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Voluntary and involuntary attention have different consequences: The effect of perceptual difficulty

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We propose that voluntary and involuntary attention affect different mechanisms and have different consequences for performance measured in reaction time. Voluntary attention enhances the perceptual representation whereas involuntary attention affects the tendency to respond to stimuli in one location or another. In a spatial-cueing paradigm, we manipulated perceptual difficulty and compared voluntary and involuntary attention. For the voluntary-attention condition, the spatial cue was predictive of the target location, whereas in the involuntary-attention condition it was not. Increasing perceptual difficulty increased the attention effect with voluntary attention, but decreased it with involuntary attention. Thus voluntary and involuntary attention have different consequences when perceptual difficulty is manipulated and hence are probably caused by different mechanisms.

Keywords: Attention; Exogenous; Endogenous; Feature integration; Spatial attention.

It has been hypothesized since Wundt (1897, p. 219) that there are at least two ways of allocating spatial attention. Observers can *voluntarily* allocate attention to the spatial location that may contain information that is important to immediate task goals. Hence, voluntary attention is sometimes termed goal-directed attention, or endogenous attention. On the other hand, stimulus events can *involuntarily* capture attention, even when the stimulus event is unrelated to the current goal-directed activity. Involuntary attention is sometimes called stimulus-driven capture or exogenous attention. The present research asks whether the consequences of voluntary and involuntary attention differ. In the present study, we found that when we manipulated discrimination difficulty, voluntary and involuntary attention behaved differently. With voluntary attention, increasing discrimination difficulty increased the attention effect. With involuntary attention, increasing difficulty reduced the attention effect. Thus these forms of attention can have opposite effects on performance, and hence they are probably mediated by different mechanisms.

The spatial-cueing paradigm developed by Posner and his colleagues (Posner, 1980; Posner, Snyder, & Davidson, 1980) is an excellent way

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of separating these two kinds of attention within the same paradigm. Participants engage in either a simple target detection or a target identification task. In both detection and identification experiments, the target was preceded by an arrow at fixation that indicated the likely location of the target. For example, on 80% of the trials, the target appeared in the location indicated by the cue (valid trials), and on 20% of the trials, the target appeared in an uncued location (invalid trials). Thus, the cue was predictive or informative of the target location. Posner et al. (1980) hypothesized that participants would voluntarily allocate their attention to the cued location. Participants should respond faster on valid trials than on invalid trials because the participant was already attending to the cued location on valid trials when the target appeared.

Jonides (1976, 1981) demonstrated that a similar paradigm could be used to investigate involuntary attention. The cues (e.g., arrowheads) were presented in the periphery, near the potential target locations. If a target appeared in the cued location, reaction time (RT) was faster than when the target appeared in an uncued location. This effect occurred even if the cue location was random with respect to the target location. A nonpredictive spatial cue has an automatic effect on RT that is similar to voluntary attention.

Although both voluntary and involuntary attention have the same general effect on RT (i.e., faster RT on valid trials), there is evidence that they differ in how they summon attention. The effects of voluntary attention (by either predictive peripheral or central cues) can be statistically independent of involuntary attention (nonpredictive peripheral cue; Berger, Henik, & Rafal, 2005; also see Lupiáñez et al., 2004). The effect of voluntary attention increases as the time between the cue and the target lengthens (stimulus onset asynchrony, or SOA) whereas the effect of involuntary attention is largest at short SOAs and decreases as SOA lengthens (Posner, Cohen, & Rafal, 1982; Warner, Joula, & Koshino, 1990). With involuntary attention, after some optimal SOA, participants are typically slower on valid trials than on invalid trials, a phenomenon known as inhibition of return (IOR; Posner & Cohen, 1984). IOR does not occur with voluntary attention (Posner & Cohen, 1984; Wright & Richard, 2000). The two kinds of attention differ developmentally; voluntary attention increases during development whereas involuntary attention decreases with age (Enns & Brodeur, 1989). Finally, recent behavioural evidence indicates that voluntary and involuntary attention have a different time course with respect to their effect on the spatial Stroop effect (Funes, Lupiáñez, & Milliken, 2007).

The question addressed here is whether there is a unitary attention that can be summoned in two different ways, or whether there are different mechanisms for voluntary and involuntary attention that have different consequences. Jonides (1981) titled his paper "Voluntary versus Automatic Control over the Mind's Eye's Movement". The title assumes that there is one "mind's eye" (attention), but that it can be controlled in different ways. The control of voluntary and involuntary attention may be different, but the mechanism that is ultimately controlled is the same. Voluntary and involuntary attention have different time courses, indicating that the mechanisms that control them may be different. The automatic or involuntary allocation of attention is very quick, but only has a transient effect (Nakayama & Mackeben, 1989). Voluntary attention takes longer to allocate than involuntary attention, but once it is allocated, its effect is sustained. All of the research cited above is consistent with the view that there is one "attention" that can be allocated in different ways with different time courses. Once allocated, it has the same consequences regardless of how it was allocated.

Recently, Prinzmetal, McCool, and Park (2005a; also see Prinzmetal, Park, & Garrett, 2005b) challenged this view and claimed that the consequences of voluntary and involuntary attention were different, and therefore they were mediated by different mechanisms. They claimed that voluntary attention enhances the perceptual representation of objects in attended locations so that there is a more veridical representation of attended objects than of unattended objects.

Although involuntary attention affects RT, it does not enhance perceptual processing leading to more accurate recognition on valid trials. Hence, voluntary attention affects perceptual processes, but involuntary attention does not.

To substantiate this claim, Prinzmetal et al. (2005a) conducted a series of experiments with peripheral spatial cues. The cue was either predictive or not predictive of the target location. Any effect of a nonpredictive cue could be said to be involuntary because there is no reason to allocate processing resources to the cued location. Predictive cues add a volitional component to the task because it is strategically advantageous to attend to the cued location.[1] By using predictive and nonpredictive cues (run between subjects), voluntary and involuntary attention could be compared with the same physical stimulus and timing parameters. Thus any difference would reflect the voluntary component induced by a predictive cue. Note, however, that "voluntary attention" operationalized in this manner contains a component of involuntary attention.

Prinzmetal et al. (2005a) used cue predictability to operationalize voluntary and involuntary attention. If we can demonstrate that predictive cues lead to one pattern of behaviour, and nonpredictive cues lead to a different pattern of behaviour, it is reasonable to assume that different mechanisms underlie these attentional effects. In Experiments 1 and 2, we compared predictable and nonpredictable cue conditions. Note that the nonpredictable cue condition contains a component of involuntary attention since we used peripheral cues. We addressed this issue in Experiment 3 where we used the anticueing procedure (e.g., Posner et al., 1982; Sereno & Holzman, 1996; Warner et al., 1990). In this procedure, a cue in one location signals that there is a high probability of the target appearing in the opposite location. Thus, in this procedure, voluntary attention is directed away from the cued location.

There are other ways of operationalizing voluntary and involuntary attention. For example, some researchers have compared predictive central cues with nonpredictive peripheral cues (e.g., Briand & Klein, 1987; Mayer, Dorflinger, Rao, & Seidenberg, 2004). There are two problems with such comparisons. First, the physical properties of the cue are confounded with cue predictability. Second, it is assumed that a nonpredictive central cue does not have an automatic or involuntary effect. However, a nonpredictive central arrow cue can have an effect that is similar to a nonpredictive peripheral cue (e.g., Gibson & Bryant, 2005; Ristic, Friesen, & Kingstone, 2002; Tipples, 2002). Thus, using a central cue can invoke involuntary attention.

Prinzmetal et al. (2005a) found that in experiments designed around RT, where participants were over 95% correct in target identification, RTs were faster on valid than on invalid trials regardless of whether the cue was predictive of the target location or not. Other experiments were designed around accuracy, and participants were instructed to take their time and to be as accurate as possible. The targets were made difficult to discriminate so that participants would be approximately 75% correct in two-alternative forced-choice tasks. Participants were more accurate on valid trials than on invalid trials only when the cue was predictive of the target location (i.e., voluntary attention). The cue had no effect on accuracy when it was not predictive of the target location. Note that in these experiments, the effect of voluntary attention was not due to location uncertainty (see, e.g., Shiu & Pashler, 1994). Participants were nearly 100% correct in localizing the targets. Thus, Prinzmetal et al. (2005a) concluded that voluntary attention enhances perceptual processing leading to more accurate identification performance, but involuntary attention does not.

This pattern of results was found with different discriminations (e.g., letters, line orientation,

[1] We used the terms voluntary and involuntary because they were used by Wundt, well before terms such as endogenous and exogenous (Posner, 1978, chap. 5). However, by voluntary, we do not mean that participants are conscious of the proportion of valid and invalid trials (see Bartolomeo, Decaix, & Siéroff, 2007).

faces), with different kinds of cues (boxes getting brighter, changing colours, auditory cues, etc), different SOAs (0 ms to 300 ms), with or without masks, and with different backgrounds (black or white). Both voluntary- and involuntary-attention conditions affected RT, but only voluntary attention affected accuracy.

To account for the difference between voluntary and involuntary attention on accuracy and RT, Prinzmetal et al. (2005a) proposed that voluntary and involuntary attention have different consequences. Voluntary attention affects the allocation of perceptual processing resources so that more information accrues in attended locations. Voluntary attention is strategic. It is advantageous to preferentially process information in the location that is most likely to contain goal-relevant stimuli (e.g., Shaw & Shaw, 1977). The function of voluntary attention is to have as veridical a representation of important stimuli as possible. There are many theories of how goal-directed attention might be implemented. For example, information might accumulate faster in attended locations than in unattended locations, leading to more "samples" in an attended location (e.g., Luce, 1977; Prinzmetal, 2005). Thus, identifying a stimulus in an attended location should be faster and more accurate than in an unattended location. Furthermore, the effect of voluntary attention should be greater if the task requires more information (i.e., a difficult discrimination).

Prinzmetal et al. (2005a) proposed that involuntary attention does not have its effect on perceptual processes. In the spatial-cueing paradigm, there is no reason for the participant to allocate perceptual processing resources to the cued location because the target is no more likely to appear in that location than in any other location. In fact, allocating resources to the cued location could lead to suboptimal performance. Hence involuntary attention does not affect accuracy. In the General Discussion we present two mechanisms that can account for the differences in voluntary and involuntary attention with respect to accuracy and RT.

Previous work by Prinzmetal et al. (2005a) demonstrated a single dissociation between voluntary and involuntary attention: Voluntary attention (predictive cues) affected accuracy, whereas involuntary attention (nonpredictive cues) did not. The purpose of the present experiments was to further test the hypothesis that voluntary attention affects perception, while involuntary attention does not. This was done by demonstrating a double dissociation between voluntary and involuntary attention and discrimination difficulty using RT.

If voluntary attention affects perceptual processes, it should have its greatest effect with a perceptually demanding task. Thus in an experiment manipulating voluntary attention, the effect of the cue (difference between invalid and valid RTs) should be larger with a perceptually demanding task than with an easy task. This result was found both by Briand and Klein (1987) and Soetens, Deroost, and Notebaert (2003).[2]

If involuntary attention does not affect perception, there is no reason why its effect on discrimination should be larger with a difficult than with an easy task. On the contrary, if involuntary attention affects postperceptual processing, we may obtain the opposite result: The effect of involuntary attention might be reduced with a perceptually difficult task, becoming larger for the easy than for the difficult task. This prediction arises because the effect of involuntary attention is transient. If it had its effect at response selection or execution stages, on a perceptually demanding task, the transient benefit of the cue may have dissipated. This hypothesis is illustrated in Figure 1. Lengthening the perceptual processing stage by increasing difficulty

[2] Briand and Klein (1987) compared predictive central and predictive peripheral cues. They claimed that one only obtained this result with predictive peripheral cues. Note, however, that not only were the cues different, but they used different interstimulus intervals and exposure durations for the central cue and peripheral cue conditions, so it is difficult to attribute the difference in results to one factor. Soetens et al. (2003) found a larger cueing effect with difficult than easy discrimination with predictive central and peripheral cues using the same temporal parameters.

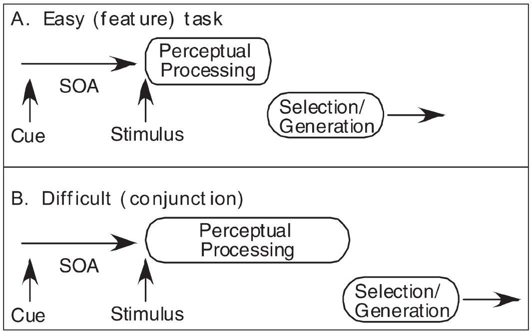

Figure 1. *A sample time course for perceptual processing and selection for response stages.*

would increase the time between perception and postperceptual selection or execution and thereby decrease the effect of a cue. Note that the conceptualization in Figure 1 is different from previous views, which have held that the critical temporal parameter is the time between the onset of the cue and the onset of the target (e.g., Warner et al., 1990; Wright & Richard, 2000). The theory illustrated in Figure 1 is a fundamental departure from this view. It assumes that the critical time period is from the onset of the cue to the selection of the response. Hence, any increase in RT due to increased perceptual difficulty should reduce the effect of a nonpredictive cue.

Experiment 1 tested the prediction that increasing perceptual difficulty would increase the attention effect with voluntary attention, but decrease the effect with involuntary attention. On each trial, participants responded whether the display contained the target letter F or T. For the easy task, the target was surrounded by the letter O (e.g., OFO). This task is easy, perhaps because the targets can be discriminated by a single feature (the horizontal middle line, "–", in the F). Therefore, this task was called the feature condition. For the difficult task, the target was surrounded by the letter H (e.g., HTH). The stimuli cannot be discriminated by a simple feature, and participants must correctly conjoin the features, a process that has been shown to require attention (e.g., Prinzmetal, Presti, & Posner, 1986; Treisman & Schmidt, 1982). We call this the conjunction condition. For half the participants, the cue was 80% valid (voluntary attention), and for half it was random with respect to the target location (involuntary attention).

EXPERIMENT 1

Method

Participants

There were 12 participants in each group. Participants were recruited from the University of California, Berkeley, Research Participation subject pool. A total of 2 participants from each group were replaced because of an excessive proportion of errors (over 15%), but the results were not substantially changed when these participants' data were included.

Procedure

The sequence of events is illustrated in Figure 2. Each trial began and ended with a fixation field that consisted of a fixation point and four grey boxes. One of the boxes became thicker and turned black (the cue) 280 ms before the target stimulus appeared and remained black until the target stimulus disappeared. The exposure duration of the target stimulus was 120 ms. Participants responded whether the display contained the letter F or T by pressing one of two buttons. When a participant erred, the computer emitted a short "beep" sound. At the end of each block, participants were given their average RT and percentage correct.

Participants were instructed to keep their eyes on the fixation dot during each trial, and this instruction was repeated on the screen between blocks. Eye movements were monitored with a video camera (see Prinzmetal, et al., 2005a, for details). When eye movements were detected, the computer emitted a two-tone sound that was somewhat like a foghorn.

Each participant began with a practice block of 40 trials with the feature condition and an

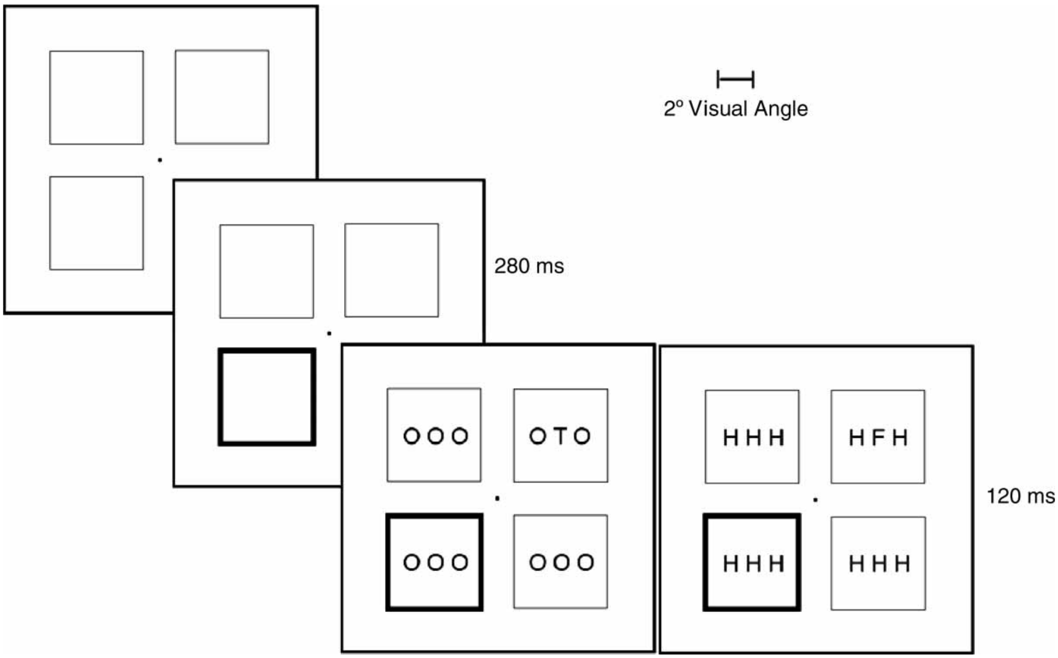

Figure 2. *The sequence of events in a trial in Experiment 1.*

exposure duration of 120 ms. This practice block was followed by practice with the conjunction condition. The exposure was initially set to 400 ms. After the participant obtained 10 correct trials in a row, the exposure duration was reduced first to 300 ms and then to 200 ms. This practice was followed by a complete block of 40 trials at 120 ms exposure duration.[3]

Data were collected in 10 blocks, 40 trials per block, alternating between the feature and conjunction conditions. For half of the participants 80% of the trials were valid. For these participants, attending to the cued location was advantageous. For the other half of participants, 25% of the trials were valid. Hence, there was no strategic reason for participants to voluntarily attend to the cued location. Participants were informed of the proportion of valid and invalid trials before the experiment began.

Stimuli

The stimuli were presented on a 15-inch monitor controlled by a Macintosh G3 computer at a viewing distance of 48 cm.[4] This distance was held constant with the use of a chin rest. Figure 2 is drawn to scale. The distance from the fixation point to the centre of the squares subtended approximately 5.4 degrees. The letters were 36-point Helvetica font.

Results and discussion

The mean correct RTs are shown in Table 1. Trials on which eye movements were detected

[3] This experiment was a replication of an experiment first presented at the Cognitive Science Association for Interdisciplinary Learning meeting, Hood River, Oregon, July 2004. The main difference between the experiments was that considerably more practice was given in the present experiment. The results were nearly identical.

[4] The software used to run these experiments can be obtained from the first author.

Table 1. *Mean correct reaction times in Experiment 1*

	Voluntary		*Involuntary*	
	Feature	*Conjunction*	*Feature*	*Conjunction*
Valid	399 (.98)	481 (.95)	388 (.98)	507 (.99)
Invalid	503 (.92)	699 (.78)	413 (.99)	514 (.99)

Note: Proportion correct in parentheses.

(<1%) were eliminated from the analysis as were RTs under 100 ms and over 2,000 ms (<1%). Overall, there was no significant difference between groups, $F(1, 22) = 2.58$, $MSE = 31{,}358.52$, *ns*, but there were significant effects of the cue, $F(1, 22) = 55.01$, $MSE = 27{,}044.35$, $p < .01$, and difficulty (conjunction vs. feature); $F(1, 22) = 48.21$, $MSE = 6{,}679.14$, $p < .01$. There was a significant three-way interaction between group (voluntary vs. involuntary), difficulty, and validity, $F(1, 22) = 9.35$, $MSE = 1{,}509.14$, $p < .01$.

The nature of the three-way interaction can be seen quite clearly in Figure 3, which shows the effect of the cue (invalid RT − valid RT). The interaction arose because the effect of the cue was larger for the conjunction trials (187 ms) than for the feature trials (104 ms) for voluntary attention. However, for involuntary attention, the cue had a larger effect for feature trials (26 ms) than for conjunction trials (6 ms). For the voluntary-attention group, the cueing effect was significantly different from zero for both the conjunction and feature tasks, $t(11) = 7.29$ and 7.21, $p < .05$, respectively.[5] For the involuntary-attention group, the cueing effect was significantly different from zero only for the feature task, $t(11) = 4.49$, $p < .01$. The cueing effect for the more difficult conjunction task was not significantly different from zero, $t(11) = 0.72$, $p = .24$.

These patterns were confirmed by planned *t* tests performed for each group separately. In an analysis of the voluntary-attention group, the effect of the cue (invalid RT − valid RT) was significantly greater for the conjunction task than for the feature task, $t(11) = 4.30$, $p < .01$. This finding replicates Briand and Klein (1987) and Soetens et al. (2003). In the analysis of the involuntary-attention group, the effect of the cue was larger for the feature task than for the conjunction task, $t(11) = 2.58$, $p < .05$. This effect follows the prediction presented above: Making the task more difficult reduced the cueing effect by lengthening the time between the selection process and the completion of perceptual processing.

Accuracy in the voluntary and involuntary groups averaged 92.1% and 96.1%, respectively. There was no evidence of a speed–accuracy trade-off: Participants were generally slower on incorrect trials. We conducted the same three-way analysis of variance (ANOVA) on accuracy results as we did with RT (Group × Cue × Difficulty). The interaction was reliable as it was with RT, $F(1, 22) = 13.63$, $MSE = .0019$, $p > .05$. The accuracy results exhibited some of the same trends as RT. Importantly, for the voluntary-attention group, the cueing effect was much larger for the conjunction than for the feature condition (see Table 1). There was only a small effect of difficulty on the cueing effect for the involuntary-attention group.

For the voluntary-attention group, participants were significantly more accurate in the feature than in the conjunction condition (96.9% vs. 87.4%), $F(1, 11) = 26.6$, $MSE = 0.0041$, $p < .05$. Participants were significantly more accurate on valid than invalid trials (96.8% vs. 87.5%), $F(1, 11) = 18.56$, $MSE = .0057$, $p < .05$. There

[5] Although all differences tested by *t* tests were in the expected direction, the reported *p*-levels refer to the more conservative two-tailed testing, unless otherwise noted.

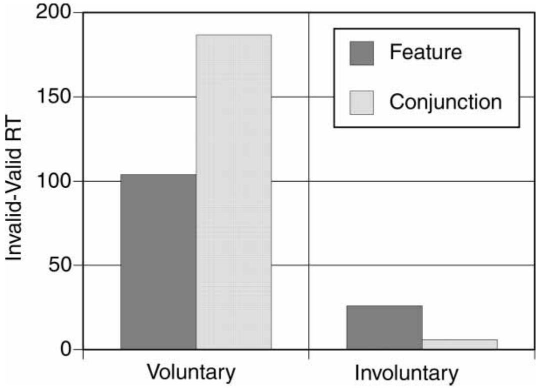

Figure 3. *The effect of the cue in Experiment 1 (invalid RT − valid RT).*

was also a significant Cue × Difficulty interaction that mirrored the RT results, $F(1, 11) = 18.57$, $MSE = 0.0036$, $p < .05$. The interaction matched the RT results. The effect of the cue was larger for the conjunction condition (95.8% valid vs. 79.0% invalid) than for the feature condition (97.9% vs. 96.1%).

In summary, the pattern of RT results was the opposite for voluntary- and involuntary-attention conditions. With voluntary attention, the effect of the cue increased as perceptual difficulty increased. In contrast with involuntary attention, the effect of the cue decreased as perceptual difficulty increased. This finding is particularly striking because the only difference between voluntary and involuntary conditions was the proportion of valid to invalid trials, thus controlling for all stimulus factors within a trial.

EXPERIMENT 2

In Experiment 1 we found that predictive and nonpredictive cues had the opposite effect on performance when we manipulated perceptual difficulty. However, Briand (1998) performed a similar manipulation and found that both predictive and nonpredictive cues had the same effect with a similar manipulation of perceptual difficulty. Specifically, for both types of cue, the effect of the cue was larger for the conjunction task than for the feature task.

In Experiment 2 we explored the possibility that Briand's results may have been due to uncontrolled eye movements. Briand instructed his participants not to move their eyes; however, he did not monitor eye movements. It is possible that for both predictive and nonpredictive trials, participants occasionally moved their eyes to the cue. One might expect more eye movements in the difficult (conjunction) task than the easy (feature) task. Prinzmetal et al. (2005b) found that eye movements had a considerable effect on performance in this paradigm. To test this possibility, we replicated Experiment 1 for the involuntary-attention group. Participants were told not to move their eyes, and this instruction was repeated on the screen between each block. We monitored eye movements, but did not give feedback when participants moved their eyes. We have informally found that without training, participants are not usually aware of whether they are moving their eyes or not. We did not replicate the voluntary-attention condition of Experiment 1 because those results were consistent with those of Briand (1998).

Method

Participants

There was a single group of 18 participants, recruited as in Experiment 1.

Stimuli and procedure

The stimuli, instructions, and procedure were identical to those for the involuntary-attention group in Experiment 1. As in Experiment 1, eye movements were monitored. The only difference between Experiment 2 and Experiment 1 was that participants were not given feedback when they moved their eyes.

Results and discussion

In Experiment 1, when participants were given feedback when they moved their eyes, eye movements occurred on less than 1% of the trials.

In this experiment, however, eye movement occurred on an average of 13% of trials and ranged from 0% to 89% of trials.

In the analysis of RT in Experiment 2, we included trials on which eye movements were made because we wanted to understand the role played by eye movements and because excluding these trials would have left some empty cells. The removal of feedback upon eye movements dramatically changed the results and created the opposite effect: The conjunction condition had a larger attention effect than the feature condition. The mean RTs for valid and invalid trials for the conjunction condition were 510 and 540 ms, respectively. (The corresponding accuracy was 95.4% vs. 91.7% correct.) For the feature condition, these values were 406 and 424 ms (97.8% vs. 97.6% correct). However, the attention effect (invalid RT − valid RT) in the conjunction condition (mean = 30 ms) was not reliably different from that in the feature condition (mean = 18 ms), $t(17) = 0.66$, $p = .51$.

The reason for the lack of reliability is quite clear. The pattern of results for participants who tended to move their eyes replicated Briand's results and Figure 3, voluntary-attention group. Those participants who did not move their eyes replicated the interaction in Figure 3, involuntary-attention group. To illustrate this, we first calculated the effect of the cue for the conjunction and feature tasks for each participant: invalid RT − valid RT (including eye movement trials). Next we calculated an index of whether the cue effect was larger for the conjunction or feature task:

$$\text{Index} = \text{cue effect}_{\text{conjunction}} - \text{cue effect}_{\text{feature}}$$

If this index is positive, the results for involuntary attention replicate Briand (1998); if the index is negative, they replicate Experiment 1. In Figure 4 this index is plotted for each participant along with the proportion of trials on which participants moved their eyes. Participants who tended to move their eyes had a greater cueing effect on the conjunction condition (positive index values), while those who did not tend to move their eyes had a greater cueing effect in the feature condition (negative index values). The correlation between the proportion of trials on which an eye movement was made and the index was $r = .85$, $p < .05$.

As shown in Figure 5, all 5 participants who made eye movements on over 20% of the trials had a larger cueing effect in the conjunction condition ($p < .05$ by a one-tailed sign test). Of 13 participants who made the eye movements on less than 20% of the trials, 11 had a larger cueing effect in the feature than conjunction condition ($p < .05$ by a one-tailed sign test). Thus those participants who moved their eyes the most replicated Briand (1998) while those who moved their eyes the least replicated Experiment 1.

Of course, we cannot determine whether Briand's (1998) participants moved their eyes, but it has been our experience that untrained participants do not know whether they are moving their eyes or not without feedback. In Experiment 1 and for the participants who infrequently moved their eyes in Experiment 2, increasing perceptual difficulty reduced the involuntary attention effect.

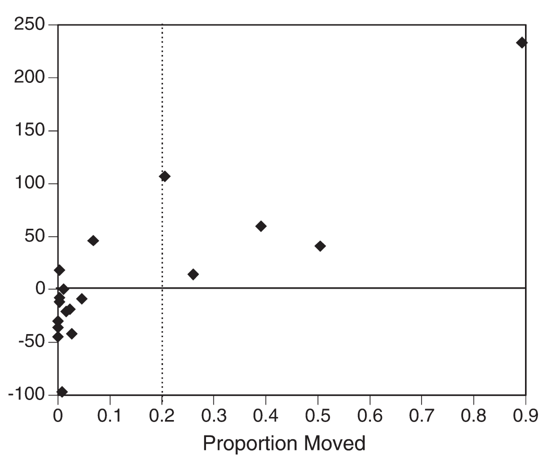

Figure 4. *The difference in cueing effect for the conjunction and feature tasks plotted as a function of the proportion of trials on which participant's moved their eyes. Negative values replicate Experiment 1, involuntary-attention group. Positive values replicate Briand (1998).*

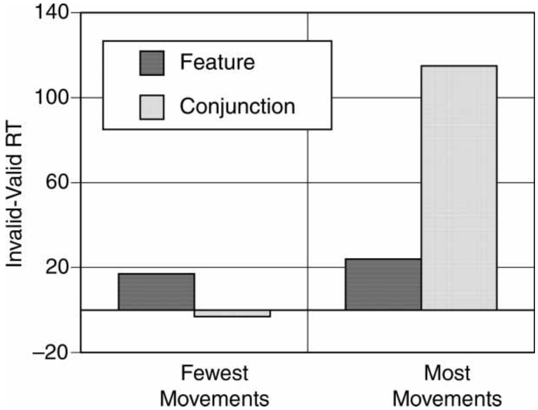

Figure 5. *The cueing effect for participants who moved their eyes on more than 20% of trials and for participants who moved their eyes on less than 20% of the trials in Experiment 2.*

Finally, it has been suggested to us that training participants not to move their eyes changes their attentional set. By this argument, when participants are discouraged from moving their eyes, different attentional processes are engaged than when they are allowed to move their eyes. We know of only one experiment that explicitly compared performance when participants were allowed or prevented from moving their eyes in a spatial attention task in a situation where eye movements probably could not affect performance (50-ms SOA). Prinzmetal et al. (2005a, Exp. 8) found no difference in involuntary attention as a function of whether eye movements were prevented or not. Of course, this single null finding does not mean that preventing eye movements would never change attentional processes. However, the notion that preventing eye movements changes attention set not only challenges the present study, but it challenges almost all research on covert attention (attention independent of eye movements) since the absence of eye movements is a defining characteristic of covert attention.

EXPERIMENT 3

Experiment 3 had three goals. The first goal was to obtain a better estimate of voluntary attention using the "anticueing" paradigm. In Experiment 1, using a direct spatial-cueing paradigm, we obtained different results depending on whether the cue was predictive of the target location or not. When the cue was not predictive, increasing perceptual difficulty decreased the cueing effect. When the cue was predictive, increasing difficulty increased the cueing effect. The logic of the design is that the nonpredictive cueing condition only represents involuntary attention. The predictive condition contains an additional voluntary attentional component. The advantage of the design is that all stimulus factors are controlled in the comparison of voluntary and involuntary attention. The same cue, target, and timing parameters can be used to compare involuntary and voluntary (+involuntary) components of attention.

The disadvantage of the design is that there is no pure measure of voluntary attention. The "voluntary" condition is increased by an involuntary attention component. One way to approach this problem is with the anticueing method (e.g., Posner et al., 1982; Sereno & Holzman, 1996; Warner et al., 1990). In this method, a cue in one location indicates that there is a high probability that the target will be in the opposite location. At short SOAs, participants are typically faster when the target is in the low-probability cued location, representing involuntary attention. At long SOAs, participants are faster when the target is in the (uncued) opposite high-probability location. In the direct-cueing procedure, the predictive condition contains both voluntary and involuntary components. In the anticueing method, at long SOAs, RTs at the opposite location are a conservative estimate of voluntary attention, because involuntary attention would prime RTs at the cued location. Experiment 3 was an anticueing experiment with the same stimulus discrimination as that in Experiments 1 and 2. There was one group of participants. There was a high probability that the target was in the location opposite the cue, and there were three SOAs (see below).

In Experiment 1, we had to use an SOA that would yield both voluntary and involuntary attention effects. It could be argued that we underestimated the involuntary attention effect because the SOA we used was too long to be optimal for involuntary attention. However, it should be noted that the involuntary cueing effect in Experiment 1 (25 ms) was not inconsequential. Furthermore, with a discrimination task (as opposed to detection task), the time between the cue and target can be as long as 400 ms without diminishing the effect of involuntary attention (Lupiáñez, Milan, Tornay, Madrid, & Tudela, 1997). Nevertheless, in the anticueing procedure we used several SOAs, from one that favoured involuntary attention (40 ms) to one that favoured voluntary attention (600 ms).

One objection that could be raised to the anticueing paradigm is that at the long SOAs faster RTs at the opposite location could represent another effect called inhibition of return (IOR; Posner & Cohen, 1984). IOR is the finding that at long SOAs participants can be slower to respond at the cued location than at any of the uncued locations. To determine whether our results at the long SOA could be attributed to IOR we ran an additional experiment (Experiment 3b). We only used the long SOA condition (600 ms), and the cue was not predictive of the target location. IOR only occurs with nonpredictive cues (Wright & Richard, 2000). The purpose of this additional experiment was to determine whether the results in the main experiment could be accounted for by IOR.

The final goal of Experiment 3 was to assess the role played by distractors in the previous experiments. In Experiments 1 and 2, the nontarget positions always contained distractors. Prinzmetal et al. (2005a) argued that there are two components to these tasks: finding the target (a search component) and identifying the target. Our method of increasing difficulty probably affected both components. We wanted to reduce the search component as much as possible to have a more pure measure of involuntary attention (also see Remington & Folk, 2001). Hence, in Experiment 3, the nontarget positions were blank (see Figure 6). Leaving the nontarget positions blank makes the experiment similar to a visual search task with a display size of one item.

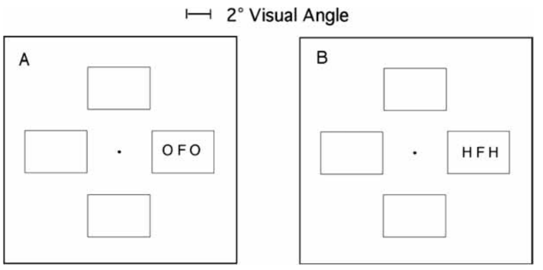

Figure 6. *Feature (A) and conjunction (B) conditions in Experiment 3.*

Method

Participants

In Experiment 3a there was a single group of 38 participants. In Experiment 3b there was a single group of 9 participants. Participants were selected from the same subject pool as that in Experiments 1 and 2.

Stimuli and procedure

To make it easier for participants to voluntarily orient their attention to the opposite location, we changed the stimulus configuration to a diamond (see Figure 6). The distance from the fixation point to the centre of the boxes was the same as that in Experiments 1 and 2 (subtending a visual angle of approximately 5.4 degrees). In Experiment 3a, the onset of the cue preceded the onset of the target by 40, 280, or 600 ms. The cue duration was fixed at 400 ms. Thus for the 40- and 280-ms SOA conditions, the cue temporally overlapped with the target. On 20% of the trials, the target appeared in the cued location, and on 80% of the trials the target appeared in the location opposite the cue. Practice was the same as that in Experiment 1, and data were collected in eight blocks with 45 trials per block. The three SOAs and two cue conditions (target in cued/opposite conditions) were varied within each block, and the difficulty condition was varied between blocks, as in Experiment 1. All other conditions such as practice, number of blocks, monitoring eye movements, and feedback were identical to those in Experiment 1.

Experiment 3b was identical to Experiment 3a, except for the following. The cue location was not predictive of the target location—that is, the target location was cued on 25% of the trials. Only the 600-ms SOA condition was run. Data were collected on four blocks of 48 trials per block.

Results and discussion

Experiment 3a

The mean correct RTs were calculated as in Experiment 1 (eye movement trials excluded) and are shown in Table 2. An overall ANOVA that included SOA, cue condition (cued vs. opposite), and difficulty (conjunction vs. feature) revealed a significant SOA by cue condition interaction, $F(2, 37) = 3.57$, $MSE = 2{,}344.94$, $p < .05$. At the short SOA, participants were faster with the target in the cued location than in the opposite location (578 ms vs. 585 ms). At the long SOA, participants were slower with the target in the cued location than in the opposite location (571 ms vs. 550 ms). These results replicate previous studies with the anticueing paradigm (e.g., Posner et al., 1982; Warner et al., 1990). There was also a significant interaction of difficulty and cue condition, $F(1, 37) = 4.27$, $p < .05$.

The effect of the cue is shown in Figure 7, which plots opposite RT minus cued RT. Faster RTs at the cued location represent involuntary attention (positive numbers), and faster RTs at the opposite location represent voluntary attention (negative numbers). As we predicted, at the short SOA, increasing difficulty decreased the effect of the cue from 19 ms to −5 ms, $t(17) = 1.72$, $p < .05$. That is, at the short SOA participants were faster at the cued location, but only for the feature

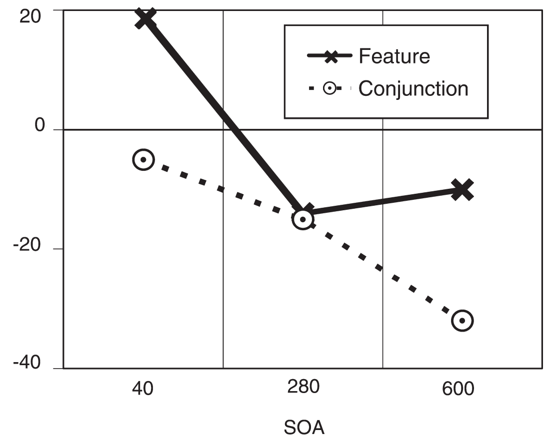

Figure 7. *The effect of the cue in Experiment 3a (opposite RT − cued RT). Positive values represent involuntary attention; negative values represent voluntary attention.*

condition. At the long SOA, increasing difficulty increased the effect of the cue from −10 ms to −32 ms, $t(17) = 1.79$, $p < .05$. Furthermore, at the short SOA, the mean RT for the feature condition was significantly different from zero, $t(37) = 2.26$, $p < .05$, whereas the conjunction condition was not significantly different from zero, $t(37) = 0.50$. At the long SOA, the feature condition was not significantly different from zero, $t(37) = 1.18$, whereas the conjunction condition was significantly different from zero, $t(37) = 2.98$, $p < .05$. The 280-ms SOA was similar to the condition run in Experiment 1, and it showed more voluntary than involuntary attention, which was similar to Experiment 1 (see Figure 3).

Experiment 3b

The purpose of this experiment was to determine whether the results at the long SOA (600 ms)

Table 2. *Mean correct reaction times in Experiment 3*

	SOA 40 ms		*SOA 280 ms*		*SOA 600 ms*	
	Conjunction	*Feature*	*Conjunction*	*Feature*	*Feature*	*Conjunction*
Cued	628 (.97)	528 (.98)	589 (.99)	526 (.99)	532 (.99)	609 (.99)
Opposite	623 (.99)	547 (.99)	574 (.99)	512 (.99)	522 (.99)	577 (.98)

Note: Proportion correct in parentheses. SOA = stimulus onset asynchrony.

could be attributed to IOR. This experiment used only the long SOA, and the cue was not predictive of the target location. There was a small cueing effect: Participants were faster when the target appeared in the cued location than when it appeared in the uncued locations (408 vs. 425 ms), $F(1, 8) = 9.95$, $MSE = 253.74$, $p < .01$. Participants were also significantly faster on the feature condition than on the conjunction condition (382 vs. 451 ms), $F(1, 8) = 10.07$, $MSE = 4{,}178.48$, but difficulty did not interact with the cueing effect, $F(1, 8) = 1.67$, $MSE = 436.75$, *ns*.

Hence with nonpredictive cues, there was no IOR at the longest SOA. The significance of this finding is that the results at the long SOA in Experiment 3a cannot be attributed to IOR. We do not know why we did not obtain IOR. It may have been that our SOA was not long enough. In discrimination tasks, IOR occurs at a longer SOA than in detection tasks (Lupiáñez et al., 1997). Alternatively, it has been observed that when the cue is present for most of the period between the cue onset and target, IOR is reduced (Collie, Maruff, Yucel, Danckert, & Currie, 2000). Whatever the reason, the facilitation at the cued location in our anticueing experiment at long SOAs (Experiment 3a) was not due to IOR, but rather voluntary attention.

Our interpretation of the results shown in Figure 7 is that voluntary attention enhances the perceptual representation and will have its greatest impact in a perceptually demanding task. It was suggested to us by a reviewer that the results might be accounted for by quicker disengagement of attention from the cued location with the conjunction task. Participants are more motivated to move voluntary attention away from the cued location to the opposite location and hence have a smaller effect at the cued location for the conjunction task. This interpretation is partly consistent with our claim because presumably participants would move their voluntary attention to the opposite location in the conjunction task because they need the additional perceptual resources for the difficult task. However, the pattern of performance in Figure 7 is not what one would expect if the only difference was due to the speed of redeploying attention. If it were, RT function for the feature task would be the same shape as that for the conjunction task, but shifted to the right (i.e., the redeploying of attention would be slower for the feature task), and this was not the case.

It has been previously found with the anticueing paradigm that at short SOAs participants were faster at the cued (low-probability) location than the opposite (high-probability) location, but at long SOAs this pattern reversed. We replicated these results. Performance at the short-SOA condition represents involuntary attention, whereas performance at the long-SOA condition represents voluntary attention. We found that our manipulation of difficulty had the opposite effect for involuntary and voluntary attention: Increasing difficulty decreased the involuntary effect, but increasing difficulty increased the voluntary effect.

GENERAL DISCUSSION

There is little doubt that both voluntary and involuntary attention affect “selection”, but the present work asks “selection for what?”. We hypothesized that voluntary and involuntary attention involve different mechanisms and that they have different consequences. Voluntary attention selects for perceptual enhancement. More perceptual processing resources are allocated to attended objects leading to a more veridical perceptual representation. Attended objects are perceptually processed faster and more completely than unattended objects. Tasks that require more perceptual processing should show larger effects of voluntary attention than those that require less information.

Involuntary attention, on the other hand, does not affect selection for perception. We propose that it affects the tendency to respond to a stimulus in one location or another. We have hypothesized that there are at least two ways in which this could occur (Prinzmetal & Landau, in press). The first explanation involves a nonperceptual-processing serial queue. Participants first check the results of perceptual analysis at the cued location. If the target is not in that location, they then search the uncued locations. Thus RT on valid trials will be faster than that on invalid trials because the cued location is checked first. This idea explains the transient nature of involuntary attention because if the target appears too late, participants may have already checked the cued location and have moved on to a uncued location. Thus the cue will have its greatest positive effect on RTs if it appears in close temporal proximity to the results of perceptual analysis (see Figure 1). We predicted that increasing the time between the selection and the completion of perceptual processing by lengthening the perceptual stage should reduce the effect of the cue and in some cases may lead to IOR.

A second nonperceptual account of involuntary attention was recently proposed by Prinzmetal (2006; Prinzmetal & Landau, in press). The theory is based on the idea of the leaky competitive accumulator model of Usher and McClelland (2001). The model postulates a separate accumulator (evidence counter) for each target at each possible target location. When the evidence in any accumulator reaches a threshold, the participant responds. The cue primes the accumulators associated with the cued location. If the target appears at the cued location, it takes less additional information to exceed threshold than if the target appears at an uncued location. The cue does not prime one response over another, but rather all responses to anything appearing in the cued location. Thus, the activity of the cue does not distinguish which target had been presented. The accumulator model also accounts for the transient nature of involuntary attention because the accumulators are "leaky", and the activation dissipates with time. Both the serial search and accumulator models are nonperceptual accounts of the RT effect of involuntary attention. They both account for the transient nature of involuntary attention. The two mechanisms are not mutually exclusive, and there may be situations, discussed below, where one mechanism or the other is responsible for the cueing effect.

Whatever causes the involuntary attention effect, we propose a two-tiered system. Voluntary attention allocates perceptual-processing resources to the likely stimulus location, but this allocation takes a relatively long time (~200 ms, Luck et al., 1996). Involuntary attention selects the output from perceptual processing, and it has its greatest positive effect when the selection occurs close in time to the completion of perceptual processes. In most situations it operates relatively quickly, and its benefits are transient.

Most investigators have suggested that the transient nature of involuntary attention, and IOR, is a function of the SOA between the cue and target. One interpretation of our results with involuntary attention is that it is not the SOA, per se, that is critical, but rather the time between the onset of the cue and the response decision or execution. Thus, if the task is made more difficult, the effects of the cue will be prolonged (i.e., the effect will be less transient), and IOR will be delayed. Future research will be required to decide whether the critical factor in involuntary attention is SOA, or the time between cue onset and response decision/execution.

We do not believe that the double interaction that we found will always be obtained, however. There are probably several critical factors such as the SOA, the degree of difficulty, and the kind of difficulty. In fact, a greater cueing effect with a more difficult task would be expected simply from a measurement artefact. RTs are generally positively skewed. In general, RTs will be faster on valid trials than on invalid trials. Because of a floor effect, the effect of the cue should be greater with a more difficult task (long RTs) than with an easy task (short RTs). The pattern of results with voluntary attention is expected from this measurement consideration alone. Hence the results of Briand and Klein (1987), Briand (1998), and Soetens et al. (2003) all could be a result of this measurement artefact. Our results cannot be accounted for by this artefact because we obtained the opposite results with involuntary attention. Since the pattern of interactions for voluntary and involuntary conditions is in the opposite direction, there is no simple monotonic transformation that can account for the results (Loftus, 1978).

We suspect that the way in which difficulty is manipulated will also be critical. There are at least four kinds of difficulty, and these may have different consequences. The present work demonstrates that difficulty in terms of a conjunction versus a feature task yields a different pattern of results for voluntary and involuntary attention. It may be that only tasks involving conjunction versus feature search will produce these results. Alternatively, an easy versus difficult feature task may also show this double dissociation.

Other dimensions of difficulty might be critical. Johnston, McCann, and Remington (1995) compared an "easy" and "difficult" task with a predictive cue and 50-ms SOA. The easy task involved letter discrimination, and the difficult task involved a pseudoletter discrimination. They found no interaction between difficulty and cue type (valid vs. invalid). It may have been that the SOA was not appropriate for clearly dissociating voluntary or involuntary attention. A more interesting possibility is that the manipulation was not one that affected perceptual difficulty, but rather a difference in remembering the response assignment for letters versus pseudoletters. We programmed their experiment, and it seemed to us that it was more difficult to remember the response assignments with the pseudoletters than with the letters, not that the pseudoletters were more difficult to discriminate. We do not know whether a difficulty manipulation involving response assignment will yield the double dissociation that we found.

The final dimension of difficulty is related to the ease of finding the target. If the target is difficult to find, we do not believe that we would have obtained the present results with regard to involuntary attention. Recall that we hypothesized that there are at least two mechanisms responsible for involuntary attention: "leaky accumulator model" that works at a decision stage and a postperceptual serial search model. It seems to us that the limit on performance in the present experiments is due to the accumulator model, not the serial search model. Serial search is more likely for conjunction targets than for feature targets (e.g., Treisman & Gelade, 1980). If serial search was causing the involuntary cueing effect, we would have expected a larger effect in the conjunction than the feature task, and of course we did not. We speculate that there are two factors that might determine whether serial search limits performance in a cueing task: (a) The difficulty of finding the target; (b) The number of display positions. Hence, we predict that if we had had larger displays, and/or the targets were more difficult to find, then the involuntary attention effects would have been larger with the conjunction than with the feature task.

Our results are consistent with recent findings with other behavioural and physiological paradigms. These findings point to different mechanisms for voluntary and involuntary attention. For example, in a variety of voluntary-attention paradigms, the effect of attention is greater with identification than detection tasks (e.g., Bonnel & Hafter, 1998; Milliken, Lupiáñez, Roberts, & Stevanovski, 2003; Müller & Findlay, 1987). It seems reasonable to assume that identification demands more perceptual resources than detection. On the other hand, in experiments with IOR, which occurs only with involuntary attention (e.g., Posner & Cohen, 1984; Wright & Richard, 2000), IOR is larger with detection than discrimination tasks (Lupiáñez et al., 1997).

We have recently conducted both functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) studies that indicate voluntary and involuntary attention have different neural consequences. These experiments used the same comparison as that in Experiment 1: predictive and nonpredictive peripheral cues. This comparison has the advantage that differences in neural responses are due only to the predictability of the cue and not to the physical attributes of the cue (e.g., peripheral vs. central) or event timing. For the fMRI research, we used a face identification task and analysed activity in the fusiform face area (FFA). The FFA is an important part of the circuitry responsible for face recognition (e.g., Wojciulik, Kanwisher, & Driver, 1998). We found greater activation in the FFA contralateral to the cue on valid trials than on invalid trials, but only with predictive cues (Esterman et al., 2007; Prinzmetal & Landau, in press). Nonpredictive cues did not modulate activity in the FFA. This result is significant because it relates voluntary attention to a ventral stream area responsible for recognition.

In a similar study, we examined EEG activity with predictive and nonpredictive cues. We focused on gamma-band activity (frequencies from approximately 30 to 70 Hz) because this activity has been shown to be modulated by voluntary attention (Gruber, Müller, Keil, & Elbert, 1999). There was a significant gamma-band response (frequencies from approximately 30 to 70 Hz) to the onset of a predictive cue, but not to a nonpredictive cue (Landau, Esterman, Robertson, & Prinzmetal, in press). Furthermore, with the onset of the target, gamma-band activity reflected the movement of attention. With predictive cues, on valid trials there was little target-related activity, presumably because participants had already moved their attention to the cued location. On invalid trials, which required a movement of attention, there was significantly more gamma-band activity. Target-related activity was not modulated by involuntary attention (nonpredictive cues).

In summary, voluntary and involuntary attention can have distinctly opposite effects on behavioural performance when perceptual difficulty is manipulated. Difficulty can increase the effect of voluntary attention but reduce the effect of involuntary attention. Taken together with previous findings that voluntary attention affects accuracy, while involuntary attention does not (Prinzmetal et al., 2005a), the present study suggests that these two kinds of attention involve distinctly different mechanisms and have different consequences.

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