

# Involuntary cueing effects on accuracy measures: Stimulus and task dependence

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Observers reported the orientation of a tilted grating that was presented together with a vertical distractor grating. In the main experiments, target contrast was low. There was location uncertainty because target location varied randomly and differences between target and distractor were small. In contrast to a previous report (T. Liu, F. Pestilli, & M. Carrasco, 2005), our results showed that non-informative peripheral cues do not improve perceptual performance at the cued location. However, informative peripheral or central cues improved perceptual performance. When we changed the task from an unspeeded perceptual task to a speeded reaction time task, the absence of involuntary cueing effects persisted when a distractor was presented. Without distractors, involuntary cueing effects re-emerged. When target contrast was increased, involuntary cueing effects re-emerged with a distractor but were smaller than without. We suggest that more difficult perceptual tasks reduce or abolish involuntary cueing effects.

Keywords: attention, voluntary attention, perceptual performance, signal enhancement, noise reduction

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## Introduction

Our ability to covertly attend cued locations can manifest itself in a variety of ways (overview in Wolfe, 2000). At the behavioral level, it is typically indexed by shorter reaction time (RT) or higher accuracy for attended than unattended targets. Although it is often assumed that similar effects are observed with exogenous (i.e., task-irrelevant peripheral flashes) and endogenous cues (i.e., arrows presented at fixation), there are a number of recent behavioral (Prinzmetal, McCool, & Park, 2005), EEG (Doallo et al., 2004, 2005; Landau, Esterman, Robertson, Bentin, & Prinzmetal, 2007), and fMRI studies (Esterman et al., 2008) inconsistent with this view. An important point of discord is whether non-informative cues modify the distinctiveness of the percept in the same way as informative cues. To preview our results, we will argue for a post-perceptual stage of involuntary cueing effects, as suggested by the difficulty to find effects on perceptual accuracy under conditions where voluntary effects on accuracy are robustly found. A short look at some classical studies will help to illustrate the different paradigms that have been used to study voluntary and involuntary attention.

In Posner, Nissen, and Ogden's (1978) spatial cueing paradigm, a central arrow cue preceded the onset of a

peripheral target (a rectangle). There were two possible target locations and no distractors were presented. The cue correctly indicated the target's location on 80% of the trials (valid trials) and pointed to the opposite location in 20% of the trials (invalid trials). RTs were found to be faster on valid than invalid trials. Because the cue was informative about the target location, there was a strategic benefit of attending to the cued location. It was therefore concluded that voluntary shifts of attention to the cued location facilitated target processing.

Subsequently, Jonides (1981) showed that peripheral cues produce faster RTs on valid than invalid trials even when they are not informative about the target location. In his paradigm, there were eight possible target locations and one of them was cued by an adjacent arrowhead. The non-target locations were filled with distractors similar to the target (letters), which required observers to search for the target (the letter L or R). Because all possible target locations were cued with equal probability, there was no strategic benefit of attending to the cue. The cueing effect in RTs is therefore believed to arise from involuntary shifts of attention. The results of Jonides were confirmed by Posner and Cohen (1984), who noted that the detection of a peripheral square was faster when it was preceded by a peripheral cue, even when the cue did not predict the target location. These classical studies show that voluntary and involuntary cueing effects may be observed with very

different display types: While Jonides (1981) used distractors and a large number of possible target locations, Posner and Cohen (1984) and Posner et al. (1978) presented the target rectangle without distractors on only two possible target locations. However, the present contribution will show that differences between display types do exist. Another noteworthy point is that observers in the classical studies by Posner and Jonides were asked to respond as fast as possible and RTs were the main dependent variable. Cueing effects on accuracy were often not significant because error rates were low (e.g., less than 10% in Jonides, 1981).

Further studies showed that voluntary shifts of attention also improved the accuracy of perceptual judgments (e.g., Bashinski & Bacharach, 1980; Cheal & Gregory, 1997; Cheal & Lyon, 1991; Doshier & Lu, 2000b; Lu & Doshier, 2000; Luck, Hillyard, Mouloua, & Hawkins, 1996; Morgan, Ward, & Castet, 1998; Experiment 1 in Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989). For instance, Bashinsky and Bacharach (1980) noted that the ability to detect the letter O to the left or right of fixation improved when a central arrow cued the target location. In this study, accuracy was around ~75% correct and RTs were not analyzed. The interpretation of the cueing effect was that voluntary attention improved perceptual sensitivity. The situation is less clear for involuntary shifts of attention triggered by non-informative peripheral cues. For instance, Henderson (1991) presented the target letter X or O in one of four locations and masked the target by the combined shape of the letters X and O. Valid peripheral cues improved accuracy, even when non-informative about the target location. Also, RTs were faster to validly cued targets. A number of other studies reported similar effects of non-informative, peripheral cues on accuracy, often without analyzing RT effects (Henderson & Macquistan, 1993; Luck & Thomas, 1999; Experiments 2 and 3 in Müller & Rabbitt, 1989; Scolari, Kohnen, Barton, & Awh, 2007).

In contrast, Prinzmetal, McCool et al. (2005) claim that non-predictive, peripheral cues do not affect performance when accuracy is the main dependent variable. In some experiments, they presented the target letters F and T, masked by circles. In experiments built around accuracy, the task was made difficult by reducing the size of the letters until accuracy was at ~75% correct. Additionally, observers were instructed to take their time to respond (unspeeded responses) and feedback was given after each trial. It was found that non-informative peripheral cues did not affect accuracy. In contrast, large effects of non-informative peripheral cues were observed when observers were instructed to respond as fast as possible (speeded responses) and the stimuli were easy to perceive (accuracy better than 90%). In fact, unspeeded responses in their [Experiment 1](#) showed lower accuracy with valid than invalid cues, while speeded responses in their [Experiment 5](#) showed the opposite effect. The dissociation suggests that unspeeded and speeded responses reflect partially

independent processes. Further, the study suggests some alternative explanations for previous reports of involuntary cueing effects on accuracy. First, previous studies may have confounded effects of speeded and unspeeded responses if no precautions to prioritize accuracy were taken. Second, a number of involuntary cueing effects on accuracy were experimental artifacts (Prinzmetal, McCool et al., 2005; Prinzmetal, Park, & Garrett, 2005).

In most of the abovementioned studies, letters or letter-like characters with a high contrast were used as stimuli. Partially, this may have been motivated by the available software and display devices. Another reason may have been the opportunity to choose sets of symbols that cannot be differentiated on the basis of a simple feature but require identification of a particular conjunction of features (e.g., the letters F and T share all low-level features but present a different combination of them). According to feature integration theory (Treisman & Gelade, 1980), attention is necessary to integrate features into conjunctions which is expected to maximize effects of spatial cueing with these stimuli.

In another line of research, Gaussian-windowed sine-wave gratings (Gabor patches) were used as stimuli, probably because they have similar characteristics as the neural spatial filters that perform early visual processing (e.g., Blakemore & Campbell, 1969) and because their contrast, size, spatial frequency, and orientation can be manipulated in a well-defined manner. An important outcome of this line of research was that attention increases contrast sensitivity (e.g., Doshier & Lu, 2000a; Solomon, Lavie, & Morgan, 1997). This may occur either because attention enhances the perceptual signal (Bashinski & Bacharach, 1980), reduces external noise (Doshier & Lu, 2000b), or reduces spatial uncertainty (Shiu & Pashler, 1994). Contrast thresholds were often measured using an orientation discrimination task (e.g., Doshier & Lu, 2000a, 2000b; Pestilli & Carrasco, 2005; Pestilli, Viera, & Carrasco, 2007). That is, observers had to indicate the orientation of the sine-wave grating while its contrast was reduced until performance on the discrimination task reached a certain level (typically ~75%). When the target location was cued, contrast could be reduced further than when the target was not cued. The flip side of enhanced contrast sensitivity is that orientation judgments at low contrast were facilitated with valid cues (Liu, Pestilli, & Carrasco, 2005). Interestingly, some of the studies reporting cueing effects on orientation judgments used non-informative peripheral cues (Liu et al., 2005; Pestilli & Carrasco, 2005; Pestilli et al., 2007) which contradicts Prinzmetal, McCool et al.'s (2005) claim that involuntary attention does not affect the accuracy of perceptual judgments. An easy (but wrong, as we will show) solution would be to limit the scope of the respective studies to the stimulus material that was used. Prinzmetal et al. used high-contrast stimuli (masked letters and lines, unmasked faces), whereas Liu et al. (2005) used low-contrast Gabors patches. If involuntary attention

enhanced the perceived contrast, cueing effects are expected with low-contrast stimuli as in Liu et al., but not with high-contrast stimuli as in Prinzmetal et al.

In the present study, we were mainly interested in the difference between exogenous and endogenous cues, and how effects of exogenous cues interact with stimulus characteristics. Stimulus characteristics are often linked to requirements of the task. Typically, responses are unspeeded when stimulus contrast is low because attention is expected to facilitate identification of poorly visible stimuli. Therefore, accuracy is the main dependent variable and observers are typically far from 100% correct. In contrast, responses are speeded when stimulus contrast is high. Because the stimuli are clearly visible, observers are close to 100% correct and RT is the main dependent variable. Further, we will briefly touch upon the question of uncertainty reduction vs. stimulus enhancement.

In [Experiment 1](#), we ran a replication of Liu et al.'s (2005) study to resolve the contradiction between their report of involuntary cueing effects and the work of Prinzmetal, McCool et al. (2005). Consistent with Prinzmetal et al., we failed to replicate effects of non-informative, peripheral cues on perceptual accuracy. In [Experiments 2](#) and [3](#), we compared involuntary and voluntary shifts of attention. We found that voluntary shifts of attention improved accuracy at low stimulus contrast, but non-informative cues again failed to affect accuracy. In [Experiments 1–3](#), observers were instructed to prioritize accuracy over speed. Therefore, accuracy was the main dependent variable. In [Experiments 4](#) and [5](#), observers were instructed to respond as rapidly as possible and RT was the main dependent variable. Even with speeded responses, involuntary cueing effects were absent with Liu et al.'s displays. However, cueing effects on RTs emerged when the task was made easier by increasing contrast or when no distractors were shown. We conclude that task difficulty may contribute to the absence of cueing effects in Liu et al.'s paradigm.

## Experiment 1

We closely replicated the study by Liu et al. (2005). A bright peripheral cue preceded a display consisting of two lateral Gabor patches. The vertical Gabor was the distractor and the tilted Gabor was the target (see [Figure 1](#)). Observers' task was to report the orientation of the tilted Gabor. The peripheral cue did not predict the target location and observers were instructed to ignore it. Further, observers were instructed to be as accurate as possible while neglecting speed. Note that Liu et al. instructed observers to respond as accurately and rapidly as possible, which would constitute a hybrid instruction according to Prinzmetal, McCool et al. (2005): Even

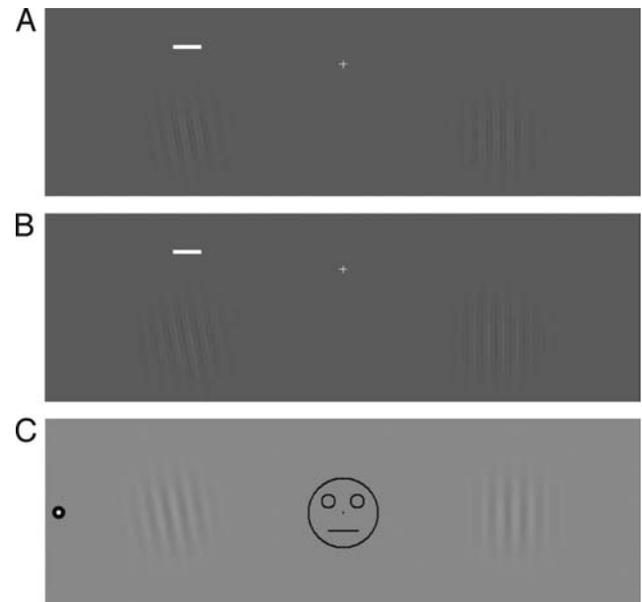


Figure 1. Sample stimuli (drawn to scale). Stimulus contrast does not correspond to the actual values. In panels A–C, cue, target, and distractor are shown in the same picture to illustrate distances and dimensions. In the experiment, the cue always preceded target and distractor. Panel A shows the stimuli from Liu et al. (2005). The Gabor patches were compound sine-waves (2 and 6 cpd) multiplied by a Gaussian with a space constant of 1. Panel B shows Stimuli used in Experiment 1 with a slightly larger space constant of 1.2. Panel C shows the stimuli used in Experiment 2.

though the principal dependent variable was accuracy, responses were speeded.

## Methods

The stimuli used by Liu et al. (2005) are shown in [Figure 1A](#). Ours are shown in [Figure 1B](#), and [Table 1](#) summarizes the different display parameters. Stimuli were presented on a gray background (24 vs. 25  $\text{cd}/\text{m}^2$  in Liu et al., 2005) at a refresh rate of 75 Hz. Viewing distance was 80 cm. A  $0.3^\circ$  fixation cross was presented in the center of the screen. The cue was a  $1 \times 0.15^\circ$  (width  $\times$  height) line that was presented  $5.5^\circ$  to the left or right and  $0.6^\circ$  above central fixation. Its luminance was 117  $\text{cd}/\text{m}^2$  (vs. 125  $\text{cd}/\text{m}^2$  in Liu et al., 2005). Target and distractor were presented  $5.5^\circ$  to the left and right (center to center) and  $2.5^\circ$  below central fixation. Target and distractor were Gabor patches (sine-wave multiplied by Gaussian) with compound sine-waves of 2 and 6 cycles per degree (cpd) at 5% Michelson contrast (i.e., each spatial frequency had a contrast of 2.5%). The space constant of the Gaussian was 1.2 (vs. 1 in Liu et al., 2005). The slightly different size of the stimuli was an omission of change when we programmed [Experiment 1](#). In [Experiments 2–4](#), which were run before [Experiment 1](#), the space constant was 1.2.

Parameter	Attribute	Liu et al. (2005)	Experiment 1	Experiment 2	Unit
Gabor patch	Space constant	1	1.2	1.2	degree
	Spatial frequency	2 and 6	2 and 6	1.8	cpd
	Contrast	5	5	5	%
Cue	Eccentricity	5.5	5.5	10	degree
	Azimuth	0.6	0.6	0	degree
	Luminance	White	White	White–black	
	Size (horizontal × vertical)	1 × 0.15	1 × 0.15	0.4 × 0.4	degree
	Area	0.15	0.15	0.13	degree <sup>2</sup>
Target	Presentation time	50	53	80	ms
	Eccentricity	5.5	5.5	6	degree
	Azimuth	–2.5	–2.5	0	degree
Cue-target	Presentation time	150	146	107	degree
	Distance	3.1	3.1	4	degree
SOA	SOA	100	94	107	ms
	SOA	100	94	107	ms
Fixation mark	Shape	Cross	Cross	Face	

Table 1. Stimulus parameters in Liu et al. (2005) and in Experiments 1 and 2. Note: \*SOA = stimulus onset asynchrony. A Gabor patch is a sine-wave (defined by spatial frequency and contrast) multiplied by a Gaussian (defined by a space constant). A negative azimuth refers to a position below the horizontal meridian. All distances are center to center.

However, we believe that this change is marginal (cf. Figures 1A and 1B). The distractor was a vertical grating, while the target was slightly tilted to the left or to the right. The experimental task was to indicate the orientation of the tilted Gabor by means of a key-press.

Liu et al.'s (2005) participants were trained for 1–2 hours before data collection. Our observers were trained in a 1-hour session. During training, we presented target and distractor, but no cues. A staircase procedure decreased the tilt of the target after two correct responses and increased the tilt after an incorrect response, which aims for 71% correct responses. Each staircase was terminated after 15 reversals and 9 staircases were run for about 700–800 trials. The mean tilt of the last 3 reversals of the best 4 staircases was used in the subsequent test session.

In the 30-minute test session about 1 week later, observers saw target and distractor stimuli preceded by the cue (see Figure 1B). The cue was presented for 53 ms (50 ms in Liu et al., 2005). The target was presented for 146 ms (vs. 150 ms in Liu et al., 2005). The SOA between cue and target was 94 ms (vs. 100 ms in Liu et al., 2005). The tilt of the target remained fixed at the value determined in the training session. In valid trials, the cue appeared on the same side as the target, whereas it appeared on the opposite side in invalid trials. The position of the cue and target varied randomly from trial to trial. Observers worked through at least 192 valid and 192 invalid trials randomly interleaved. After blocks of 48 trials, the experimenter checked whether the mean performance was above 90% or below 60%. In these cases, the experimenter decreased or increased the tilt and restarted the experiment which resulted in more trials per subject. All trials were included in the final analysis. The average tilt of the grating was 3° of rotation, which is in

the same range of orientations (1.5–4°) presented by Liu et al. (2005).

Participants were instructed to prioritize accuracy over speed. In the test session, participants were told to ignore the cues because they did not predict the target location. Sixteen undergraduate students at the University of Geneva participated.

## Results

### Accuracy and reaction time

For each participant, mean proportion correct and median response times were calculated for invalid and valid trials (see top row in Figure 2). The mean proportion of correct responses did not differ between invalid and valid cues (75.2% vs. 75.8%),  $t(15) = 0.64$ ,  $p = .53$ . The mean response time did not differ between invalid and valid cues (888 vs. 898 ms),  $t(15) = 1.26$ ,  $p = .23$ , which rules out speed-accuracy trade-offs.

### Power analysis of accuracy data

A post hoc power analysis was performed using  $g^*$ power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). In Liu et al. (2005), the mean difference between invalid and valid trials (pre-cue condition) was 7.3% with a standard deviation of 5.8 (Taosheng Liu, personal communication, July 26, 2007). The effect size for matched pairs,  $d_z$ , is defined as the ratio of the mean difference and the standard deviation of the difference. For Liu et al.'s cueing effect, the effect size is  $d_z = 1.26$ , which is considered a very large effect. Effect sizes of 0.2, 0.4, and 0.8 are considered as small, medium, and large,

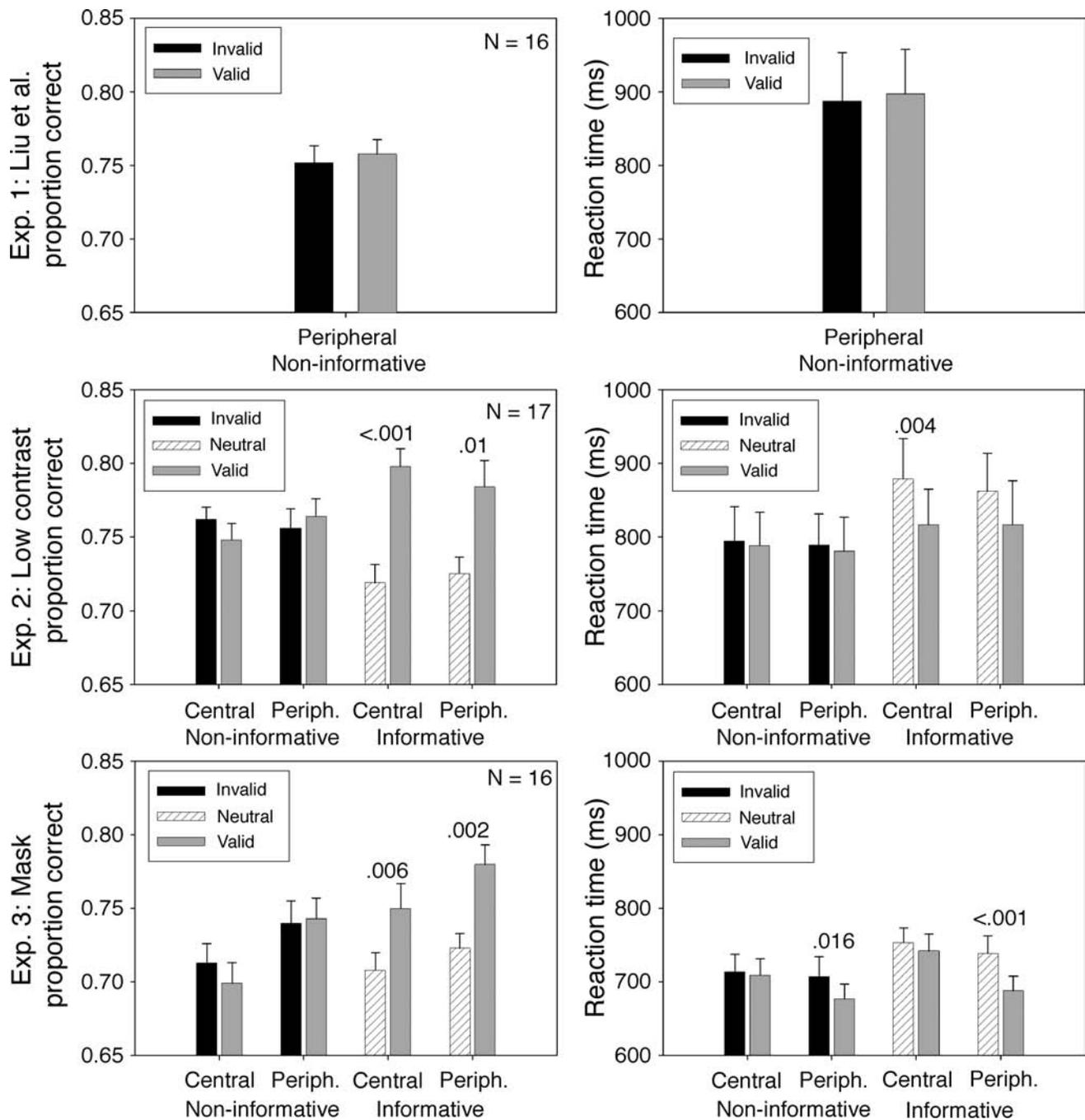


Figure 2. Accuracy (left column) and reaction times (right column) in Experiments 1–3 (rows 1–3) as a function of validity (invalid/neutral, valid), cue type (central, peripheral), and information content of the cue (non-informative, informative). In the non-informative condition, the cue indicated the wrong location in 50% of the trials (invalid cue). In the informative condition, a neutral cue did not indicate any specific location in 50% of the trials. In both the informative and the non-informative condition, a valid cue correctly indicated the target location in 50% of the trials. Invalid and neutral trials were compared to valid trials by *t*-test (two-tailed) and the *p*-values of significant tests are reported above the respective bars. Error bars represent between-subjects standard error.

respectively (Cohen, 1992). Assuming a one-tailed *t*-test at  $\alpha = .05$  and given our sample size of 16 observers, the power to detect an effect of this size is .9992. The power is defined as 1-beta where beta is the probability of wrongly accepting  $H_0$  when in reality  $H_1$  is true (Type II error). A power of .8 is considered an adequate compromise

between the risk of a Type II error and expenses (Cohen, 1992). Consequently, given the large power of our experiment, we may be almost certain of not having incorrectly accepted  $H_0$  in the present experiment. Further, one may wonder what the minimal difference was that we could have detected given the variability in

our sample. The standard deviation of the difference between invalid and valid trials was 3.7. Assuming a one-tailed  $t$ -test with  $\alpha = .05$ , the minimal difference we could have detected was 1.6%. The observed mean difference was less than half that criterion (0.6%), however. Overall, given the large statistical power for comparing performance in valid and invalid trials, our experiment was a fair test of the hypothesis of involuntary cueing effects.

Finally, one may worry about the reliability of the estimations of individual performance. Due to the requirements of the fMRI measurements, Liu et al. (2005) collected 448 trials for each combination of cue presentation time (before or after target presentation) and validity (valid, invalid), which by far exceeds the typical number of repetitions in behavioral studies. Here, we collected at least 192 trials per condition, which is also far more than what is typically done. Our hunch is that most researchers in the field would consider means based on  $\sim 100$  repetitions as a very robust estimation of the true mean. The average performance in our sample of 16 participants was 75.5% with a standard deviation of 3.8 compared to 79.1% with a standard deviation of 7.5 in Liu et al.'s sample of 6 observers. Thus, our sample was somewhat more homogenous, confirming the robustness of our data.

## Discussion

In sum, we failed to observe effects of non-informative, peripheral cues on perceptual performance with non-speeded responses in a near copy of Liu et al.'s (2005) experiment. This result supports Prinzmetal, McCool et al.'s (2005) hypothesis that uninformative cues have no effect on accuracy and extends it to low-contrast stimuli. In the subsequent experiments, we will show that informative peripheral and central cues do affect accuracy, however.

## Experiment 2

To clarify the reasons for our failure to replicate Liu et al. (2005), we manipulated the information content of the cue (see Figure 3). In the non-informative condition, the cues did not carry information about the likely target location (50% valid and 50% invalid, as in Experiment 1). In the informative condition, the cue either indicated the location of the target or it did not contain any directional information (50% valid and 50% neutral cues). The comparison of valid and neutral cues measures the combined effects of exogenous and endogenous attention because there is both a strategic benefit in attending to the

cued location and a salient visual event close to the target that may capture attention involuntarily.

In addition to manipulating the information content of the cues, we added a condition with central gaze cues. Central cues do not affect RTs if they are non-informative about the target location (Jonides, 1980) (but see Gibson & Bryant, 2005). Effects of central cues are therefore believed to depend on voluntary attention. More recent studies show that directional symbols (i.e., arrows or gaze direction) are overlearned to such an extent that they produce involuntary effects on RTs (Friesen & Kingstone, 1998; Tipples, 2002). However, non-predictive gaze cues do not produce involuntary cueing effects on RTs with identification tasks and short cue-target intervals (Friesen & Kingstone, 1998).

The comparison of informative vs. non-informative cues, as well as the comparison between central and peripheral cues will indicate whether cueing effects on accuracy result from voluntary or involuntary shifts of attention. In contrast to Experiment 1, we only replicated the most important aspects of the methods of Liu et al. (2005): orientation discrimination, location uncertainty due to a distractor, peripheral cueing, and SOA of about 100 ms (see Table 1).

## Methods

The same equipment was used as in Experiment 1. Stimuli were presented on a gray background ( $54 \text{ cd/m}^2$ ) at a viewing distance of 60 cm. A circular face with a diameter of  $2.5^\circ$  served as fixation mark (see Figure 1C). Sine-wave gratings of 1.8 cpd multiplied by a Gaussian with a standard deviation of  $1.2^\circ$  were presented at  $6^\circ$  to the left and right of fixation. The Michelson contrast of the sine-wave was 5%. Target and distractor were presented for 107 ms. A central or peripheral cue preceded target onset by 107 ms. Circular  $0.2^\circ$  pupils appearing in the outline eyes ( $0.4^\circ$  diameter) served as central cue and a black ring ( $0.4^\circ$  diameter) with a white center served as peripheral cue. To cue the left or right position, the pupils were offset by  $0.1^\circ$  to the left or right, and the peripheral cue appeared at an eccentricity of  $10^\circ$  on the left or right. If the peripheral cue and the gratings had been shown simultaneously, there would have been no overlap between the two (see Figure 1C). As neutral cues, the pupils were presented in the center of the eyes and the annulus was presented on the nose. For ease of exposition, we refer to the annulus as “peripheral cue” even though it was presented in the fovea in the neutral condition. The central cue stayed on until a key was pressed (as in Friesen & Kingstone, 1998), while the peripheral cue was presented for 80 ms. To make the experimental situation in blocks with peripheral and central cues as similar as possible, the outline face was used as a fixation mark in blocks with peripheral cues. However, we believe that it

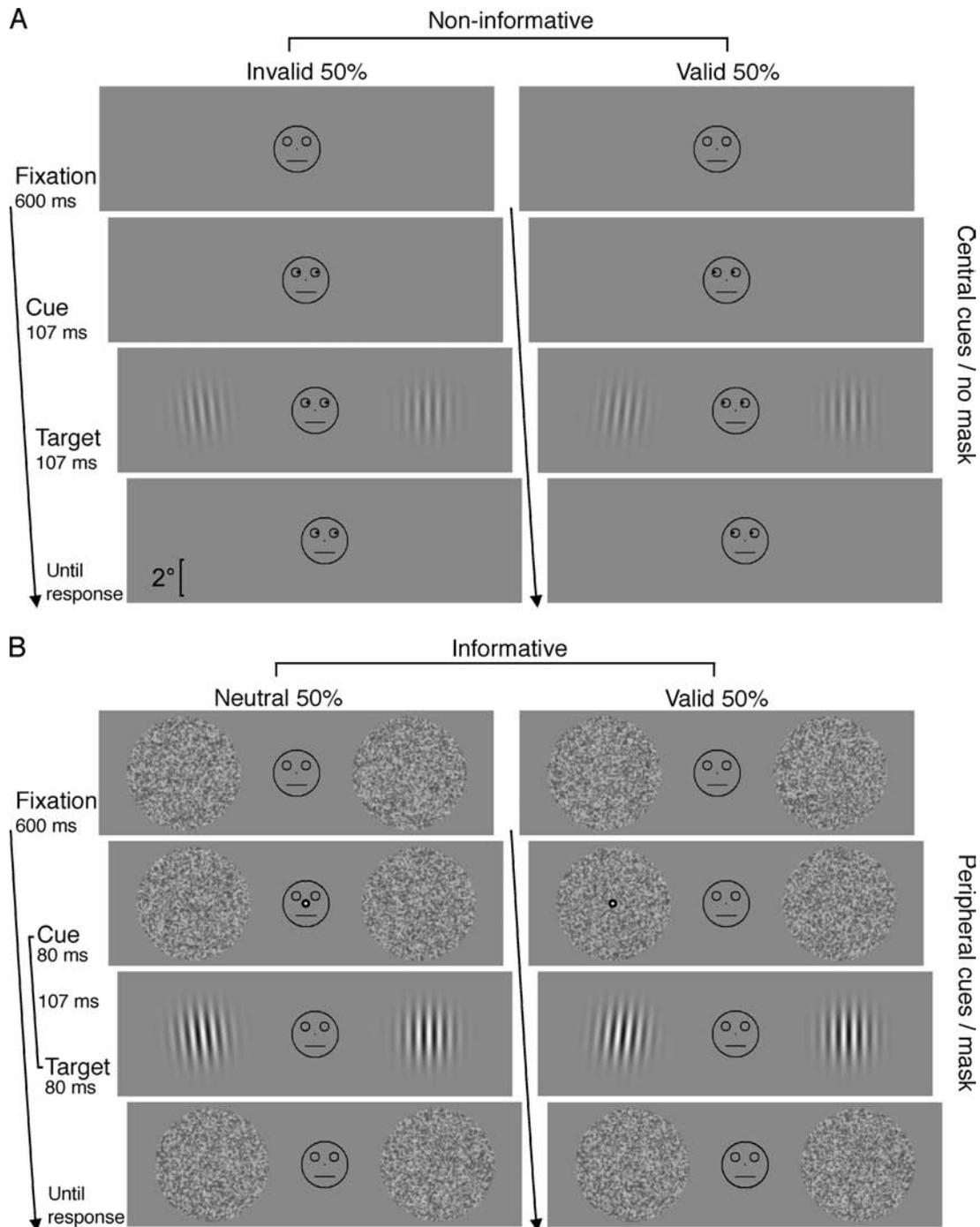


Figure 3. Sample stimuli (drawn to scale) and time course in [Experiments 2](#) and [3](#). Participants were asked to detect the tilted grating (the target) and indicate its orientation by pressing a key. In the illustration, the target is always on the left. Panel A shows the comparison between invalid and valid conditions for central cues, while panel B shows the comparison between neutral and valid cues for peripheral cues. Central and peripheral cues as well as informative and non-informative conditions were run in [Experiments 2](#) and [3](#). Stimuli were masked in [Experiment 3](#), but not in [Experiment 2](#). The peripheral cue was presented for 80 ms, while the central cue stayed on the screen. In both cases, the onset of the cue preceded the onset of the target by 107 ms.

functioned just as any other fixation mark (cross, bull's eye, line, etc.) because of its invariable shape in those blocks.

The non-informative and informative conditions were run in separate sessions on different days. Each session took about 1 hour and started with practice trials.

Observers were trained without cues for about 20 minutes while the grating orientation yielding 71% correct responses was determined. The mean adjusted orientation of the target grating was 2° in both informative and non-informative blocks. After training, the position of the target and the validity of the cue were randomized, but central and peripheral cues were run in alternating blocks of 24 trials. The order of information content (session) and cue type was counterbalanced across subjects. Each of the eight combinations of validity, cue type, and information content was repeated 48–72 times for a total of 480 trials per participant. As in [Experiment 1](#), the experimenter adjusted the orientation of the target if performance was out of range which may have increased the total number of trials. Participants were instructed to prioritize accuracy over speed, to ignore the cues in the non-informative condition because they did not predict the target location, and to direct their attention to the spatially selective cue in the informative condition because the target always appeared at the cued location. Seventeen undergraduate students at the University of Geneva participated.

## Results and discussion

Mean accuracy and median RTs were determined for each participant and combination of validity (invalid/neutral vs. valid), cue type (central vs. peripheral), and information content (informative vs. non-informative). In three-way analyses of variance (information content  $\times$  cue type  $\times$  cue validity), invalid and neutral trials were opposed to valid cues.

### Accuracy

Mean accuracy and RT across participants are shown in [Figure 2](#) (second row) and were subject to a three-way, within-subject ANOVA. Accuracy was higher with valid than with invalid/neutral cues (77.4% vs. 74.0%),  $F(1, 16) = 11.68, p < .005$ . The interaction of validity and information content,  $F(1, 16) = 14.75, p < .001$ , showed that an increase in accuracy with valid cues was only observed when the cues were informative (79.1% vs. 72.2%), but not when they were non-informative (75.6% vs. 75.9%). No other effects were significant.

Further, we compared the neutral condition in the informative block to the valid and invalid condition in the non-informative condition. With central cues, the neutral condition was 4%,  $t(16) = 3.63, p = .002$ , and 3%,  $t(16) = 2.42, p = .028$ , worse than the invalid and valid conditions, respectively. With peripheral cues, the neutral condition was 3%,  $p = .13$ , and 4%,  $t(16) = 2.52, p = .023$ , worse than the invalid and valid conditions. Thus, the neutral condition with central cues seems to misbehave because one would expect it to be intermediate between invalid and valid cues, when in fact it is worse

than both conditions. With peripheral cues, the pattern seems to suggest that there are benefits (valid > neutral) but no costs (invalid = neutral).

The misbehavior of the neutral condition may be due to any of the following. First, the estimated 71% correct threshold was adjusted between sessions. As threshold estimates were noisy (15% change between sessions), comparisons between sessions may produce spurious results. Because we were unable to replicate the misbehavior in the following experiment, this seems to be the most likely cause. Also, thresholds were adjusted before the cues were presented. Thus, thresholds do not take into account the difficulties that may arise from having to interpret the cues. The requirement to interpret the cues may have reduced accuracy in the informative conditions, in particular with central cues that are harder to interpret than peripheral cues. Second, subjects' overall effort may depend on the conditions in each block and previous studies suggest that the neutral condition should only be compared to conditions run in the same block (Jonides & Mack, 1984).

### Reaction times

Because we instructed subjects to focus on the precision of their responses, and to disregard speed, we do not expect to observe consistent cueing effects in the RT data. The main purpose of the analysis was to rule out speed-accuracy trade-offs. RTs were faster with non-informative than with informative cues (788 vs. 843 ms),  $F(1, 16) = 11.05, p < .005$ , and with valid than with invalid/neutral cues (800 vs. 831 ms),  $F(1, 16) = 11.67, p < .005$ . The interaction between validity and information content,  $F(1, 16) = 5.95, p < .05$ , showed that faster responses with valid cues were only observed with informative (816 vs. 870 ms), but not with non-informative cues (784 vs. 792 ms). The pattern of RTs rules out that accuracy effects were due to speed-accuracy trade-offs.

### Power analysis of accuracy data

Assuming a one-tailed  $t$ -test at  $\alpha = .05$  and given our sample size of 17 observers, the power to detect a cueing effect with  $d_z = 1.26$  was .9995. In the non-informative condition of our experiment, the standard deviation of the difference between invalid and valid trials was 3.9 and 7.5 with central and peripheral cues, respectively. Assuming a one-tailed  $t$ -test with  $\alpha = .05$ , the minimal difference we could have detected was 1.7% and 3.2%, respectively. The observed mean differences were smaller than 1%, however. Again, the power analysis shows that our experiment was a fair test of the hypothesis of involuntary cueing effects.

Finally, one may worry about the reliability of the estimations of individual performance. We collected 48–72 trials for each of the eight combinations of validity, cue

type, and information content, which is in the range of previous studies reporting reliable cueing effects. For instance, Luck and Thomas (1999) and Henderson and Macquistan (1993) presented 40 and 48 valid trials, respectively. Besides, unreliable estimates of individual performance should have inflated between-subjects variability. However, the between-subjects variability was sufficiently small to detect the predicted differences, and in fact cueing effects of the predicted size were confirmed with informative cues.

## Discussion

Again, we failed to obtain effects of non-informative, peripheral cues on perceptual performance. The absence of involuntary cueing effects on accuracy with gaze cues replicates two recent studies that used letters or letter-like characters as targets (Prinzmetal, Leonhardt, & Garrett, 2008; Stevens, West, Al-Aidroos, Weger, & Pratt, 2008). At the same time, the experiment shows that our methods were sensitive enough to reveal cueing effects on accuracy with informative cues. The size of our cueing effects with informative cues (6–8%) was in the same range as the cueing effect reported by Liu et al. (2005). We believe that the effects of voluntary attention in our experiments are caused by reduced location uncertainty (e.g., Palmer, Ames, & Lindsey, 1993; Shaw, 1982; reviewed in Smith & Ratcliff, 2009). Remember that valid cues in the informative condition reliably indicated the target location whereas neutral cues did not provide any information about the target location. Because observers did not have to distinguish the target and the distractor when a valid cue was presented, they were less likely to confuse the target with the distractor. In other words, valid cues allowed perceptual activity at the distractor location to be excluded from the decision process which improved performance. In contrast, we do not believe that the effects of voluntary attention are due to contrast enhancement because Gould, Wolfgang, and Smith (2007) showed that cueing effects on low-contrast Gabors were absent when effects of signal enhancement were separated from effects of spatial uncertainty.

## Experiment 3

In a review of the literature, Smith, Ratcliff, and Wolfgang (2004) showed that most studies presenting evidence for signal enhancement used backward masks. Thus, one reason for the lack of involuntary cueing effects in the previous experiments may be the absence of a mask. To test this hypothesis, we presented high-contrast Gabors that were followed by masks. In an experiment not

reported here, we noted that presenting the cue outside the circular mask at 10° (as in Experiment 2) interfered with processing of the adjacent Gabor, resulting in significantly worse performance in valid than invalid trials. We therefore presented the cue inside the circular mask.

## Methods

The methods were as in Experiment 2 with the following exceptions. The eccentricity of the peripheral cue was reduced to 6° (i.e., the center of the subsequent Gabor patch). The gratings had a contrast of 100% and were presented for 80 ms, preceded and followed by circular masks of 6.1° diameter. The masks consisted of  $0.08 \times 0.08^\circ$  squares with a random contrast of 0–50%. The mean adjusted orientation of the target grating was 5° and 6° in the non-informative and informative blocks (difference, *ns*), respectively. Each of the eight combinations of validity, cue type, and information content was repeated 72 times for a total of 576 trials per subject. Sixteen undergraduate students at the University of Geneva participated.

## Results and discussion

The results are shown in Figure 2.

### Accuracy

Accuracy was higher with peripheral than with central cues (74.6% vs. 71.7%),  $F(1, 15) = 9.04$ ,  $p < .01$ , and with valid than with invalid/neutral cues (74.3% vs. 72.1%),  $F(1, 15) = 5.34$ ,  $p < .05$ . The interaction of validity and information content,  $F(1, 15) = 12.27$ ,  $p < .005$ , showed that valid cues only improved accuracy when the cues were informative (76.5% vs. 71.6%), but not when they were non-informative (72.1% vs. 72.6%). No other effects were significant.

Further, we compared trials with neutral cues in the informative block to trials with invalid/valid cues in the non-informative block. None of those comparisons was significant,  $ps > .31$ .

### Reaction times

RTs were faster with peripheral than with central cues (703 vs. 729 ms),  $F(1, 15) = 11.16$ ,  $p < .005$ , and with valid than with invalid/neutral cues (703 vs. 728 ms),  $F(1, 15) = 23.52$ ,  $p < .001$ . Faster responses with valid cues were only observed for peripheral (682 vs. 723 ms), but not for central cues (726 vs. 733 ms),  $F(1, 15) = 10.44$ ,  $p < .01$ . The pattern of RTs rules out that accuracy effects were due to speed-accuracy trade-offs.

### Power analysis of accuracy data

In the non-informative condition, the between-subject standard deviation of the difference between valid and invalid trials was 6.9 and 5.8 with central and peripheral cues, respectively. Assuming a one-tailed  $t$ -test with  $\alpha = .05$ , we could have detected differences of 3% and 2.6%, respectively. However, the differences between valid and invalid cues in the non-informative condition were smaller than 1%.

## Discussion

Again, we observed no effect of non-informative cues on accuracy despite the presence of a backward mask. Thus, involuntary cueing effects on accuracy do not necessarily occur when a backward mask is added to the display. It may be that masks only produce cueing effects in experiments using informative cues (e.g., Doshier & Lu, 2000b; Smith, Ratcliff, & Wolfgang, 2004) or with certain stimuli such as letters (Experiment 5 in Henderson, 1991; Henderson & Macquistan, 1993; Luck & Thomas, 1999; Experiments 2 and 3 in Müller & Rabbitt, 1989).

## Experiment 4

Experiments 1–3 failed to replicate involuntary cueing effects with displays similar to those used in Liu et al. (2005), but with unspeeded responses. Liu et al. instructed observers to respond as accurately and as quickly as possible (speeded responses). Consistent with the different instructions, observers in our Experiment 1 were about 150 ms slower than in Liu et al. ( $\sim 750$  vs.  $\sim 900$  ms). To clarify whether the instructions explained the different results, we reran Experiment 1 with speeded responses. To anticipate the results, we were unable to find involuntary cueing effects on speeded responses with the stimuli used in Experiment 1. Because this null effect is at odds with a large number of studies reporting cueing effects on RTs, we manipulated the difficulty of the task and the presence of a distractor. Recently, Prinzmetal, Zvinyatskovskiy, Gutierrez, and Dilem (2009) showed that effects of involuntary attention were larger for easy perceptual tasks than for difficult perceptual tasks. To test effects of difficulty, we added a condition with targets tilted by  $45^\circ$ . Remember that target orientation was adjusted to produce  $\sim 71\%$  accuracy in previous experiments, resulting in grating orientations of  $\sim 5^\circ$ . Targets tilted by  $45^\circ$  were expected to be more easily perceived. Further, we presented one group of participants with the displays used in Experiment 1, and another group with a single target grating. The comparison between target-only and target + vertical distractor was run between subjects.

## Methods

The methods were as in Experiment 1 with the following exceptions. We instructed observers to respond as rapidly as possible without making too many errors. Because the emphasis was on speed, we gave visual feedback after trials with latencies longer than 900 ms (“too slow”) in addition to the auditory feedback after choice errors. In one block of trials, the orientation of the target was fixed at  $45^\circ$ . This condition will be referred to as “easy condition.” In another block of trials, we adjusted the orientation of the target in two staircases with 15 reversals each (“difficult condition”). The resulting thresholds were  $6^\circ$  with bilateral and  $10^\circ$  with unilateral presentation. The same latency criterion was used during the threshold procedure as in the experiment. Because of the time pressure, subjects tended to make errors early on in the threshold procedure which resulted in elevated threshold estimates. Inspection of Figure 4 shows that performance in the difficult condition was indeed higher than the expected 71% performance (around 80–85%). Learning may also have contributed to the higher performance. The difficult and easy conditions were blocked and 192 trials were administered in each block. One group of observers ( $N = 16$ ) saw the displays used in Experiment 1 which consisted of a tilted target and a vertical distractor. Another group of observers ( $N = 12$ ) saw displays consisting only of the tilted target. For each group of observers, the order of the easy and difficult conditions was counterbalanced.

## Results and discussion

The results are shown in Figure 4 (top row). Preliminary analysis showed that our manipulation of difficulty was not successful in the group without distractor. Inspection of Figure 4 shows that this is due to the rather poor performance in the “easy”  $45^\circ$  condition. We had expected subjects to be over 90% correct in this condition, but they were at 85%. With a distractor, performance in the easy condition was slightly above 90%. We ran separate two-way ANOVAs (difficulty  $\times$  cue validity) on the two groups. Only the easy condition was compared between groups in a mixed-factor ANOVA (presence of distractor  $\times$  cue validity).

### Target and distractor

A two-way ANOVA on median RTs showed faster responses in the easy than in the difficult condition (619 vs. 653 ms),  $F(1, 15) = 10.83$ ,  $p < .005$ . The effect of cue validity did not reach significance,  $p = .11$ . A two-way ANOVA on accuracy showed that subjects made fewer errors in the easy than in the difficult condition (.90 vs. .81),  $F(1, 15) = 10.63$ ,  $p = .005$ . There was no effect of

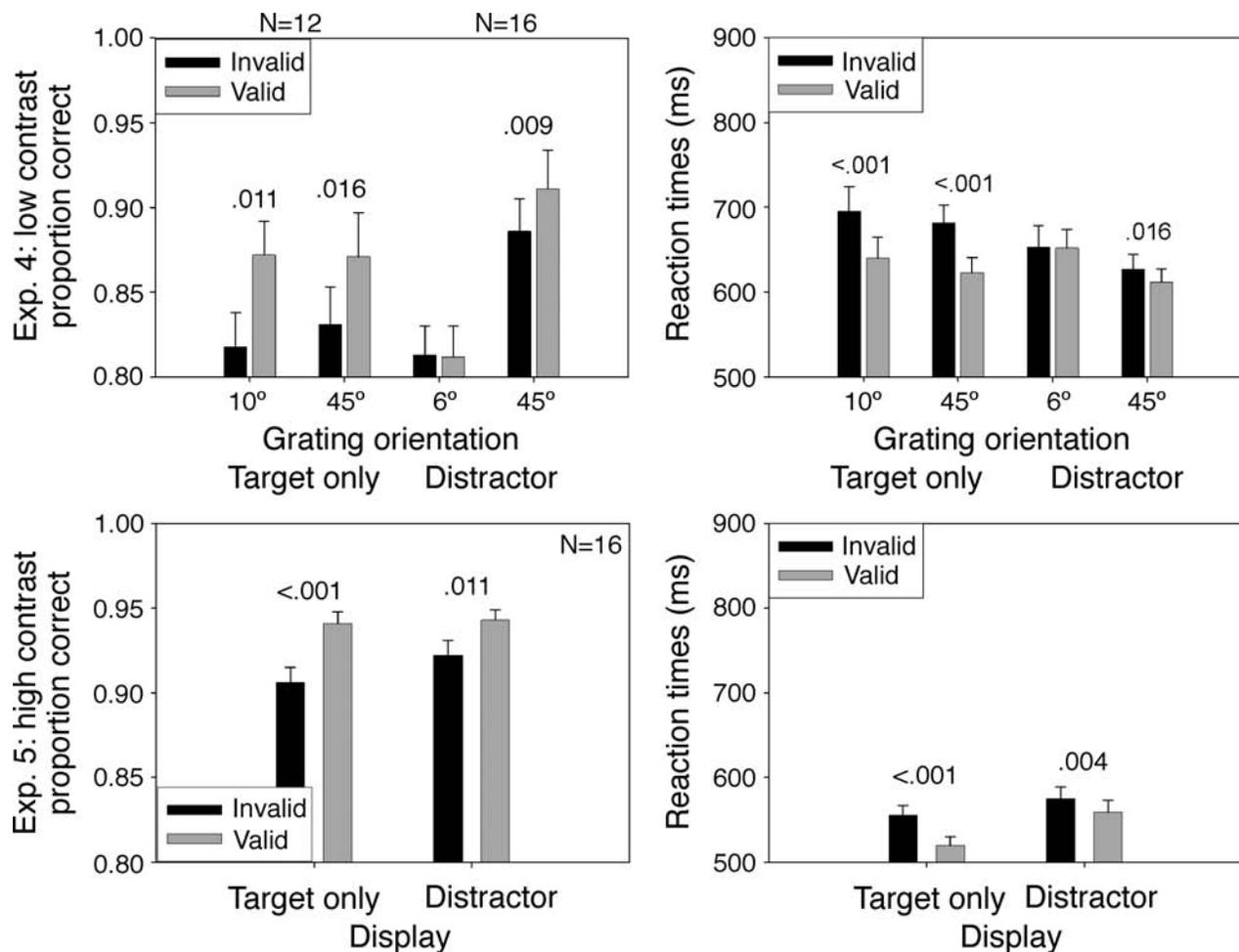


Figure 4. Accuracy (left column) and reaction times (right column) in Experiments 4 and 5 as a function of distractor presence (target only, distractor), grating orientation, and cue validity. In Experiment 4, the target's orientation was adjusted by a staircase procedure in the difficult condition and kept at 45° in the easy condition. In Experiment 5, the target's orientation was always at 45°. Invalid trials were compared to valid trials by *t*-test (two-tailed) and the *p*-values of significant tests are reported above the respective bars. Error bars represent the between-subjects standard error. Note the different offset of the ordinates compared to Figure 2.

cue validity,  $p = .15$ . The interaction of difficulty and cue validity approached significance,  $F(1, 15) = 3.44$ ,  $p = .083$ , indicating that there was a small cueing effect in the easy condition (.91 vs. .89), but none in the difficult condition (.81 vs. .81). Post hoc *t*-tests confirmed this pattern. Figure 4 shows that there was no effect of cue validity in the difficult condition which replicates the results with non-speeded responses in Experiment 1. However, the easy condition with gratings tilted by 45° produced small, but significant cueing effects on RTs (15 ms) and accuracy (2.5%). However, the results of these follow-up tests should be interpreted with care, as the interaction between task difficulty and cue validity was not significant.

#### Target only

A two-way ANOVA on median RTs showed faster responses with valid than invalid cues (631 vs. 689 ms),  $F(1, 11) = 67.81$ ,  $p < .001$ , but no effect of difficulty,  $p =$

.573. A two-way ANOVA on accuracy showed that proportion correct was higher with valid than invalid cues (.87 vs. .82),  $F(1, 11) = 10.98$ ,  $p = .007$ , but again no effect of difficulty emerged,  $p = .87$ . Inspection of Figure 4 shows that the difference between valid and invalid was significant for all conditions.

#### Comparison with and without distractor

We ran a mixed-factor two-way ANOVA (presence of distractor  $\times$  cue validity) on the easy condition with 45° target inclination. Analysis of median RTs showed faster RTs with valid than invalid cues (617 vs. 654 ms),  $F(1, 26) = 39.39$ ,  $p < .001$ . Presence of distractor and cue validity interacted,  $F(1, 26) = 14.1$ ,  $p < .001$ , indicating that the cueing effect was larger with target-only than with target + distractor (59 vs. 15 ms). Analysis of accuracy showed that fewer errors were made with valid than with invalid cues (.89 vs. .86),  $F(1, 26) = 14.8$ ,  $p < .001$ . The

interaction was not significant,  $p = .4$ , but the means follow the pattern of RTs, ruling out speed-accuracy trade-offs.

## Discussion

The results of [Experiment 4](#) confirm and extend the conclusions of [Experiments 1–3](#). Above all, the results show that involuntary cueing effects are also absent with low-contrast displays consisting of a target and a highly similar distractor when RTs are the main dependent variable. When the distractor was more easily distinguished from the target because the difference in inclination was larger, some small cueing effects emerged. This finding is consistent with larger involuntary cueing effects in easy than difficult tasks (Prinzmetal et al., 2009). Further, cueing effects on RTs were larger in target-only than in target + distractor displays. The simplest explanation would be that the task was also easier without distractors. However, the main effect of presence of distractor was not significant; perhaps because the presence of a distractor was manipulated between-subjects and the high between-subjects variability masked the effect of distractor.

## Experiment 5

The first aim of [Experiment 5](#) was to compare conditions with and without distractor in a between-subject design. The second aim was to make the task easier by increasing contrast to 50%. [Figure 4](#) shows that accuracy with low contrast in [Experiment 4](#) was never better than 90%, suggesting that even with a tilt of 45°, it was relatively difficult to judge target orientation.

## Methods

The tilt of the target was always 45°. In the bilateral condition, it was accompanied by a vertical distractor on the opposite side. In the unilateral condition, it was presented alone. The Michelson contrast of the Gabors was 50% (i.e., each spatial frequency had a contrast of 25%). Conditions with and without distractor were run in separate blocks of 192 trials each and block order was counterbalanced across subjects. Sixteen students participated.

## Results and discussion

The results are shown in [Figure 4](#) (bottom row). The data were analyzed by two-way ANOVAs (presence of distractor  $\times$  cue validity).

## Reaction times

The ANOVA showed that median RTs were faster without than with a distractor (538 vs. 567 ms),  $F(1, 15) = 4.9$ ,  $p = .043$ , and with valid than with invalid cues (539 vs. 565 ms),  $F(1, 15) = 47.82$ ,  $p < .001$ . Presence of distractor and cue validity interacted,  $F(1, 15) = 5.33$ ,  $p = .036$ , showing that the cueing effect was larger without than with a distractor (36 vs. 16 ms).

## Accuracy

Overall, accuracy was higher than 90% which is more typical for experiments built around RTs. The ANOVA confirmed more accurate responses with valid than invalid cues (.94 vs. .91),  $F(1, 15) = 34.37$ ,  $p < .001$ . The interaction did not reach significance,  $p = .123$ , but the means follow the pattern of RT effects, ruling out speed-accuracy trade-offs.

## Discussion

Involuntary cueing effects occurred with and without a distractor but were smaller when a distractor was presented. RTs were shorter and accuracy higher in the present than in the previous experiment, confirming that the task was easier with 50% than with 5% contrast (cf. bottom and top row of [Figure 4](#)). Also, RTs were slower when a distractor was present than when the target was presented alone. A similar effect may have occurred in [Experiment 4](#) but may have been masked by between-subjects variability.

Overall, there was a tendency for involuntary cueing effects to increase when difficulty was decreased and RTs were shorter. Removing the distractor ([Experiment 5](#)) or increasing the angular distance between target and distractor ([Experiment 4](#), bilateral condition) reduced RTs. At the same time, involuntary cueing effects increased or emerged. Prinzmetal et al. (2009) suggested that non-predictive cues do not affect perceptual processing, but the selection or the generation of responses. Based on the leaky competing accumulator model by Usher and McClelland (2001), Prinzmetal et al. proposed that evidence for each target at each target location accumulates. In the present case, there would be four accumulators because there were two target locations and two targets. If the evidence in any accumulator exceeds a certain threshold, a response is triggered. A spatial cue boosts the evidence in the accumulators at the respective location. For instance, a cue on the left would increase the evidence in the accumulators for both target orientations at that location. Thereby, the amount of evidence from the stimulus needed to trigger a response is reduced, which explains faster RTs with valid cues. Another property of the model is that evidence in the accumulators dissipates

over time. Therefore, the boost of evidence caused by the cue dissipates when perceptual processing takes more time. In the present experiments, processing was delayed when the target had to be discriminated from the distractor, in particular when the difference between target and distractor was small. Because of the additional delay, cueing effects may have decreased. Nonetheless, not all aspects of our data are consistent with the model. RTs decreased substantially from Experiment 4 to Experiment 5, yet the size of the cueing effects was not larger in Experiment 5 than in Experiment 4 (Experiment 5: 36 ms without distractor and 16 ms with distractor; Experiment 4, easy condition: 59 ms without distractor and 15 ms with distractor). Again, this comparison was run between-subjects groups and the null effect should therefore be treated with care.

Further, one may wonder whether the involuntary cueing effects on accuracy in Experiments 4 and 5 contradict the claim that non-informative cues do not affect perceptual processing. In fact, one may argue that the higher accuracy with valid than invalid cues was due to improved perceptual performance. While we cannot entirely rule out this possibility, we believe it is rather unlikely. In Experiments 4 and 5, RT was the main dependent variable because the task was speeded. The stimuli in Experiment 5 were clearly visible and there is reason to believe that without time pressure, subjects would have been close to 100% correct responses. Because perceptual performance was at ceiling, we believe that cueing effects on accuracy reflect decision processes. For instance, invalid cues may create competition between accumulators that do not correspond to the target and those that correspond to the target, resulting in more errors in invalid trials (see above). In general, it would be odd to claim that changes of accuracy always have a perceptual origin (see also Prinzmetal, McCool et al., 2005). For instance, responses are faster and less error prone when participants have to move toward the stimulus than away from it (Fitts & Deininger, 1954) which is clearly unrelated to perceptual processing. Therefore, we do not believe that cueing effects in Experiment 5 have a perceptual origin. In Experiment 4, the stimuli were difficult to identify and therefore a perceptual explanation may be feasible. However, because the pattern of results was similar with low and high contrast (cf. effects of distractor presence in Experiments 4 and 5), it is not very convincing to claim that perceptual enhancement explained cueing effects in one case, and post-perceptual priming in the other.

## General discussion

In the present study, we tried to clarify whether involuntary attention improves perceptual performance.

To this end, we re-examined a previous report of involuntary cueing effects on orientation discrimination at low stimulus contrast (Liu et al., 2005). We were unable to replicate involuntary cueing effects in unsped and speeded versions of the task. We do not have a good explanation for the significant effects reported by Liu et al. (2005). The most likely explanation is a sampling error. Liu et al. (2005) used a small number ( $N = 6$ ) of observers, some of whom were trained. Other studies reporting effects of involuntary cueing on orientation discrimination had even fewer subjects: four in Pestilli and Carrasco (2005) and three in Pestilli et al. (2007). We believe that it is unwise to rely on such a small sample. A reader of the manuscript suggested that trained observers know what they are doing and know how to ignore the cue. We disagree because these assumptions seem like relapse into introspection. Because strategic factors are important and not all cognitive processes reach consciousness, studies on involuntary cueing effects should include a rather large number of participants. That way, different individual strategies will cancel out. A priori, the lack of involuntary cueing effects should be considered as more trustworthy because subjects were explicitly instructed to ignore the cue. It should not surprise us to see that observers are able to follow these instructions.

Further, the results from Experiments 2 and 3 are consistent with a large body of studies reporting perceptual enhancement with informative cues (e.g., Bashinski & Bacharach, 1980; Cheal & Gregory, 1997; Cheal & Lyon, 1991; Doshier & Lu, 2000b; Lu & Doshier, 2000; Luck et al., 1996; Morgan et al., 1998; Experiment 1 in Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989). The dissociation of voluntary and involuntary cueing effects on accuracy support Prinzmetal, McCool et al.'s (2005) theoretical framework. However, we are not sure that effects of involuntary attention on accuracy will be absent for all display types. In some studies reporting effects of non-informative cues on perceptual accuracy, letter-like stimuli were used (Experiment 5 in Henderson, 1991; Henderson & Macquistan, 1993; Luck & Thomas, 1999; Experiments 2 and 3 in Müller & Rabbitt, 1989). Because we were interested in whether the absence of involuntary cueing effects on accuracy in Experiments 1–3 extends to these display types, we replicated an experiment by Henderson (1991) in which observers had to discriminate the letter X from the letter O. The possible target locations were masked by a shape composed of the superimposed letters X and O. Target presentation time (70 ms) and the interval between cue and target onset (100 ms) were short. The short presentation time and the efficient mask made it difficult to tell where the target was (location uncertainty). We reduced the display size of four in Henderson's study to two in our replication and observed significant involuntary cueing effects on accuracy. Thus, effects of non-informative cues are not always absent. They may re-emerge with different display types that may require a different explanation. For instance, it seems implausible to

attribute enhanced letter identification at validly cued locations in Henderson's paradigm to increased contrast sensitivity. Subjectively, successful performance with Henderson's displays requires rapid identification of the target letter because a highly efficient mask (consisting of the two target letters) wipes out the percept after a brief interval. Thus, perceptual precision is less important than perceptual speed. Involuntary cueing effects may therefore be attributable to prior entry of attended objects (Hikosaka, Miyauchi, & Shimojo, 1993; Schneider & Bavelier, 2003) or to early access into visual short-term memory (Smith & Ratcliff, 2009). Alternatively, it may be that location uncertainty induced by a distractor presented at the same time as the target is not the same as location uncertainty induced by masks appearing after a single target. With a distractor, the question is which one of two percepts is the target, but two target-like percepts are available. With a single target and two masks, the question is where the target was presented, and only a single target-like percept is available (at best). More research is needed to clarify these issues.

Further, we did not observe any differences between central and peripheral cues. Because central cues need some form of interpretation, this result strengthens our conclusion that cueing effects on accuracy depend on subjects' intention to attend to the cued location. This does not imply that central and peripheral cues entail identical perceptual processes. In studies using informative cues, a faster rise and decay of accuracy has been reported with peripheral than with central cues (Cheal & Lyon, 1991; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989). Attention shifts due to peripheral cues were therefore characterized as "transient." However, the time course should not be equated to the distinction between voluntary (= slow, sustained) and involuntary (= transient) attention. Effects of peripheral cues on accuracy may be transient yet require voluntary attention.

One may ask how our findings relate to reports of changes in appearance due to involuntary shifts of attention. For instance, the perceived contrast of a grating increased when a flash was presented nearby compared to a neutral condition in which the flash was presented at fixation (Carrasco, Ling, & Read, 2004). However, recent studies indicate that these effects do not reflect perceptual changes but are the result of selection biases induced by the cue (Kerzel & Zarian, *submitted*; Prinzmetal, Long, & Leonardt, 2008; Schneider & Komlos, 2008) (but see Carrasco, Fuller, & Ling, 2008). Altogether, our findings are in line with our everyday experience that many salient transients (e.g., an electronic billboard starting to flash) can be ignored and exempt from detailed visual processing if we are not interested in them (e.g., when we know that the bill board is going to flash and do not like the ad).

Finally, electrophysiological studies support the dissociation between exogenous and endogenous cuing. Gamma band synchronization, increasingly pinpointed as the mechanism by which selection is achieved at the

network level (Fries, 2009), was recently found to be locked to the cue onset with endogenous but not exogenous cues (Landau et al., 2007) (but see Yuval-Greenberg, Tomer, Keren, Nelken, & Deouell, 2008). Trials with exogenous cues showed enhanced gamma band synchronization only in response to the target onset. The former and present studies offer new challenges for research and strongly argue for refinement of theories addressing effects of top-down or bottom-up attention.

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