

Visual attention and temporal discrimination: Differential effects of automatic and voluntary cueing

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Yeshurun and Levy (2003) reported that visual attention impairs temporal discrimination in a temporal gap detection task. To assess whether this counter-intuitive finding generalizes to another temporal discrimination task, we examined the influence of visual attention on temporal-order discrimination. Experiment 1 showed that an exogenous cue (automatic orienting) impairs temporal-order discrimination. In contrast, however, Experiment 2 revealed that an endogenous cue (voluntary orienting) facilitates temporal-order discrimination. Experiment 3 addressed whether these discrepant results are due to cue type or to cue predictability and revealed that a nonpredictive endogenous cue induces the same effect on temporal discrimination as the exogenous cue in Experiment 1. The complete pattern of results shows that automatically oriented attention impairs temporal-order discrimination, whereas voluntary oriented attention enhances it. Thus, the results emphasize the different nature of automatic and voluntary orienting. It is suggested that both kinds of attentional orienting operate at different processing levels within the visual system.

There is ample evidence that an efficient allocation of visual attention at a target location facilitates the processing of a stimulus that occurs at this location (cf. Pashler, 1998). For example, participants respond faster to a stimulus when it occurs at the attended than at the unattended location (e.g., Henderson, 1991; Jonides, 1980; Posner, 1980; Posner, Snyder, & Davidson, 1980). In addition, attending a specific location enhances the performance in a variety of perceptual tasks. For example, luminance changes are easier detected at the attended than at the nonattended location (e.g., Bashinski & Bacharach, 1980; Downing, 1988; Hawkins et al., 1990). Such an enhancement of performance by visual

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attention has also been reported for the discrimination of line length (Bonnell, Possamai, & Schmitt, 1987), line orientation (e.g., Cheal, Lyon, & Hubbard, 1991; Downing, 1988), orientation of Gabor patches (Yeshurun & Carrasco, 2000), vernier stimuli (Yeshurun & Carrasco, 1999), Landolt-squares (Yeshurun & Carrasco, 1999), and letters (e.g., Henderson, 1991, 1996). All these studies support the hypothesis that visual attention should always facilitate perceptual processing, yet there are two exceptions to this rule. First, Yeshurun and Carrasco (1998) found that visual attention improves the detection of texture segregation at the periphery, but impairs detection performance at foveal and parafoveal locations.

Second, an even more dramatic impairment was recently reported by Yeshurun and Levy (2003) providing strong evidence against the generality of this hypothesis. Their participants performed a temporal discrimination task. In some trials, two successive light flashes separated by a brief interval were presented to the same location in the display. In the remaining trials, however, a single continuous flash was presented. Participants were asked to discriminate between both types of trials. Furthermore, a peripheral cue appeared shortly before the presentation of the target stimulus. In the valid condition, this cue shifted visual attention to the location at which the stimulus appeared. In the neutral condition, however, the cue did not restrict attention to a particular location. Surprisingly, the detection of the temporal gap was impaired in the valid condition.

Yeshurun and Levy (2003) conducted an additional experiment to reject the possibility that the decrement of performance in the valid condition can be attributed to nonattentional interference effects. This additional experiment required the participant to detect a spatial gap in a quadratic frame (i.e., Landolt-square) instead of a temporal gap. Consistent with the bulk of studies on visual attention (e.g., Yeshurun & Carrasco, 1999), the detection of the spatial gap was improved in the valid condition. In a further study, Yeshurun (2004) employed a less luminant neutral cue and thus could rule out that the decrement of performance in the valid condition is due to temporal interference. In sum, then, the results of Yeshurun and Levy (2003) show that visual attention enhances the performance of spatial discrimination but impairs specific temporal discrimination. In other words, attention enhances the spatial yet lowers the temporal resolution of the visual system. Yeshurun and Levy (2003) have considered two alternative neurophysiological mechanisms that might underlie this tradeoff.

First, according to a spatial summation account, attention primarily reduces the size of receptive fields, which in turn, might lower the temporal resolution. Yeshurun and Levy (2003) argue, however, that the results of their third experiment provide evidence against this account. This experiment employed an especially small-sized target stimulus to minimize the effect of spatial summation. Nonetheless, attention still reduced the performance of temporal discrimination. Consequently, the authors rejected the idea that spatial summation underlies this tradeoff.

Their second and favoured account relates this tradeoff to another neurophysiological mechanism. Accordingly, visual attention facilitates the activity of parvocellular neurons at the attended location, which in turn inhibits the activity of magnocellular neurons at the same location. Neurophysiological studies have shown that parvocellular neurons not only exhibit smaller receptive fields but also longer response durations than magnocellular neurons (e.g., Levitt, Schumner, Sherman, Spear, & Movshon, 2001; Maunsell & Gibson, 1992; Schmolesky et al., 1998). Thus, Yeshurun and Levy (2003) have argued that the increased activity of parvocellular neurons at the attended location enhances the spatial resolution. Crucially, however, the associated prolonged response minimizes the possibility to detect the temporal gap of the flickering target stimulus at the attended location, since stimulus input at the attended location is integrated over a longer period according to this neurophysiological account.

Another series of experiments provided further evidence for this account (Yeshurun, 2004). In this study, Yeshurun employed isoluminant colour stimuli. As the magnocellular system is not engaged in colour processing, a task involving such stimuli should primarily activate the parvocellular system. Thus, the supposed inhibitory effect of attention on the magnocellular system should be less pronounced. Consistent with this prediction, Yeshurun (2004) found a reduced negative cueing effect for the temporal gap detection task.

The present experiments were designed to provide further information on the relationship between visual attention and temporal discrimination. Specifically, we examined whether the novel and counterintuitive finding that attention impairs temporal discrimination generalizes to another perceptual task. As in Yeshurun and Levy's (2003) study, two successive dots occurred within a specific location in the display, which was either attended or unattended. In contrast to their study, however, the two dots were presented side by side and the participant had to judge the temporal order of the two dot onsets. Thus, we assessed the performance of this temporal-order judgement (TOJ) when both dots appeared at the attended or at the unattended location. Although both tasks (i.e., gap detection and TOJ) require the processing of temporal information, different processes seem to be involved in each task. Whereas gap detection requires the resolution of a temporal gap within a neuronal burst, TOJ requires the temporal resolution of two neuronal burst onsets, that is, the organization of the two events with respect to time (Hirsh & Sherrick, 1961; Sternberg & Knoll, 1973; Ulrich, 1987).¹ To sum up, if attention impairs TOJ performance, this

¹ It is somewhat difficult to predict the effect of visual attention on TOJ within the specific framework of Yeshurun and Levy's (2003) neurophysiological account. Clearly, the order of the two neuronal burst onsets need somehow registered by the central nervous system. Thus, discrimination performance depends on the arrival variability of these bursts at a central comparison mechanism. Since the latency variability of parvocellular cells is larger than that of magnocellular cells (Bair, Cavanaugh, Smith, & Movshon, 2002; Schmolesky et al., 1998), one should expect that visual attention hampers temporal-order discrimination.

would support the view that attention generally lowers the quality of temporal information within the visual system. If, however, attention does not impair TOJ performance, one could reject the view that attention lowers the quality of temporal information in general.

We conducted a series of three experiments to assess both alternatives. Experiment 1 employed an exogenous cue to investigate the effect of covert visual attention on temporal-order discrimination performance. Experiments 2 and 3 examine whether the effect obtained in Experiment 1 is restricted to exogenous cueing or generalizes to endogenous cues.

EXPERIMENT 1

In contrast to Yeshurun and Levy (2003), two spatially adjacent dots were presented in a rapid succession rather than two dots one after another at the same location. Participants were asked to indicate the temporal order of the two dot onsets (TOJ task). An exogenous cue preceding the two dots directed attention automatically to one of two target locations (Jonides, 1981; Luck & Thomas, 1999; Müller & Rabbitt, 1989; Posner, 1980). The two adjacent dots were presented either to the attended or to the non-attended location. As in previous studies (e.g., Gottlob, Cheal, & Lyon, 1999; Henderson, 1991; Snowden, Willey, & Muir, 2001), this exogenous cue had no predictive validity. That is, the location of the cue and the location of the square were uncorrelated across all trials. This experiment assessed whether attention impairs temporal discrimination in the TOJ task. If so, discrimination performance in the valid condition should be worse than in the invalid condition.

Method

Participants. Twenty-two students with normal or corrected-to-normal vision participated in partial fulfilment of curriculum requirement.

Stimuli and apparatus. All stimuli were presented in white (61 cd/m^2) on a blue screen (2.3 cd/m^2). Two white dots (diameter 0.2°) served as target stimulus. Both dots were horizontally aligned and separated by a gap of 1.1° (Figure 1). The dots were presented at one of two locations, each marked by a frame subtending a visual angle of $2.7^\circ \times 2.7^\circ$ with a thickness of $3.5'$. Both frames were horizontally aligned and the distance between their adjacent sides was 3.7° . A fixation cross (0.4°) was placed between both frames in the centre of the screen. An additional frame around one of the two position frames served as cue. The thickness of this additional frame was $7'$. A mask was constructed from a $2.2^\circ \times 2.2^\circ$ matrix, which was randomly filled with white pixels.

Participants viewed the screen from a distance of 54 cm. A chinrest was adjusted to place the fixation cross in the centre of the participant's horizontal straightahead line of sight. Participants responded on external response buttons.

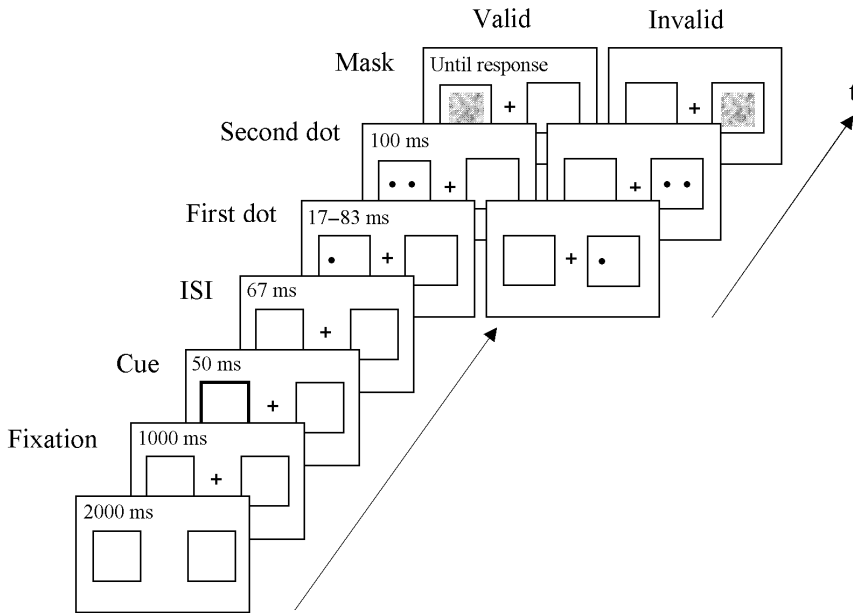


Figure 1. Time course of a single trial in Experiment 1. Following the fixation cross, the cue (thick frame) orients attention to the left location in the display. After an interstimulus interval (ISI) of 67 ms, the target dots are presented, one after the other separated by a variable dot SOA (17, 33, 50, or 83 ms), either at the cued location (valid condition), or at the uncued location (invalid condition). Participants had to judge the temporal order of the dot onsets.

There was one separate panel with a response key for each hand. Both forearms of the participant rested comfortably on a table and the response fingers on the respective response buttons. The experiment was conducted in a soundproof cabin and was run on a PC connected to a 17-inch monitor (60 Hz).

Procedure and design. A trial began with the presentation of the two position frames. A fixation cross was added 2000 ms later. After an additional interval of 1000 ms, the cue appeared for 50 ms. The first of the two target dots always occurred 67 ms after cue offset. The second dot was presented with a variable stimulus onset asynchrony (SOA) to the onset of the first dot. Both dots remained on the screen for a further 100 ms before being masked. The temporal order of the two dots varied randomly from trial to trial. The mask disappeared as soon as a response was registered or after 3000 ms when no response was registered. The next trial was initiated after 600 ms (Figure 1). At the end of each experimental block, feedback about the overall percentage of correct responses was provided on the screen. The participants initiated the next block by pressing a key.

The experiment comprised 19 blocks of 40 trials each. The first block was considered practice and excluded from the data analysis. Each block consisted of equiprobable factorial combinations of cue validity (valid or invalid), dot SOA (17, 33, 50, 67, or 83 ms), target position of the two dots (left or right), and temporal order of target dots (left dot first or right dot first). In 50% of all trials the target stimulus appeared at the same side as the cue (valid condition) and in the remaining 50% of all trials at the opposite side of the cue (invalid condition).

A two-alternative forced-choice (2AFC) task was employed to assess the discrimination performance (Macmillan & Creelman, 1991). Participants were asked to judge which of the two dots was presented first. They pressed the left key with their left index finger if the left dot was perceived first, and the right key with their right index finger if the right dot was perceived first. Participants were asked to keep their eyes on the fixation cross as long as the cross was visible and they were asked to respond correctly and quickly, though accuracy was emphasized. The interval between cue onset and the onset of the second dot (134–200 ms) was too brief to allow an eye movement towards the target dots (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Mayfrank, Kimming, & Fischer, 1987). The importance of maintaining the gaze at the fixation point was emphasized. Participants in this and the following experiments were told that the stimuli would not be on the screen long enough to move their eyes to the cued location and thus it would lower their task performance if they move their eyes.

Results and discussion

A separate two-way analysis of variance (ANOVA) with factors cue validity and dot SOA was performed for the percentage of correct responses and for reaction times (RT) of correct responses. Two participants were excluded from data analysis, because their discrimination performance did not exceed 80% correct responses in the easiest experimental condition, that is, with the longest temporal separation between the two dots (dot SOA = 83 ms). Figure 2 depicts mean RT for correct responses and the percentage of correct responses as a function of dot SOA and of cue validity.

Consistent with other cueing studies, mean RT was shorter for valid than for invalid cues, $F(1, 19) = 42.0$, $p < .001$, $M = 611$ vs. 680 ms. This indicates that the attentional manipulation by the cue was successful. In addition, RT became shorter as dot SOA increased, $F(4, 76) = 15.1$, $p < .001$, because the task becomes easier as the temporal separation between the onsets of the two dots increases (e.g., Heath, 1984). Dot SOA did not modulate the effect of cueing on RT, $F < 1$.

As one should expect, more correct responses were obtained as dot SOA increased, $F(4, 76) = 218.7$, $p < .001$. Of most theoretical importance was the finding that participants performed worse in the valid than in the invalid

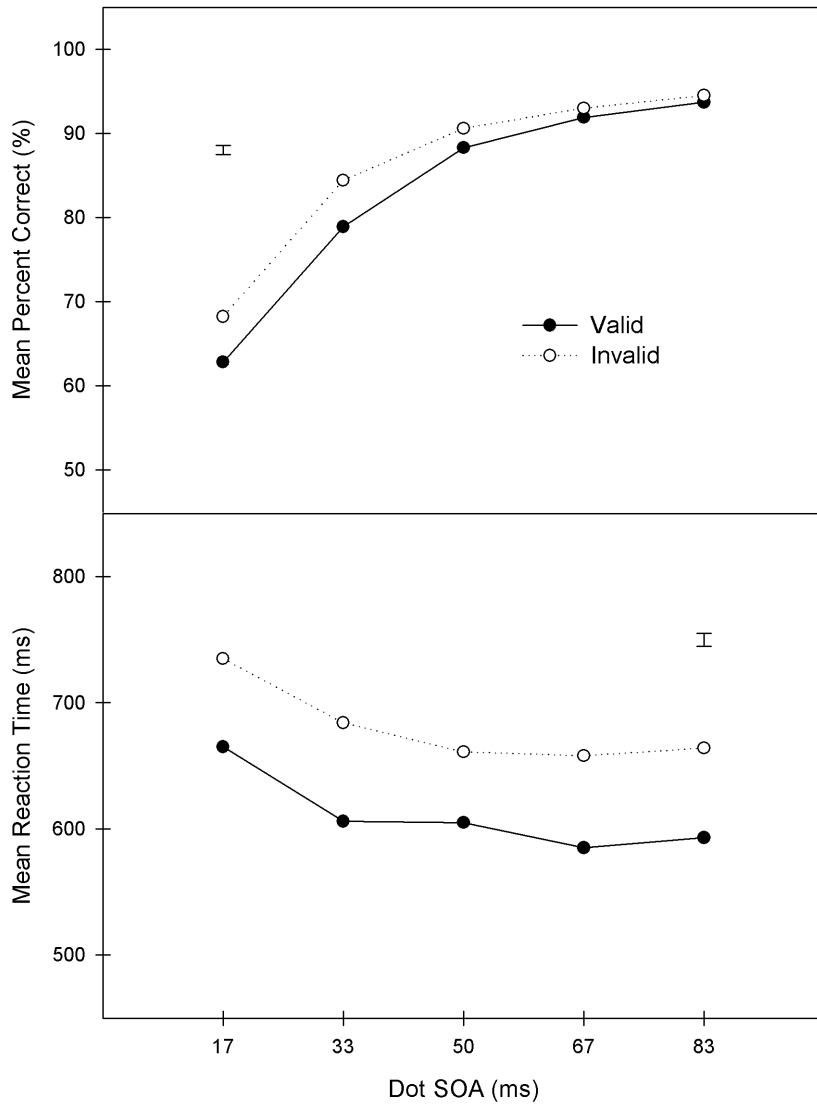


Figure 2. Percentage of correct responses and RT of correct responses as a function of dot SOA (temporal interval between first and second target dot) and cue validity (valid or invalid) in Experiment 1. The error bar in each panel indicates the standard error, which was estimated from the pooled error terms of the corresponding ANOVA (Loftus, 2002).

condition, $F(1, 19) = 9.1$, $p = .007$, $M = 83.1$ vs. 86.1% . This negative cueing effect, however, agrees with the finding of Yeshurun and Levy (2003) that valid cues should reduce the performance in a temporal discrimination task. In addition, and also in agreement with their results, the performance decrement was more pronounced at short than at long dot SOAs, $F(4, 76) = 3.9$, $p = .007$.

As in a study of Yeshurun and Carrasco (1999), a Weibull psychometric function was employed to estimate the TOJ threshold. Specifically, the computer program PMETRIC (Miller & Ulrich, 2004) fitted this function to the accuracy data of each participant and each validity condition. The 75% threshold value was determined for each fitted function. Consistent with the above analysis, the average threshold was 31.3 and 24.0 ms in the valid and invalid condition, respectively, $t = 3.34$, $df = 19$, $p = .003$.² The magnitude of these threshold estimates agree with previous TOJ studies (e.g., Hirsch & Sherrick, 1961; Pöppel, 1997).

As participants were less accurate yet faster in the valid condition, it might be possible that the present results reflect a speed-accuracy tradeoff (SAT). In order to investigate this possibility, we conducted a median-split analysis to examine performance on TOJ separately for short and long RTs. To this end, a median RT was computed separately for each participant in each condition, and the trials from that condition were then partitioned into those with RTs shorter versus longer than the median. The above ANOVA on TOJ performance was extended by the additional factor of response speed (short vs. long RTs). In general, this ANOVA replicated the results of the previous one. Crucially, however, response speed did not interact with cue validity, $F(1, 19) = 0.01$, $p = .927$. This outcome argues against the idea that the present cueing effect on TOJ performance is merely an effect of SAT.

Finally and similar to Yeshurun and Levy (2003), we conducted a control experiment to reject the possibility that the exogenous cue produced nonattentional interference and thus lowered TOJ performance in the valid condition. In this control experiment, we replaced the two dots by a Landolt-square, which involved spatial instead of temporal discrimination.³ Consistent with previous

² In 5 out of all 40 cases the fitted psychometric functions were significant ($p = .05$). This indicates that the Weibull psychometric function did not always provide an adequate description of the observed functions. Therefore, we also employed the nonparametric Spearman-Kärber method to estimate the gap threshold for each precue condition (Ulrich & Miller, 2004). The additional analysis yielded mean thresholds of 31.5 and 36.8 ms for the invalid and the valid precue, respectively. This difference was also statistically reliable, $t = 2.96$, $df = 19$, $p = .008$.

³ This control experiment employed the same procedure and exogenous cue as in Experiment 1. In brief, the Landolt-square appeared at the cued or uncued location and there was a small gap either on the left or right side of this square. Participants were asked to press one key if the gap appeared on the left side, and another key if it appeared on the right side. Mean RT was again shorter for valid than for invalid trials (559 vs. 636 ms) and, most importantly, significantly more correct responses were observed in the valid than in the invalid condition (87.1 vs. 85.2%).

results (e.g., Yeshurun & Carrasco, 1999), better spatial discrimination was obtained in the valid than in the invalid condition. This argues against the idea that TOJ results of the present experiment are due to nonattentional interference.

In sum then, the results of this experiment are in sharp contrast to the more usually found positive cueing effect on discrimination performance. Instead of enhancing discrimination, valid cues lowered temporal discrimination in this experiment. This pattern of results, however, is in line with the findings reported by Yeshurun and Levy (2003). Overall, visual attention oriented by an exogenous cue seems to impair temporal discrimination.

EXPERIMENT 2

In the previous experiment and in the study of Yeshurun and Levy (2003), an exogenous cue accomplished the shift of visual attention. This kind of shift is commonly attributed to bottom-up processes, which are not under voluntary control. By contrast, it is usually accepted that endogenous cues elicit a voluntary (i.e., top-down) shift of visual attention to the cued location (e.g., Jonides, 1981; Klein & Shore, 2000; Müller & Rabbitt, 1989; but see Ristic, Friesen, & Kingstone, 2002, for an elaboration). There is, however, a debate whether both kinds of cues operate on a common attentional system (Jonides & Yantis, 1988; Warner, Juola, & Koshino, 1990) or on separate systems (Briand, 1998; Briand & Klein, 1987). If fundamentally different attentional systems underlie both kinds of cueing, it might be possible that the negative cueing effect observed in Experiment 1 disappears when visual attention is voluntarily shifted.

In order to examine this hypothesis, Experiment 2 utilized an endogenous cue. Prior to the appearance of the target (i.e., the presentation of the two successive dots), an arrow at the fixation pointed either to the left or to the right. In valid trials, the arrow pointed to the location of the subsequent target, whereas in invalid trials the arrow pointed to the opposite location. In addition, the proportion of valid trials was higher than the proportion of invalid trials (75 vs. 25%). If the negative cueing effect found in Experiment 1 is limited to exogenous orienting, we expect TOJ performance to be better in valid than in invalid trials.

Method

Participants. Twenty-five participants were recruited. No participant took part in the previous experiment. The data of five participants were discarded because their 2AFC performance did not attain 75% of correct responses at the largest dot SOA value (the criterion was lower in this than in the previous experiment, because the largest dot SOA value in the present experiment was smaller).

Stimuli and apparatus. The experiment was similar to the first experiment apart from (a) the shape and the location of the cue, (b) the proportions of valid to invalid trials within a single block, and (c) the number of dot SOA values. As before, the identical pair of successive dots was presented either to the left or right beside the fixation cross (Figure 3). An outline arrowhead with a width of 0.4° and a height of 0.5° served as an endogenous attentional cue. Its arrowhead pointed either to the left or to the right side. In each trial, it was positioned in the centre of the screen such that its tip was 2.4° from the closest dot in case it pointed toward the target (i.e., in valid trials).

Procedure and design. A trial began with the presentation of the blank screen to which a fixation cross was added after 2000 ms. The endogenous cue replaced the fixation cross 1000 ms later. Since such cues require more time to become effective compared to exogenous cues, cue SOA was increased to 150 ms. The onset of the second target dot occurred either 33 or 50 ms afterwards. As in Experiment 1, both dots remained on the screen for a further duration of 100 ms until mask onset.

The experiment consisted of 16 blocks of 32 trials each. Each block comprised 24 valid and 8 invalid trials. As before, the first block was considered

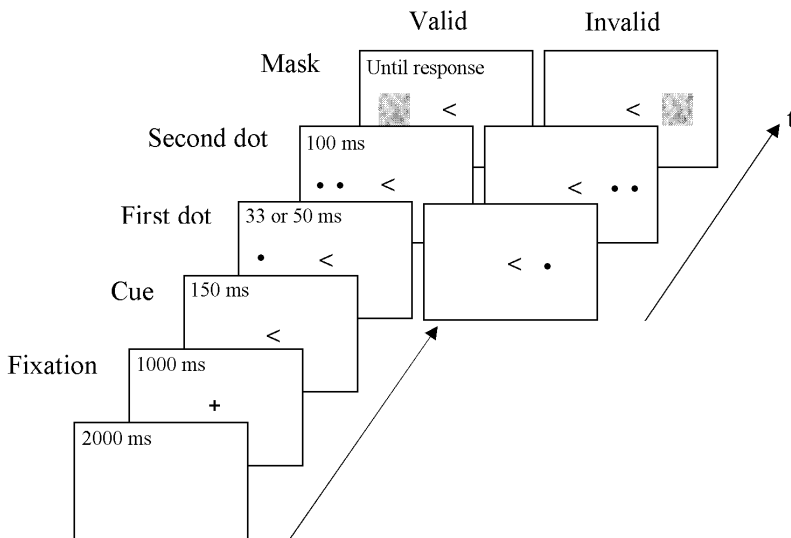


Figure 3. Time course of a single trial in Experiment 2. Following the fixation cross, an endogenous cue (arrowhead in the display centre) induces an attentional shift to the left display location. 150 ms later, the first target dot is presented, followed by the second dot after a variable dot SOA of 33 or 50 ms. Both target dots appeared in 75% of the trials at the cued (valid condition) and in 25% of the trials at the uncued (invalid condition) display location.

practice and excluded from data analysis. This experiment combined the factors cue validity (valid or invalid), dot SOA (33 or 50 ms), position of the target dots (left or right side), and temporal order of the two dots (left dot first or right dot first). Only two dot SOA levels were employed this time, otherwise the number of invalid trials per block would have been too small for realizing the full design.

Results and discussion

A separate two-way ANOVA with factors cue validity and dot SOA was computed for the percentage of correct responses and for RT of correct responses. Figure 4 summarizes the results.

The attentional manipulation by the endogenous cue was successful as the main effect of cue validity on RT attests. Consistent with previous studies (e.g., Jonides, 1981; Posner et al., 1980; Riggio & Kirsner, 1997), shorter RTs were obtained for valid than for invalid cues, $F(1, 19) = 37.5$, $p < .001$, $M = 725$ vs. 775 ms. As in the previous experiment, shorter RTs were observed as dot SOA increased, $F(1, 19) = 15.5$, $p = .001$, and dot SOA did not modulate the cueing effect on RT, $F < 1$. This pattern of RT agrees with the one of the previous experiment and is consistent with the notion that the cues in both experiments are capable to evoke effective shifts of attention.

Most crucially and in contrast to the previous experiment, however, poorer discrimination performance resulted this time in the invalid than in the valid cueing condition, $F(1, 19) = 4.8$, $p = .041$, $M = 87.8$ vs. 90.5%. As in Experiment 1, temporal discrimination improved as dot SOA increased, $F(1, 19) = 62.0$, $p < .001$, but the interaction of both factors was insignificant, $F < 1$.

The most important result of this experiment is the positive cueing effect on temporal-order discrimination. This result contrasts with the negative cueing effect obtained in Experiment 1 and indicates that the negative attentional effect on temporal discrimination does not generalize to an endogenous cueing situation. The cueing results of Experiments 1 and 2 point to the possibility that automatic and voluntary shifts of attention operate on different attentional systems. Accordingly, the system associated with voluntary attentional shifts seems to improve the temporal resolution of the visual system. At this stage, however, it seems premature to conclude that this dissociation reflects different attentional systems. Thus, Experiment 3 was designed to provide further evidence for this idea that distinct attentional systems underlie this dissociation.

EXPERIMENT 3

The endogenous cue employed in Experiment 2 was predictive, because the target stimulus appeared with a higher probability at the cued than at the uncued location. It has recently been shown that certain endogenous cues involuntarily trigger shifts of attention even when participants were informed in advance that the cues were nonpredictive (e.g., Ristic et al., 2002; Tipples, 2002). Therefore,

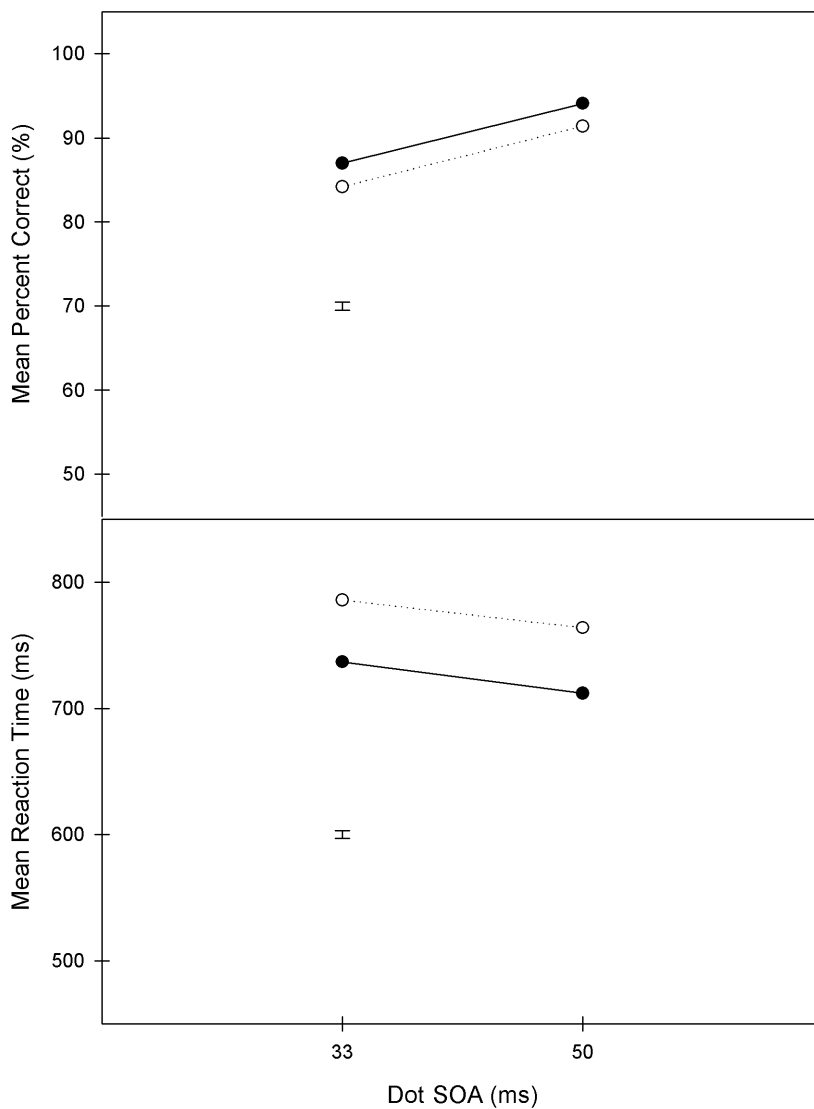


Figure 4. Percentage of correct responses and RT of correct responses as a function of dot SOA (temporal interval between first and second target dot) and cue validity (valid or invalid) in Experiment 2.

if automatic orienting of attention really matters, the negative cueing effect observed in Experiment 1 should re-emerge with an endogenous cue that elicits an involuntary shift of attention.

Experiment 3 adapted the endogenous cueing paradigm used by Tipples (2002) to examine this possibility. As in his second experiment, the endogenous cue consisted of two trimmed arrows, which could point either to the left or to the right. Identical to Tipples' experiment, but in contrast to Experiment 2, the target could appear equally likely at the cued or uncued position. In addition, we informed our participants about the nonpredictive nature of these cues at the beginning of the experiment. Finally, as in the experiment of Tipples, we also examined the time course of the cueing effect by varying the temporal interval (cue SOA) between the onsets of cue and target. Since the cue SOA could be as large as 300 ms in this experiment, eye movements towards the cued direction could in principle be performed prior to target onset, though participants were advised to fix their eyes on the central point. Therefore, in this experiment eye movements were recorded and trials showing such movements were discarded from data analysis.

Method

Participants. A fresh sample of 23 students was required from the same population as in the previous experiments. The data of three participants were discarded from data analysis, because their 2AFC performance did not exceed 75% of correct responses in the easier TOJ condition (i.e., for dot SOA = 50 ms).

Stimuli and apparatus. The stimuli and apparatus were identical to the ones of the previous experiments apart from the following changes: First, the endogenous cue was the same as the one used by Tipples (2002, Exp. 2). It consisted of two arrowheads, each being 0.9° high and 0.5° wide, separated by a gap of 1.2° and centred in the middle of the screen. Second, as in Tipples, we used an asterisk (0.7°) as fixation point, which appeared, as in his study, 0.5° above the centre of the screen. Finally, and similarly to Tipples, a 0.7° wide, green plus-or-minus sign was used to provide feedback at the end of each trial (Figure 5).

Recording of eye movements. The horizontal electrooculogram (HEOG) was recorded bipolar with Ag/AgCl electrodes from the outer canthi of both eyes. The sampling rate was 250 Hz and the signal was filtered (bandpass 0.05–30 Hz) and stored for further analysis. Offline analysis was used to screen trials in which eye movements occurred between cue onset and target offset. On average 2.9% of all trials were discarded from further data analysis due to such eye movements.

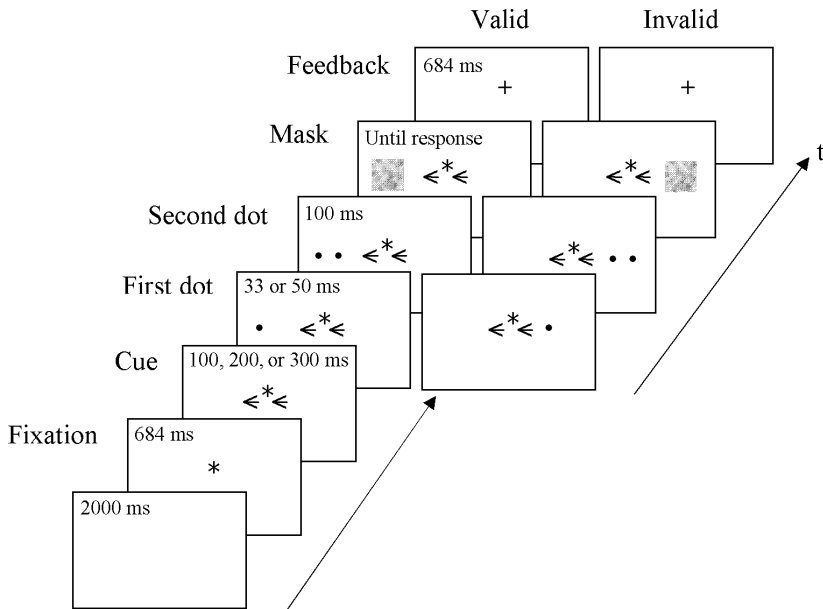


Figure 5. Time course of a single trial in Experiment 3. Following the fixation point (asterisk), an endogenous cue (two arrowheads in the display centre) induces an attentional shift; in this case to the left display location. After a variable cue SOA (100, 200, or 300 ms), the first target dot is presented, followed by the second dot after a variable dot SOA of 33 or 50 ms. Both dots are presented in 50% of the trials at the cued (valid condition) and in 50% of the trials at the uncued (invalid condition) display location.

Procedure and design. The sequence of a single trial was identical to Experiment 2 with three exceptions: First, in accordance with Tipples (2002), the duration of the fixation point was 684 ms instead of 1000 ms. Second, the cue SOA varied randomly from trial to trial and was 100, 200, or 300 ms. Third, trial feedback was provided at the end of each trial for 684 ms. In case of a correct response, a plus sign occurred, whereas a minus sign signalled an incorrect response.

The experiment consisted of 16 blocks of 48 trials each, separated by a break after the 24th trial. The first block was considered practice and hence excluded from data analysis. Each block included one trial of each of the 48 factorial combinations of cue validity (valid or invalid), cue SOA (100, 200, or 300 ms), dot SOA (33 or 50 ms), target position (left or right), and temporal order (left dot first or right dot first). As before, the order of these trials was randomized within each block. In half of all trials, the target appeared at the side to which the arrowhead pointed; in the remaining half of all trials it appeared on the opposite side. Thus, the cue was nonpredictive with regard to target position.

Results and discussion

Separate three-way ANOVAs with cue validity, cue SOA, and dot SOA were conducted for the percentage of correct responses and for mean RT of correct responses. Figure 6 depicts percentage of correct response and mean RT as a function of all three factors.

The significant main effect of cue validity on RT, $F(1, 19) = 12.2$, $p = .002$, shows that the attentional manipulation was again successful. Consistent with previous studies (e.g., Jonides, 1981; Posner et al., 1980; Riggio & Kirsner, 1997) and the two previous experiments, RT was shorter for valid than for invalid cues, $M = 706$ vs. 738 ms. This effect of 32 ms is smaller than the one in our previous experiment (50 ms). This probably reflects the fact that a non-predictive cue was used this time. Comparable to the results reported by Tipples (2002), shorter RTs were obtained as cue SOA increased, yet this effect only approached statistical significance, $F(2, 38) = 2.75$, $p = .076$, $M = 729$, 720, and 716 ms. Similar to Tipples' study, we also observed no interaction between cue validity and cue SOA, $F < 1$. This pattern of RT results confirms the ones reported by Tipples and by Ristic et al. (2002) and thus further strengthens the notion that nonpredictive endogenous cues are capable to orient attention. Similar to Experiments 1 and 2, mean RT was shorter when dot SOA was long than when it was short, though this difference just reached statistical significance this time, $F(1, 19) = 4.24$, $p = .054$, $M = 717$ vs. 726 ms. Furthermore, cue validity interacted with dot SOA, $F(1, 19) = 11.1$, $p = .004$, due to a larger cueing effect at the short than at the long dot SOA. The interaction of all three factors was not significant, $F < 1$.

Theoretically most important, and in contrast to the results of Experiment 2, poorer discrimination performance resulted for valid than for invalid cues, $F(1, 19) = 4.7$, $p = .043$, $M = 81.2$ vs. 83.2%. As in Experiments 1 and 2, performance improved as dot SOA increased, $F(1, 19) = 113.5$, $p < .001$, and again cue validity did not interact with dot SOA, $F < 1$. The cue became less effective as cue SOA increased, though the interaction between cue validity and cue SOA just failed to reach statistical significance, $F(2, 38) = 3.0$, $p = .061$. Although this latter result appears to be surprising for an endogenous cueing situation, it is consistent with the short living attentional effect of automatic orienting (e.g., Luck, Hillyard, Mouloua, & Hawkins, 1996; Müller & Rabbitt, 1989). As one should expect, performance increased as cue SOA increased, $F(2, 38) = 33.1$, $p < .001$, $M = 77.1$, 83.3, vs. 86.1%. Furthermore, TOJ performance benefited especially from an increase of cue SOA, when temporal discrimination was more difficult (dot SOA = 33 ms) than when it was easier (dot SOA = 50 ms), $F(2, 38) = 5.2$, $p = .010$. The threefold interaction of all factors was significant, $F(2, 38) = 5.0$, $p = .012$; as can be seen in Figure 6, the cueing effect was modulated by cue SOA and dot SOA, in a way such that the cueing effect was basically absent at long cue SOA and long dot SOA.

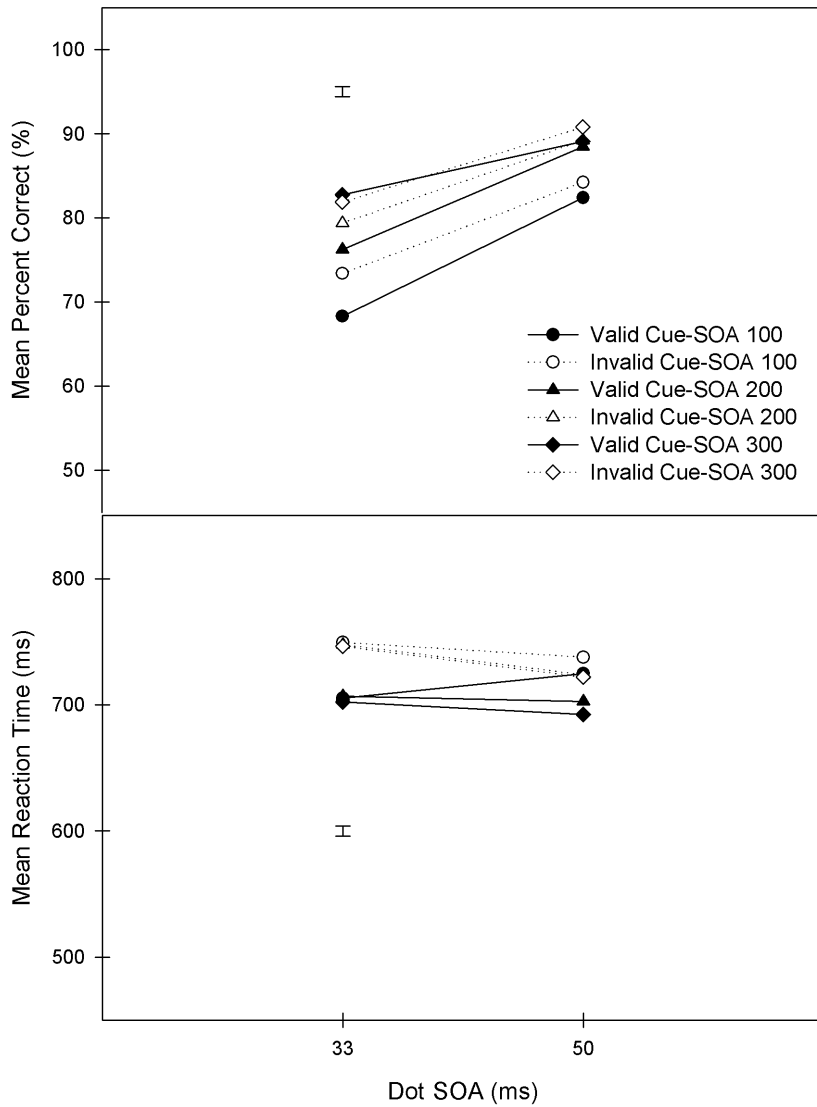


Figure 6. Percentage of correct responses and RT of correct responses as a function of dot SOA (temporal interval between first and second target dot), cue validity (valid or invalid), and cue SOA (temporal interval between cue and target onset) in Experiment 3.

A median-split analysis analogous to the one in Experiment 1 was performed to examine the possibility that the present cueing effect on TOJ performance can be explained by SAT. A further ANOVA including the factor response speed revealed again no significant interaction between response speed and cue validity, $F(1, 19) = 1.1, p = .312$. Thus, this additional analysis argues once more against the idea that a SAT effect underlies the negative cueing effect.

In sum then, the negative cueing effect observed in Experiment 1 re-emerged with a nonpredictive endogenous cue, which according to Tipples (2002) and Ristic et al. (2002) produces an automatic shift of attention. Thus, the present experiment strengthens the notion that automatic orienting of attention lowers the temporal resolution of the visual system, whether this shift of attention is elicited by an exogenous cue or by a nonpredictive endogenous cue.

GENERAL DISCUSSION

Recent studies (Yeshurun, 2004; Yeshurun & Levy, 2003) suggest that although visual attention improves the spatial resolution of the visual system, it surprisingly degrades its temporal resolution. Participants in these studies performed a temporal gap detection task. When an exogenous cue directed attention to the stimulus location, a longer temporal interruption was required to detect this gap. Thus these authors have concluded that the temporal resolution of the visual system is lowered at the attended location.

The aim of the current study was to assess whether or not Yeshurun and Levy's intriguing finding (2003) generalizes to another temporal discrimination task, that is, to a TOJ task. If their finding generalizes to this task, this would strongly indicate that attention impairs generally the temporal information processing within the visual system. By contrast, if attention does not impair TOJ performance, this would render such a general effect as unlikely.

We conducted three experiments to evaluate both alternatives. Experiment 1 showed that when attention is automatically oriented by an exogenous cue, TOJ performance is impaired at the attended location. Experiment 2 employed a predictive endogenous cue, to assess whether this negative cueing effect is also observed when attention is shifted voluntarily. In contrast to Experiment 1, a predictive endogenous cue facilitated TOJ performance. Experiment 3 showed that the negative cueing effect of Experiment 1 re-emerges when a nonpredictive endogenous cue directs attention.

In all three experiments visual attention shortened RT. This effect usually emerges in spatial cueing tasks (e.g., Henderson 1991; Jonides, 1980; Posner, 1980; Posner et al., 1980). Since speed and accuracy was negatively correlated in Experiments 1 and 3, one might argue that the impaired discrimination performance in the valid cueing condition reflects a strategic tradeoff between speed and accuracy. Additional median-split analyses on RT, however, indicate that the negative cueing effect on TOJ performance cannot be attributed to such

a SAT effect. Therefore, the overall pattern of results reveals that an automatic shift of visual attention impairs TOJ performance, whereas a voluntary shift enhances it. In summary then, the present results not only generalize the results of Yeshurun and Levy (2003) to another temporal task but also indicate that their conclusion is constrained to automatic shifts of attention.

The present results provide novel evidence for the idea that automatic and voluntary shifts of attention act at different levels within the visual system (Briand, 1998; Briand & Klein, 1987; Klein, 1994; Klein, Kingstone, & Pontefract, 1992; Riggio & Kirsner, 1997). For example, Briand and Klein (1987) have proposed that automatically but not voluntary controlled attention is involved in early visual processing stages. In brief, these authors found larger cueing RT effects for conjunction than for single feature detection tasks, when exogenous cues oriented attention. However, when a predictive endogenous cue shifted attention, no such differential cueing effect occurred. Thus, Briand and Klein (1987) concluded within the framework of the feature integration theory (Treisman & Gelade, 1980) that attention, elicited by an automatic shift, acts on the level of feature integration. Klein (1994) provided further evidence for the notion that automatic and voluntary guided attention operates at different levels. Specifically, he showed that voluntary but not automatic attention modulates the effect of stimulus expectancy on RT. In short, the cueing effect on RT of an endogenous cue was much larger for expected than for unexpected visual targets. By contrast, no such differential cueing effect was observed for exogenous cues. Therefore, the results by Klein together with the aforementioned results establish a double dissociation of automatic and voluntary induced attentional shifts on visual performance. This double dissociation clearly supports the notion that voluntary and automatic guided attention operate at different levels within the visual system. This notion is further strengthened by the finding that endogenous and exogenous cues can produce additive effects on RT (Riggio & Kirsner, 1997), which suggests that both types of cues exert a selective influence on the visual system (Sternberg, 2001).

The present results also support the notion that automatic and voluntary induced attentional shifts influence the visual system at different levels. In Experiments 1 and 3, the cues directed visual attention automatically to the stimulus location, whereas in Experiment 2 the shift was voluntary. Accordingly, one may assume that attention at an early stage of visual processing impairs the temporal resolution of the visual system, whereas attention would enhance the temporal resolution at higher levels within the visual system. Although, this account does not point directly to the mechanisms underlying these differential effects, an explanation for the impairment of temporal resolution at the lower level might well correspond to the neurophysiological mechanism suggested by Yeshurun and Levy (2003). As described in the introduction, the primary premise of their explanation holds that attention facilitates parvocellular over magnocellular processing. Consequently, the visual system gains a higher spatial resolution because parvocellular neurons exhibit smaller receptive fields. In

addition, the prolonged response activity of these neurons lowers the possibility to discriminate between a double-flash and a single-flash stimulus, since the response of the first flash tends to be fused with the response of the second flash (Yeshurun & Levy, 2003). This account may also explain why stimulus duration appears longer at the attended than at the unattended location (e.g., Enns, Brehaut, & Shore, 1996, 1999; Mattes & Ulrich, 1998; Schmidt & Klein, 1997) and why attention prolongs the duration of visible persistence (Visser & Enns, 2001).

This neurophysiological mechanism can also explain the impairment of TOJ performance at the attended location in Experiments 1 and 3. Parvocellular neurons not only exhibit longer onset latencies than magnocellular neurons but also exhibit increased onset latency variability (Bair et al., 2002; Schmolesky et al., 1998). Because TOJ performance deteriorates as onset variability increases (Sternberg & Knoll, 1973), TOJ performance should be impaired when attention favours parvocellular processing. Thus the neurophysiological model of Yeshurun and Levy (2003) can also explain why automatically oriented attention may lower TOJ performance.

This neurophysiological model, however, does not account for the present RT results, which revealed faster responses in validly cued trials regardless of the type of cue. It is tempting to assume that this effect reflects attentional mechanisms at higher processing levels. As demonstrated by several studies (e.g., Schneider & Bavelier, 2003; Shore, Spence, & Klein, 2001; Stelmach & Herdman, 1991; Sternberg & Knoll, 1973), attention enhances response speed in TOJ tasks. Although, these studies had a different research agenda and their experimental approach differed significantly from the current approach, they found that a visual stimulus at an attended location is perceived before a stimulus at an unattended location. This prior entry effect can be induced with exogenous cues as well as with endogenous cues (Shore et al., 2001; Stelmach & Herdman, 1991). Whether this prior entry effect shortens the duration of early or late perceptual processes, however, is an unsettled issue. In fact, Schneider and Bavelier (2003) have more recently provided evidence accordingly the prior entry effect emerges from non-attentional factors (i.e., decision or sensory processes). Hence, it is possible, that this sort of influence is also responsible for our finding that attention generally accelerated response speed in the TOJ task.

Finally, the present results are consistent with those reported by Ristic et al. (2002) and Tipples (2002). According to these studies, endogenous cues provoke either a voluntary or an automatic attentional shift depending on their stimulus predictability. Accordingly, nonpredictive endogenous cues trigger automatic shifts, whereas predictive ones induce voluntary shifts. Our results clearly emphasize the importance of this distinction, as the predictability of the endogenous cue exerted a differential effect on perceptual performance in Experiments 2 and 3. Consistent with the hypothesis suggested by Ristic et al. (2002), the nonpredictive endogenous cue in Experiment 3 resembled the attentional effect of the exogenous cue in Experiment 1. This clearly supports the idea that both cues are functionally equivalent and that both exert an auto-

matic attentional shift. Although predictability plays a crucial functional role for endogenous cues, predictability seems less important for exogenous cues. The exogenous cue in Experiment 1 was nonpredictive, whereas Yeshurun and Levy (2003) employed a 100% predictive exogenous cue. Thus exogenous cues seem to exert attentional shifts irrespective of their predictability.

In conclusion, then, the present study revealed that automatic spatial attention impairs temporal discrimination in a TOJ task, whether the automatic shift was elicited by exogenous or by nonpredictive endogenous cues. In contrast, voluntary spatial attention enhances TOJ performance. We have argued that these differential effects reveal the impact of attention at lower and higher processing levels within the visual system. More specifically, automatic shifts of attention seem to influence visual information processing at early levels, where they impair temporal resolution, possibly by favouring parvocellular processing. Voluntary shifts of attention, however, seem to affect information processing at higher levels within the visual system, thereby improving the temporal resolution of the visual system.

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