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Shifts of spatial attention in perceived 3-D space

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Previous studies have shown that spatial attention can shift in three-dimensional (3-D) space determined by binocular disparity. Using Posner's precueing paradigm, the current work examined whether attentional selection occurs in perceived 3-D space defined by occlusion. Experiment 1 showed that shifts of spatial attention induced by central cues between two surfaces in the left and right visual fields did not differ between the conditions when the two surfaces were located at the same or different perceptual depth. In contrast, Experiment 2 found that peripheral cues generated a stronger cue validity effect when the two surfaces were perceived at a different rather than at the same perceptual depth. The results suggest that exogenous but not endogenous attention operates in perceived 3-D space.

Although the visual system is usually confronted with a large number of inputs, it can only deal with a limited amount of information that is of high task relevance. The selection of information from the environment is accomplished by visual attention, which has been supposed to work like a spotlight or zoom lens that can move around in the visual field (e.g., Eriksen & St James, 1986; LaBerge, 1983; Posner, 1980). The processing of stimuli in an attended area is enhanced relative to those outside the attentional spotlight. For example, reaction times (RTs) are faster to stimuli presented at cued locations than to stimuli at uncued locations (Posner, 1980). This cue validity effect is taken to reflect the time required for spatial attention to shift from attended to unattended locations in the visual field.

In the vast majority of previous studies, stimuli have been presented in a frontal-parallel plane (e.g., the screen of a computer monitor), so that the findings reflect shifts of attention

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in two-dimensional (2-D) space. However, there has been an increasing interest in whether shifts of visual spatial attention occur in 3-D rather than 2-D space. For example, using rows of lights at different depths (Downing & Pinker, 1985), real 3-D scenes (Gawryszewski, Riggio, Rizzolatti, & Umiltà, 1987), or stereoscopic displays (Theeuwes, Atchley, & Kramer, 1998), some researchers have cued attention to locations at different depths as well as different spatial locations. In such experiments, RTs are typically slower when the cue and target appear at locations at different depths rather than at the same depth. Moreover, reallocation of attention is faster when switching from far to near than from near to far depth locations. However, Iavecchia and Folk (1994) failed to find a difference in the time course of within-plane and across-plane attention shifts in stereographic space induced by central cues. Other investigators have presented targets and distractors at different simulated depths, generated by binocular disparities (Andersen, 1990; Andersen & Kramer, 1993). In these cases, distractors close to targets in depth produce greater interference effects on responses to targets than do distractors distant from targets in depth. In addition, spatial cueing effects are larger when cues and targets appear at different depths rather than the same depth on invalid cueing trials (Atchley, Kramer, Andersen, & Theeuwes, 1997), and cueing effects increase with increased binocular disparity (He & Nakayama, 1995). Finally, attention shifts in 3-D space can be allocated in depth on the basis of surface information available in the display, but surface information is not necessary for the allocation of attention in 3-D space (Marrara & Moore, 2000). Taken together, the findings reported in the prior literatures strongly support the proposition that spatial attention can shift in 2-D as well as 3-D space.

However, given that there are neurons being sensitive to disparity in early parts of the visual system (Livingstone & Hubel, 1987), the aforementioned results may reflect special properties to shifting attention in stereo-defined depth planes, which may or may not hold when depth relation must be derived from cues in 2-D space, such as occlusion. To assess this, the present study examined effects of depth disparities on selective attention using 2-D occlusion cues to depth. Example displays are shown in Figure 1. In Context A of Figure 1, the four white squares can be perceived in front of the central grey square, and all are equally

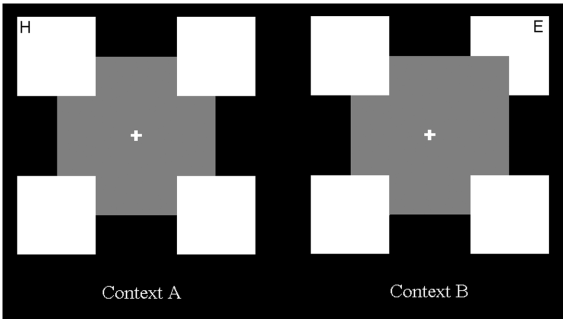

Figure 1. Illustration of the visual contexts used in Experiments 1 and 2A. In Context A all the white squares were perceived to cover the central grey square and were at the same depth. In Context B the upper right white square was perceived to be behind the central grey square and farther away from the observer relative to the other three white squares.

close to the observer; in contrast, in Context B, the upper right white square can be perceived to be behind the central grey square and farther away from the observer relative to the other three white squares. Here there is the internal perception of depth, though there are no real 3-D or disparity cues to depth. If shifts of spatial attention between the upper left and right white squares take a longer time in Context B than in Context A, it may be proposed that attentional shifts can occur in perceived 3-D space without cues from convergence, accommodation, or disparity. This can be tested by examining whether the cue validity effect (i.e., the difference in RTs between invalid and valid conditions) is influenced by the visual context. We would expect larger cue validity effect in Context B than in Context A. This follows because Context B produces a perceived depth difference between the upper left and upper right white squares whereas Context A does not. Therefore, in Context B, attention may shift both between the left and right visual fields in the frontoparallel plane and between the near and far perceptual depth, increasing RTs relative to the shifts between the fields alone, induced in Context A.

EXPERIMENT 1

Central cue

Two types of visual context were used in Experiment 1 (see Figure 1). Attention was directed to the upper left or right white square by a central cue (i.e., an arrow presented at fixation pointing to the left or right of the fixation). Observers were asked to discriminate between letters at the cued or uncued locations. Because the target locations were the same in Contexts A and B, any shifts of attention were exactly the same in 2-D space. However, any attentional shift occurred at the same perceived depth in Context A but at a different perceived depth in Context B.

Method

A total of 16 graduate and undergraduate students (6 men, 10 women, aged 19–24 years) from Peking University participated in Experiment 1 as paid volunteers. All were right-handed and had normal or corrected-to-normal vision. Data collection and stimulus presentation were controlled by a personal computer. Stimuli were presented on a 17-in. LG colour monitor. Two types of visual context were used in Experiment 1, as shown in Figure 1. Each context pattern consisted of a large grey square and four small white squares on a black background. The large grey square was centred at fixation, and each of the four small white squares was centred at one of the four corners of the grey square. The four small squares were arranged so that either each of them occluded one of the corners of the grey square (Context A) or the upper right one was occluded by the grey square (Context B). All the small white squares were perceived to be in front of the grey square in Context A whereas the upper right one was perceived to be behind the grey square in Context B. At a viewing distance of 45 cm the large grey square subtended a visual angle of $7.6 \times 7.6°$. Each of the small white squares subtended a visual angle of $3.8 \times 3.8°$. Targets were black letters "E" or "H", which were $0.5 \times 0.5°$ (high and wide) and located at the corners of the upper left or right white squares (5.2° vertically and 5.2° horizontally from the fixation). The fixation across and arrow cue subtended a visual angle of $0.4 \times 0.4°$ and $0.5 \times 0.5°$, respectively.

The two types of context pattern were presented in separate blocks of trials. Each trial began with the exposure of one type of context for 1,000 ms, centred at fixation. A central arrow was then presented, pointing horizontally either to the left or to the right, or a cue appeared with two arrow heads pointing to both hemifields (the neutral cue). After another 1,000 ms target letters were displayed for 200 ms and then disappeared with the cue. The interstimulus interval (ISI) between the offset of targets and the onset of cues in the next trial varied randomly between 1,500 and 2,000 ms. Subjects were asked to discriminate between the target letters by pressing one of two keys on a standard keyboard with the right and left index fingers. There were four blocks of 100 trials for each type of visual context after 40 trials for practice. On 60% of the trials targets appeared in the hemifield to which the arrow pointed (the valid condition). On 20% of the trials targets appeared in the hemifield opposite to the cue (the invalid condition). On 20% of the trials the cue (↔) did not provide information about the location of the upcoming target (the neutral condition). The order of blocks of trials using the two types of visual context and the relationship between the target letters and the responding hand was counterbalanced across subjects. Subjects were instructed to keep their eyes fixated on the central cross throughout each block and to respond as accurately and quickly as possible.

Results and discussion

Experiment 1 employed a three-factor within-subject design with the factors being visual context (Context A vs. Context B), attention (valid, neutral, or invalid), and visual field (targets appeared in the left visual field, LVF, vs. the right visual field, RVF). However, as preliminary analyses in all experiments showed that visual field did not interact with other factors, it was taken out of further analysis as it was not relevant for the main hypothesis tested in the study.

The mean RTs for correct responses in Experiment 1 are shown in Table 1. There was a significant main effect of attention, $F(2, 30) = 14.3$, $p < .001$. RTs in the valid condition were shorter than those in the neutral condition, which were in turn shorter than those in the invalid condition. However, neither the main effect of visual context, $F(2, 30) = 0.237$, $p > .6$, nor its interaction with attention was significant, $F(2, 30) = 0.175$, $p > .8$. To illustrate the effect of visual context on attentional shifts in Experiment 1, the costs plus benefits (RTs in the invalid condition minus RTs in the valid condition) related to each visual context are shown in Figure 2.

The mean percentage of errors for discriminating target letters was 4.2%. There was only a significant main effect of attention, $F(2, 30) = 6.86$, $p < .004$, suggesting that the error rate in the invalid condition (5.5%) was slightly higher than those in the valid (3.8%) and neutral (3.2%) conditions. Comparisons between the error rates and the mean RTs indicate that there was no speed–accuracy trade-off.

TABLE 1
Mean RTs for correct responses in Experiment 1

	Context A		*Context B*	
	M	*SE*	*M*	*SE*
Valid	499	17.9	499	17.2
Neutral	513	18.5	517	17.5
Invalid	524	17.9	525	18.4

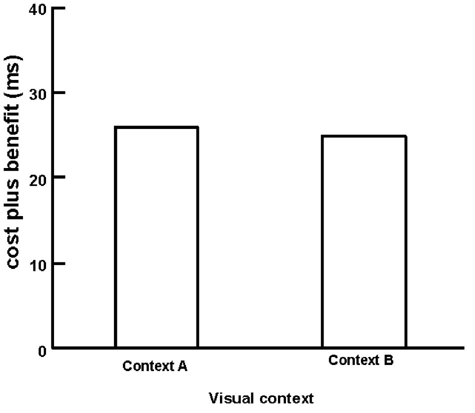

Figure 2. Illustration of costs plus benefits in RTs as a function of visual context (i.e., Contexts A and B) in Experiment 1.

Experiment 1 showed a clear cue validity effect. Responses to targets in the valid condition were faster than those in the neutral condition, which in turn were faster than those in the invalid condition. These are consistent with previous reports (Posner, 1980), suggesting facilitation of target processing at attended relative to unattended locations. However, the visual contexts did not affect the cue validity effect regardless of whether or not perceived depth was available in the visual context.[1] One possibility is that the arrow cues presented at fixation were perceived on the surface of the large grey square and informed subjects of only whether targets would appear to the left or right of the fixation but did not provide depth information. Thus shifts of attention induced by the central cues took place between the LVF and RVF—that is, in 2-D space. As a result, spatial attention could not shift in perceived 3-D space, even though target letters appeared on surfaces with different perceptual depths in Context B.

EXPERIMENTS 2A AND 2B

Peripheral cue

Experiment 1 showed that the visual contexts did not influence attention shifts induced by central cues. One possibility is that the central cues could not direct attention shifts along the perceptual depth produced by the visual context, when the stimuli were represented on a 2-D surface. This is consistent with Iavecchia and Folk's (1994) work using stereographic displays, suggesting that endogenous cueing may be depth blind. Alternatively, the visual contexts used in Experiment 1 might not have produced strong enough depth cues to

[1]One reviewer suggested that, as the cue validity effect was small and only a long cue-to-target interval (ISI) was used, the null hypothesis of Experiment 1 should be tested with short ISIs. We thus ran an additional experiment that simply replicated Experiment 1 but used relatively short ISIs. The results of the additional experiment were consistent with the null hypothesis and are reported in the Appendix.

generate attention shifts in 3-D space. These issues were clarified in Experiment 2, in which the visual contexts were the same as those in Experiment 1, but peripheral cues (i.e., symbols presented at the outside corner of the upper left or right white square) were used to induce shifts of spatial attention. Peripheral cues not only provided information about whether targets would appear to the left or right of fixation but they also informed subjects about the surface depth of the target, since the cues, like the targets, appeared at a particular depth in the contextual figure. If peripheral cues can generate attentional orienting in perceived depth produced by the visual context used in Experiment 1, it may be proposed that the null effect observed in Experiment 1 could not arise from inefficient depth cues in the display.

In Experiment 2A, the local contrast in the upper right white square differed between Contexts A and B (see Figure 1)—that is, the upper right square in Context B was covered by the corner of the large grey square. Hence any difference in the cue validity effect across the two contexts might arise from the difference in local contrast rather than the difference in perceived depth. Experiment 2B was designed to examine how the difference in local contrast influenced the cue validity effect by removing the large grey square but keeping the difference in local contrast between Contexts A and B (see Figure 3). If the local contrast differences were important, differential cue validity effects should be found here too.

Method

A total of 32 graduate and undergraduate students (6 men, 26 women, aged 17–24years) from Peking University participated in Experiments 2A and 2B as paid volunteers (16 in Experiment 2A and 16 in Experiment 2B). All were right-handed and had normal or corrected-to-normal vision. The stimuli and procedure were the same as those in Experiment 1 except the following. Each trial began with the presentation of one type of context centred at fixation for 500 ms. Then a white symbol "⌈" (or "⌉") of $1.0 \times 1.0°$ flashed at the outside corner of the upper left or right white square in the visual context for 100 ms. After an ISI of 100 or 300 ms a target letter appeared at the corner of a cued (valid) or uncued (invalid) small square and lasted for 200 ms. In the neutral condition, two symbols ("⌈" and "⌉") flashed simultaneously at the outside corners of the upper left and right white squares. All aspects of Experiment 2B were the same as those in Experiment 2A except that the grey square was removed from the context pattern, but we kept the local contrast difference in the upper right small square, as shown in Figure 3.

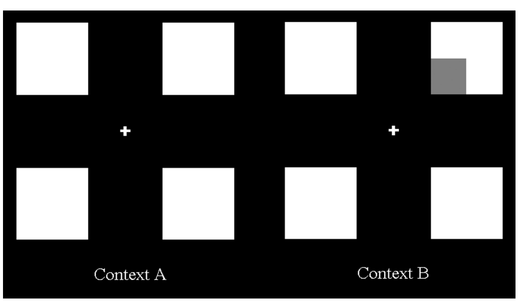

Figure 3. Illustration of the visual contexts used in Experiment 2B. The four white squares in both Contexts A and B were perceived at the same depth. However, they were the same contrast in Context A, but different in Context B.

Results and discussion

Both Experiments 2A and 2B employed a three-factor within-subject design with the factors being visual context (Context A vs. Context B), attention (valid, neutral, or invalid), and ISI (100 vs. 300 ms).

The mean RTs for correct responses in Experiments 2A and 2B are shown in Table 2. The effect of attention was significant in both experiments, $F(2, 30) = 77.4$, 37.6, respectively, both $p < .001$. RTs in the valid condition were shorter than those in the neutral condition, which were in turn shorter than those in the invalid condition. There were also main effects of ISI in both experiments, $F(1, 15) = 28.9$ and 16.4, respectively, $p < .001$; responses were faster when ISIs between cue and target stimuli were long than when they were short.

The main effect of visual context was not significant, for either experiment, $p > .2$. However, the interaction between visual context and attention was significant in Experiment 2A, $F(2, 30) = 4.61$, $p < .02$; the effect of spatial attention was larger in Context B than in Context A. In addition, there was a reliable triple interaction of Visual Context $\times$ Attention $\times$ ISI, $F(2, 30) = 3.86$, $p < .03$, indicating that the effect of visual context on attentional shifts was larger at the long than at the short ISI. The triple interaction of Visual Context $\times$ Attention $\times$ Visual Field was not significant, $F(2, 30) = 2.17$, $p > .1$, suggesting that the larger cue validity effect in Context B than in Context A did not differ between LVF and RVF targets. To illustrate the effect of visual context on attentional shifts in Experiment 2A, the costs plus benefits (RTs in the invalid condition minus RTs in the valid condition) in each condition are shown in Figure 4. It can be seen that cost plus benefits were larger in Context B than in Context A, and this difference was more salient at long than at short ISIs. Nevertheless, no interactions involving visual context were significant in Experiment 2B, $p > .2$, suggesting that visual context did not influence shifts of attention when the contexts were different only in local contrast.

The mean percentages of errors for discriminating target letters in Experiments 2A and 2B were 2.8% and 4.3%, respectively. The main effect of attention was significant in Experiment 2A, $F(2, 30) = 5.63$, $p < .008$, and marginally significant in Experiment 2B,

TABLE 2
Mean RTs for correct responses in Experiments 2A and 2B

		Experiment 2A				*Experiment 2B*			
		Context A		*Context B*		*Context A*		*Context B*	
ISI	*Attention*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Short									
	Valid	493	13.3	492	13.3	498	10.2	492	10.8
	Neutral	523	16.4	532	16.1	533	13.4	524	15.0
	Invalid	571	17.9	578	17.0	571	17.7	574	22.0
Long									
	Valid	475	13.9	474	14.1	479	10.3	472	11.5
	Neutral	521	16.3	521	15.4	519	15.6	523	16.5
	Invalid	550	18.2	569	17.4	557	20.1	557	21.0

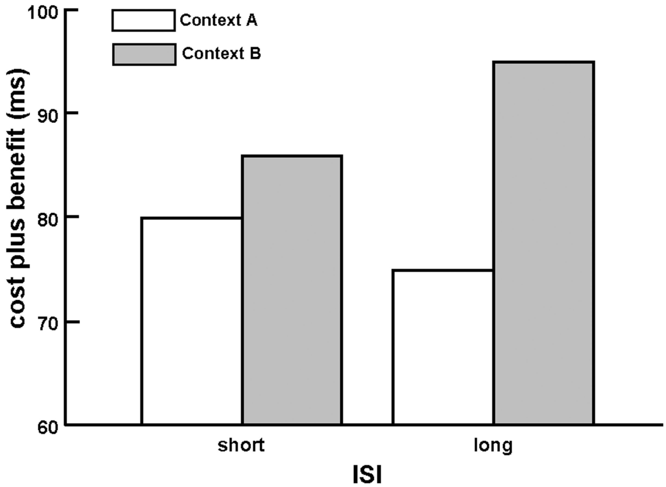

Figure 4. Illustration of costs plus benefits in RTs as a function of visual context (i.e., Contexts A and B) in Experiment 2A.

$F(2, 30) = 3.22$, $p < .053$. The error rates in the invalid condition (3.8% and 5.3% in Experiments 2A and 2B, respectively) were higher than those in the neutral (2.6% and 4.3%) condition, which were in turn higher than those in the valid condition (2.0% and 3.2%). Comparisons between the error rates and the mean RTs indicated that there was no speed–accuracy trade-off.

Cue validity effects were observed in both Experiments 2A and 2B. Responses to targets in the valid condition were faster than those in the neutral condition, which were in turn faster than those in the invalid condition. Interestingly, we found that the cue validity effect was larger when attention shifted between two surfaces at different perceptual depths than when it shifted between surfaces at the same perceptual depth. There was little difference between attention shifts from near to far positions (e.g., on invalid trials with right targets in Context B, Experiment 2A) and attention shifts from far to near positions (on invalid trials with left targets). The effect of visual context on shifts of spatial attention could not be attributed to any local contrast differences in the different depth conditions because the local contrast difference alone did not influence attentional shifts between the upper left and right white squares in Experiment 2B. The results of Experiments 2A and 2B suggest that shifts of attention were influenced by the perceived 3-D space induced by occlusion.

GENERAL DISCUSSION

The present work addressed the issue of whether visual contexts that produce depth information by occlusion influence the shifting of spatial attention in perceived 3-D space. Experiment 1 used central cues to direct shifts of attention between two surfaces in the left and right visual fields that were at the same or different perceived depths. While our results showed that responses to targets at cued locations were faster than those at uncued locations, this cue validity effect was not influenced by the visual context, irrespective of whether the cued and uncued planes were perceived at the same or different depths. In Experiment 2A peripheral cues were employed to direct the movement of spatial attention between two surfaces at the same or different perceived depths. Similar to Experiment 1A, Experiment 2A showed longer RTs in the invalid than in the valid conditions. However, in this case the cue validity effect was stronger when the surfaces on which cues and targets appeared were perceived at different depths than when they were perceived at the same depth. We also showed that the effect of relative perceived depth was unlikely to be due to the difference in local contrast between the upper left and right white squares when they were at different depths, because the local contrast difference alone in Experiment 2B did not affect the cue validity effect.

We suggest that the results of Experiment 2A reflect the cost of making shifts of spatial attention across different depths in perceived 3-D space. Because the cue and target positions in Contexts A and B were identical in Experiment 2A, factors determining shifts of spatial attention in 2-D space (i.e., the frontal-parallel plane) were the same in the two contexts. The larger cue validity effect observed in Context B than in Context A, then, suggests that spatial attention is deployed in 3-D as well as in 2-D space. This is consistent with the results of previous work using stimuli in real 3-D scenes and depth produced by binocular disparity (Atchley et al., 1997; Downing & Pinker, 1985; Gawryszewski et al., 1987; He & Nakayama, 1995; Theeuwes et al., 1998). Nevertheless, unlike shifts of spatial attention in real 3-D scenes (Downing & Pinker, 1985; Gawryszewski et al., 1987), shifts of spatial attention toward or away from the observer in the perceived 3-D space appear not to be different, since our data did not find any difference in the cue validity effect in Context B relative to Context A, as a function of whether responses were made to (near) LVF or (far) RVF targets that were perceived at different depths. Taken together the data strongly indicate that spatial attention is depth aware rather than depth blind.

However, unlike the previous work, the depth difference between the upper left and right white squares in Context B was not produced by real 3-D scenes or binocular disparities because the lateral separation between the two white squares was identical in the critical contexts (Contexts A and B). The perceptual depth was produced by occlusion and existed only in the internal representation of space. Therefore our results further suggest that spatial attention can shift in 3-D perceived space produced by occlusion. In addition, the contrast in the central cueing effects here, compared to studies using real 3-D displays, may reflect qualitative difference in how attention interacts with contrasting depth cues. Stereo depth may be coded early in vision and in a relatively hard-coined manner (e.g., through neurons sensitive to binocular disparity). Attention may enhance processing at cued depths by sharpening or increasing the activity of the depth-selective neurons (cf. Corbetta, Miezin, Dobmenger, Shulman, & Petersen, 1991). In contrast, occlusion relations generate the perception of depth through 2-D cues, which may remain available only to exogenous attention. The issue of how different depth cues interact with attention is clearly a topic for further research, especially given that there are some contrasting results in the literature even when stereo cues are used (e.g., Iavecchia & Folk, 1994, vs. Theeuwes et al., 1998).

It should be noted that, in some of the prior studies manipulating both real 3-D space and depth simulated through binocular disparities, it is possible that there were contributions to performance through convergence and accommodation cues, rather than purely from perceived 3-D space. This may be particularly true when using relatively long cue-to-target intervals and long cue-to-target distances in depth. Similarly, in the current study, attention to a specific perceived depth plane might be accompanied by convergent eye movements, and effects from these movements may contribute at least partially to the depth effects in the studies. Although the effect of vergence eye shifts should be smaller when a short cue-to-target interval was used (Experiment 2) than when a long cue-to-target interval was used (Experiment 1), the effect of vergence eye shifts in the current study cannot be ruled out drastically without measurement of eye movements. This should be addressed in the future work.

Interestingly, the current study showed that the differential effects of cueing attention in depth emerged with peripheral cues but not central cues. Previous work has shown that endogenous attention induced by central cues can differ from exogenous attention induced by peripheral cues in several aspects. For example, Jonides (1981) showed that, while instructions to ignore cues eliminated the effects of central cues, peripheral cues produced cost and benefits even when subjects were instructed to ignore them, suggesting that peripheral cues attract attention more automatically (Warner, Juola, & Koshino, 1990). In addition, peripheral cues elicit sharp rises in costs and benefits whereas central cues show slower rise times (Müller & Rabbitt, 1989). Peripheral cues also produce their largest effects on discrimination performance at short stimulus onset asynchronys (SOAs) whereas central cues require longer SOAs to achieve maximum effects (Cheal & Lyon, 1991). Recent neuroimaging studies also show that the two types of cue may be mediated by different brain mechanisms (Rosen et al., 1999). Moreover, peripheral and central cues may have contrasting functional effects on selection. Briand and Klein (1987) showed differential effects of central and peripheral cues on feature and conjunction search. Central cues had equal effects on both searches, whilst peripheral cues differentially improved conjunction search. Briand and Klein suggested that peripheral cues help to integrate the features of the stimuli (e.g., by improving location coding) so that conjunction search, in particular, benefits. In contrast, central (endogenous) cues may speed stimulus processing without selectively improving location coding or feature integration. Applied to the current study, any benefit in feature binding may enhance depth effects in selection, since it could lead to surfaces being better tied to their locations in the perceived 3-D space. Because depth is simply a stimulus feature (akin to colour or orientation; Theeuwes et al., 1998), peripheral cues may serve to bind surfaces to their perceived depths. In contrast, the binding of surfaces to their relative depths may be less robust under endogenous cueing conditions, so that effects of cueing attention across different depths are generally weaker, and effects based on more primitive 2-D representations may emerge. At least when depth information is derived from 2-D occlusion cues (as here), then endogenous cueing is insensitive to depth. In contrast, under exogenous cueing conditions, attention operates in perceived 3-D space.

Robertson and Kim (1999) found similar effects of visual context on shifts of spatial attention. In their study two lines of equal length were presented in the left and right hemifields. The context around the lines made one line appear longer than the other (a perceptual illusion). Subjects were cued to attend to one end of one of the two lines, and targets appeared at the cued or uncued end of the attended line. They found that the RT difference following invalid relative to valid cues was larger for the line perceived as longer than for the line perceived as shorter. Robertson and Kim's work indicates an effect of perceived 3-D space on shifts of attention in perceived 2-D space (i.e., along one of the two lines), whereas our results show an effect of perceived depth on shifts of attention in perceived 3-D space. Taken together, the findings strongly indicate that attention operates in perceived 3-D space under at least some circumstances.

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APPENDIX

An additional experiment was conducted to test the null result of depth obtained in Experiment 1. We simply replicated Experiment 1 but used shorter interstimulus intervals (ISIs) between cue and targets.

Method and results

A total of 16 graduate and undergraduate students (8 men, 8 women, aged 19–23 years) from Peking University participated in this experiment as paid volunteers. All were right-handed and had normal or corrected-to-normal vision. The stimuli and procedure were the same as those in Experiment 1 except that the ISIs between the cue and targets were either 300 or 600 ms. There were two blocks of 200 trials for each type of visual context. This experiment employed a three-factor within-subject design with the factors being visual context (Context A vs. Context B), attention (valid, neutral, or invalid), and ISI (300 vs. 600 ms).

The mean RTs for correct responses in the additional experiment are shown in Table A1. There was a significant main effect of attention, $F(2, 30) = 24.5$, $p < .001$, and a significant interaction between attention and ISI, $F(2, 30) = 3.47$, $p < .04$. At the long ISI, RTs in the valid condition were shorter than those in the neutral condition, which were in turn shorter than to those in the invalid condition. At the short ISI, RTs in the valid condition were faster than those in the neutral and invalid conditions, whereas RTs did not differ between the latter two conditions. However, neither the main effect of visual context, $F\ (2, 30) = 0.12$, $p > .7$, nor its interaction with attention was significant, $F(2, 30) = 0.55$, $p > .5$. These results indicate that the visual context with different perceived depth did not influence the cue validity effect, even when ISIs between cue and targets were shorter than that used in Experiment 1.

The mean percentage of errors for discriminating target letters was 4.7%. There were main effects of Attention, $F(2, 30) = 3.23$, $p < .05$, and ISIs, $F(1, 15) = 14.6$, $p < .002$. The error rate in the invalid condition (5.4%) was slightly higher than those in the valid (4.1%) and neutral (4.7%) conditions. Subjects made more errors in responding to targets when the ISI was 300 ms than when it was 600 ms (5.5% vs. 3.9%). Comparisons between the error rates and the mean RTs indicate that there was no speed–accuracy trade-off.

TABLE A1
Mean RTs for correct responses in the additional experiment

	ISI 300 ms				*ISI 600 ms*			
	Context A		*Context B*		*Context A*		*Context B*	
Attention	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Valid	533	18.9	533	18.9	528	18.6	528	20.5
Neutral	550	18.1	557	18.9	540	18.6	544	20.2
Invalid	552	18.6	555	18.6	554	18.9	556	19.4