$, $p = .1699$. Planned comparisons revealed a pattern of results that was similar to that of the RT data and was not consistent with the predictions of the perceptual load model (Figure 7b and Table 2). The accuracy in the incompatible condition was significantly different than the neutral condition in the low central load condition ($p < .02$). However, a similar significant effect was found in the high central load condition ($p < .0001$). The accuracy in the compatible condition was not significantly different from the neutral condition in both central load conditions.

The results of this experiment are inconsistent with the predictions of the perceptual load model. Distractor interference was found regardless of the level of central load, both with the RT and accuracy measures. In fact, with both measures the difference between the neutral and incompatible conditions was larger in the high than in the low load condition. Because there was no peripheral load in this experiment, the fact that we found distractor interference in high load conditions of this and our previous experiments (Experiments 1, 2a, 2b) cannot be attributed to the presence of such a load. In Experiment 4 we explored whether the level of spatial uncertainty regarding the distractor location can explain the fact that we did not replicate previous results.

EXPERIMENT 4

An additional methodological difference between our experiments and previous studies of the perceptual load model is the level of spatial uncertainty regarding the distractor location. Whereas in previous studies (e.g., Forster & Lavie, 2007; Lavie & Cox, 1997) the critical distractor could appear in one of two possible locations, in the experiments described thus far (Experiments 1–3) there were 10 possible locations. Hence, the level of uncertainty regarding the location of the critical distractor was considerably higher in our experiments. The current experiment was designed to explore the contribution of this factor to the ability to ignore the distractor. To that end, the experiment was identical to Experiment 3 other than the fact that the distractor letter could only appear in one of two locations—to the left or right of the central circle of letters. This experiment is the most akin replication of Lavie and Cox (1997). If the distractor interference found with high central load in Experiments 1–3 is related to the relatively high location uncertainty regarding the distractor position, in the current experiment we should only find interference with low central load, because this location uncertainty is reduced to the level employed in prior studies.

Method

Participants. Twenty students from the University of Haifa participated in the experiment. All had normal or corrected to normal vision and all were naive to the purpose of the study. None of them participated in the previous experiments.

Stimuli and procedure. The stimuli and procedure were identical to those of Experiment 3 except that the distractor letter could only appear in one of two possible locations on the imaginary peripheral circle, to the right or left of the central circle.

Results and discussion

RT analysis. A two-way repeated measures ANOVA, Central load (low vs. high) × Compatibility (incompatible, compatible, and neutral), was conducted on mean correct RT data. Trials with RTs shorter than 100 ms or longer than 2000 ms were excluded from the analysis (0.85% from the total number of trials). The main effect of central load was significant, $F(1, 19) = 74.49$, $p < .0001$; RTs were longer with high than low load (736 ms vs. 563 ms, respectively). The main effect of distractor compatibility was also significant, $F(2, 38) = 7.73$, $p < .002$; RTs of the incompatible condition (657 ms) were longer than the two other compatibility conditions (compatible: 644 ms, $p < .0002$; neutral: 647 ms, $p < .03$). Most important, the interaction between central load and compatibility was significant, $F(2, 38) = 7.55$, $p < .002$ (Figure 8a and Table 2). Planned comparisons indicated that the predictions of the perceptual load model were met: The difference between the incompatible and neutral conditions was significant in the low load condition ($p < .0003$), but not in the high load condition ($p = .5886$). The difference between the compatible and neutral conditions was marginally significant in the low load condition ($p = .0995$) and not significant in the high load condition ($p = .8587$).

Accuracy analysis. A similar analysis was conducted on mean accuracy data. Trials with RTs shorter than 100 ms or longer than 2000 ms were excluded from the analysis (0.85% from the total number of trials). The main effect of central load was significant, $F(1, 19) = 89.06$, $p < .0001$; accuracy was lower with high than low load condition (90.54% vs. 96.64%, respectively). The main effect of distractor compatibility was also significant, $F(2, 38) = 7.35$, $p < .003$. The accuracy in the incompatible condition (92.38%) was significantly lower than in the other compatibility conditions (compatible: 94.34%, $p < .0001$; neutral: 94.05%, $p < .0004$).

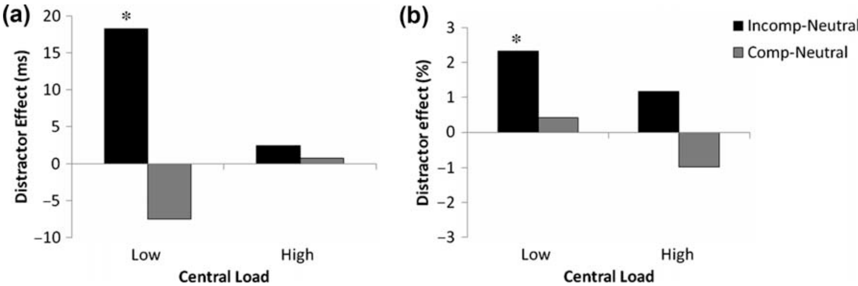

Figure 8. Distractor interference (incompatible minus neutral) and distractor facilitation (compatible minus neutral) as a function of central load in Experiment 4. (a) RT; (b) accuracy. * Significant effect of the simple pairwise comparisons with neutral conditions.

The interaction between central load and compatibility did not attain statistical significance, $F(2, 38) = 1.67$, $p = .2011$ (Figure 8b and Table 2). However, planned comparisons revealed effects that are consistent with the perceptual load model: With low levels of load, the accuracy in the incompatible condition was significantly lower than in the neutral condition ($p < .0005$). But with high levels of load, this effect did not attain statistical significance ($p = .1022$). There was no significant difference between the compatible and neutral conditions regardless of the level of load. Thus, once the uncertainty regarding the location of the distractor was reduced from 10 to two possible locations, a pattern of results that is similar to that obtained by prior studies (e.g., Forster & Lavie, 2007; Lavie & Cox, 1997) emerged. This finding suggests that such uncertainty plays an important role in our ability to ignore nonrelevant information.

GENERAL DISCUSSION

This study examined the effects of peripheral load on our ability to ignore a nonrelevant distractor and whether or not such effects interact with those of the central load. To that end, we manipulated the levels of perceptual load at both the central region (the task-relevant central circle of letters) and peripheral region (the nonrelevant peripheral circle of letters). We found that the levels of peripheral load affected overall performance. Performance was better with low than high levels of peripheral load. Because we employed peripheral letters that are more similar to the target as a means to increase the level of peripheral load, the decrement in performance with higher levels of peripheral load may be due to higher levels of noise generated by distractors that share more features with the target (e.g., Eckstein, 1998). This effect of peripheral load, however, was only found when the levels of central load were low. When the central load was high the levels of load at the periphery did not affect performance. This finding is in line with the assertions of the perceptual load model; when the central load is high no resources are left to process the peripheral letters, and therefore the levels of peripheral load are not relevant.

In contrast to the effects of peripheral load on general performance, the pattern of distractor interference in Experiments 1–3 does not follow the predictions of the perceptual load model. Only in Experiment 4 were these predictions fully met. The model predicts that distractor interference should only be found with low levels of central load, when the limitations of perceptual capacity are not exhausted. Yet, in Experiments 1–3 reliable distractor interference was also found under levels of high central load. Such a reliable distractor interference was found even when there was no peripheral load (i.e., in the HN condition of Experiment 1, 2a, and 2b, and in the blocked high load trials of Experiment 3), and with a load manipulation that was found to be effective in previous studies (e.g., Beck & Lavie, 2005; Forster & Lavie, 2007; Lavie & Cox, 1997; Maylor & Lavie, 1998). The exact pattern of results, as expected by the model, was found only in Experiment 4, whose methodology closely replicated Lavie and Cox (1997, Exp. 1). The critical difference between this experiment and Experiments 1–3 is that in the latter experiments the distractor letter could appear in one of 10 locations, whereas in Experiment 4 it could only appear in one of two locations. The fact that the expected results were only found when the spatial uncertainty regarding the distractor location was low suggests that this uncertainty plays an important role in our ability to select relevant information.

The perceptual load model portrays the selection processes that prevent distractor interference as passive processes. According to the model, people allocate attention to the relevant task, but if the task load is not high enough, residual attentional capacity spills over to process nonrelevant distractors. In contrast, if the task load is high enough no residual attentional capacity is left to process the distractors and no distractor interference is found. Hence, according to the model, under high load conditions distractor interference is prevented because there were no resources left for distractor processing rather than an active inhibition of the distractors. However, such a passive description of selectivity cannot comprise the role that location uncertainty seems to play in our results. If no resources are left for the processing of the nonrelevant peripheral information, the level of uncertainty regarding the location of this information should not matter.

An alternative view portrays selectivity as a more active process. In this view, distractor interference is prevented via an active inhibition of nonrelevant stimuli. Unlike the passive view, the active view of selectivity can comprise the role played by location uncertainty. When there are only two possible distractor positions, it is possible to successfully inhibit these two positions and prevent distractor interference. However, when the level of uncertainty is high because there are many more possible locations, it is harder to simultaneously inhibit all those locations and distractor interference may emerge. This "active view" of selectivity can also account for the typical effects of perceptual load. When perceptual load (or simply task difficulty) is low, there is no need to apply active inhibition because the task can be accomplished to a satisfactory level even if the distractor is perceived. This may result in fast response times and high accuracy level but also significant effects of distractor compatibility. Yet, when the perceptual load is high, adequate performance requires the active inhibition of the distractor, since under such load conditions perceiving the distractor might have a detrimental effect on performance. Thus, the results under these conditions should reveal slower response times, lower accuracy levels, but no compatibility effects. In most of the previous studies that found these typical load effects (e.g., Lavie & Cox, 1997; Maylor & Lavie, 1998) and in Experiment 4 of the current study, there were only two possible distractor locations, and therefore such an active inhibition was feasible. In Experiments 1–3 of the current study there were 10 possible distractor locations, which rendered this active inhibition hard to implement, resulting in distractor interference even under high load conditions. Note that this view can also account for the finding that peripheral load affects performance only when the levels of central load are low. Applying the same logic, when the levels of central load are low (i.e., the task is relatively easy) there is no need to actively inhibit the nonrelevant peripheral information, and the noise it generates affects performance. Indeed, as can be seen in Figures 3 and 5, performance in the low central load condition is still quite good even with the effects of peripheral load. In contrast, when the levels of central load are high, and the task is hard, peripheral information and the noise it generates are actively inhibited to avoid further performance deterioration due to the peripheral noise. This inhibition may be good enough to overcome differences in the noise generated by the different load levels, but not enough to completely overcome distractor interference. An inhibitory mechanism that is only activated when processing demands are relatively high has some merit because it is always possible that unexpected yet relevant information may reside in unexpected regions of the visual scene. Thus, as long as the cost that may be inflicted by such seemingly nonrelevant information is not too high, it is advantageous to avoid its inhibition. This active view of selectivity requires further, more direct, testing.

A more active view of the selectivity was also suggested by Torralbo and Beck (2008). They suggested that high selectivity reflects attentional biasing that is generated when there are local interactions that compete over neuronal representation. In support of this claim, they found distractor interference only when the target and other nonrelevant items were presented to different hemifields. When the target and nonrelevant items were presented to the same hemifield, there was no distractor interference. Thus, evidence of selectivity was found only when there were nearby nonrelevant items that could generate such competitive interactions. Although Torralbo and Beck suggested that these active biasing processes operate to improve the representation of the target, whereas we emphasize the inhibitory aspect of active selection processes, both—enhancement of the relevant information and inhibition of nonrelevant information—may take place simultaneously.

The perceptual load theory has been challenged in the past few years (see Khetrapal, 2010, for a review). Some researchers have found, in accordance with our current findings, evidence for distractor interference under high load conditions (e.g., Chen, 2003; Eltiti, Wallace, & Fox, 2005; Theeuwes, Kramer, & Belopolsky, 2004; Tsal & Benoni, 2010). For instance, Theeuwes et al. (2004) found that when high and low load conditions were intermixed within the same block of trials, distractor interference was found in both conditions. An analysis of trial-by-trial effects showed that, on high load trials, distractor interference occurred when the previous trial was of low load but not when the previous trial was of high load. They concluded that low perceptual load can bring about broad attentional processing that carries over to the subsequent high load trial. This explanation, however, cannot account for our current findings because in Experiment 3 the load manipulation was blocked and distractor interference under high load conditions was found nevertheless. Chen (2003) also found similar levels of interference under low and high levels of load. She found that, when the nonrelevant and relevant information were part of the same object, the levels of perceptual load did not modulate the degree of interference. This finding is not applicable to the current study, because the relevant and nonrelevant information in the current study always belonged to different objects. Eltiti et al. (2005) claimed that the ability to engage in highly selective attentional mode depends not only on the level of perceptual load but also on the saliency of the target and distractor in comparison to the neutral items. They showed that when they increased the target and distractor saliency by using a target that was slightly larger than the neutral letters and employing onset distractors, an interference effect emerged even under conditions of high perceptual load. They claimed that because the target and the distractor were the most salient items both captured attention and this resulted in interference. Specifically, they suggested that the larger target might have encouraged the observers to adopt a "singleton search" mode, which led to the capturing of attention by the onset distractor. This interpretation of the interference effect under high load levels is also not relevant to our findings because the target in our experiments was not more salient than the neutral letters. Finally, the dilution account of Tsal and Benoni (2010) suggests that the lack of interference under high load level is not due to the increase in load level. Instead, it is due to the addition of neutral letters that share features with the target and distractor. These neutral letters dilute the interference effect brought about by the incompatible distractor. Indeed, they have shown that with neutral letters of different colour than the target (i.e., ensuring low levels of perceptual load), there was no distractor interference. Interestingly, they also found that when they compared the dilution condition to the high load condition, larger distractor interference was found in the high load then dilution condition. In the current study we also found larger interference in the high load conditions (Experiments 1 and 2b—accuracy; Experiment 3—RT and accuracy), but in comparison to the original low load condition (i.e., not diluted).

Findings were also reported suggesting that low load conditions can result in high selectivity (e.g., Eltiti et al., 2005; Johnson, McGrath, & McNeil, 2002; Paquet & Craig, 1997; Tsal & Benoni, 2010). These findings were explained by suggesting additional factors that affect selectivity such as saliency (Eltiti et al., 2005) dilution (Tsal & Benoni, 2010), target–distractor distinctiveness (Paquet & Craig, 1997), and precueing the target location (Johnson et al., 2002). In the current study we always found interference under the low load conditions (with averaged RTs), but, as mentioned earlier, sometimes this interference effect was smaller than the effect under high load conditions.

To conclude, the levels of perceptual load at the periphery affected overall performance; increasing the levels of peripheral load impaired performance. However, the effect of peripheral load interacted with that of central load. Peripheral load affected performance only when the levels of central load were low. In Experiments 1–3, in which the distractor could appear in one of 10 possible locations, the pattern of distractor interference did not follow the predictions of the perceptual load model. Distractor interference emerged even under conditions of high perceptual load. Only in Experiment 4, in which the distractor could appear in one of two possible locations, the model's predictions were fully met. These findings suggest that spatial uncertainty plays an important role in our ability to select relevant information suggesting more active selection processes.

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