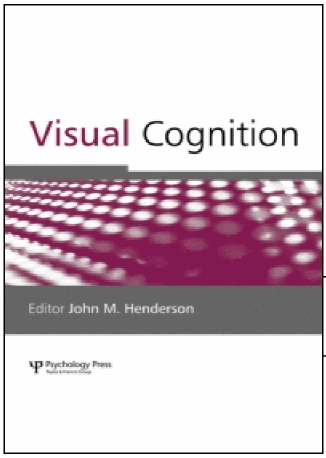

Visual Cognition
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713683696

# Does gaze direction affect accuracy?

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First Published on: 01 April 2008

To cite this Article: Prinzmetal, William, Leonhardt, James and Garrett, Rosalie (2008) 'Does gaze direction affect accuracy?', Visual Cognition, 16:5, 567 — 584

To link to this article: DOI: 10.1080/13506280801981341
URL: http://dx.doi.org/10.1080/13506280801981341

VISUAL COGNITION, 2008, 16 (5), 567–584

Psychology Press
Taylor & Francis Group

# Does gaze direction affect accuracy?

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The gaze direction effect is the finding that observers are typically faster at detecting or identifying a target when it appears in the direction indicated by the gaze of a centrally presented face as compared to other locations. The present research investigated whether the gaze direction effect would occur in accuracy when the target was visually degraded and accuracy was emphasized. In two experiments, the targets were easy to identify correctly, and reaction time (RT) was the dependent variable. In similar experiments, the targets were made difficult to identify and accuracy was the dependent variable. Gaze direction affected RT, but not accuracy. A theoretical mechanism for the gaze direction effect that accounts for these findings is presented.

Investigators have uncovered several stimuli that "automatically" capture visual attention. For example, the sudden appearance of an object can capture attention (e.g., Jonides, 1976, 1981; Jonides & Yantis, 1988), as can the sudden disappearance of an object (e.g., Miller, 1989; Theeuwes, 1991). The onset of motion can capture attention (Abrams & Christ, 2003), as can a sudden change in colour or luminance (Franconeri, Simons, & Junge, 2004; von Mühlenen, Rempel, & Enns, 2005). One of the more interesting kinds of stimulus-driven capture of attention is the gaze direction effect. A shift in gaze direction can automatically cause a shift in attention (e.g., Downing, Dodds, & Bray, 2004; Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen & Leppänen, 2003; Langton, 2000; Langton & Bruce, 2000; Langton, Watt, & Bruce, 2000; Ristic, Friesen, & Kingstone, 2002).

Much of the research on the effect of gaze direction on visual spatial attention comes from experiments using a variant of the spatial cueing paradigm (Posner, 1980). Observers typically fixate at the centre of a

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We would like to thank Artem Violentyev for his help in running numerous pilot studies that lead to the experiments reported here and Steven Whittle and Hui (Charles) Li for their help in running Experiments 4 and 5. We would also like to thank Ayelet Landau, Allison Connell, Richard Ivry, and Art Shimamura for their helpful comments on the manuscripts, and Tom Wickens for his insightful discussions on meta-analysis.

http://www.psypress.com/viscog DOI: 10.1080/13506280801981341

monitor. A face appears, and then the face shifts its gaze to, for example, the left or right. A target appears in either the direction in which the gaze is directed, or in another location. Observers are typically faster at detecting or identifying the target when it appears in the direction of gaze (valid trials) as compared to other locations (invalid trials). This effect occurs even though the gaze direction is not predictive of the subsequent target location and observers are instructed to ignore the direction of gaze. Thus, gaze is said to automatically capture attention. The gaze direction effect has been found with a wide variety of spatial and temporal parameters such as target eccentricity, stimulus–onset asynchrony, and exposure duration. It has been found with a variety of cues including schematic cartoon faces, photographs of faces, inverted faces, and faces with differing expressions and facial features, to name a few variations (Tipples, 2005).

Nearly all of the experiments with gaze direction have used target stimuli that were easy to identify or detect and reaction time (RT) was the dependent variable. There is reason to believe that not every spatial attention effect that is found with RT will also affect the accuracy of perception. Prinzmetal, McCool, and Park (2005); see also Prinzmetal, Park, & Garrett, 2005) conducted a series of spatial cueing experiments in which accuracy was high and RT was the dependent variable of interest. In every experiment, observers were faster on valid trials than invalid trials, even when the spatial cue was not predictive of the target location. They then ran accuracy versions of these experiments by degrading the target stimulus and emphasizing accuracy instead of speed. For example, in a letter identification task, the font size of the letter was reduced so that observers were approximately 75% correct even when instructed to take their time and be as accurate as possible. If the spatial cue was not predictive of the target location, it had no effect on accuracy. They found this dissociation between RT and accuracy with letter identification, judgements of line orientation, and face identification. They found this pattern of results with visual onset cues and offset cues, as well as with auditory spatial cues. The auditory cues consisted of white noise or tones emitted from speakers to the left or right of the observer (also see Spence, 2001). They found this dissociation between RT and accuracy with and without poststimulus masks and with a variety of intervals from the onset of the cue to the onset of the target (stimulus–onset asynchrony, SOA). In contrast to the automatic capture of attention, when the cue was predictive of the target location (i.e., voluntary attention), it always affected accuracy in that observers were more accurate on valid trials than invalid trials.

It is important to note that Prinzmetal, McCool, and Park (2005) obtained the dissociation between RT and accuracy with involuntary attention when four conditions were met. First, eye movements were controlled (cf, e.g., Dufour, 1999, and Prinzmetal, Park, & Garrett, 2005).

It is important to control for eye movements to distinguish covert orienting from the effects of retinal eccentricity. Second, accuracy experiments were true accuracy experiments, not hybrid RT accuracy experiments. That is, observers were instructed to take their time and be as accurate as possible. Third, there was no location uncertainty so that observers knew which location contained the target (Luck, Hillyard, Mouloua, & Hawkins, 1996; Prinzmetal, Nwachuku, Bodanski, Blumenfeld, & Shimizu, 1997; Shiu & Pashler, 1994). Finally, difference in the attention manipulation (e.g., valid vs. invalid trials) was not confounded with any other factor.

If automatic spatial attention affects RT but not accuracy, then it may be that its effect is not perceptual (Santee & Egeth, 1982). For example, some varieties of automatic attention might not enhance perception, but rather affect a response selection stage of processing. Santee and Egeth argued that "response accuracy is sensitive to early perceptual interference between target and noise items, whereas reaction time is more sensitive to later processes" (1982, p. 489). If effects are only obtained in RT, it would suggest that automatic attention does not have a perceptual locus. Later we will present a theory that can account for an effect of RT without an affect on accuracy with data-limited displays.

The goal of the present research was to determine whether the automatic effect of gaze direction will affect accuracy as well as RT or whether it will be similar to other automatic cues and only affect RT.

We know of two studies with gaze direction that have used accuracy as the main dependent variable in unspeeded tasks.[1] Schneider (2006) used gaze direction cues to vary attention in a contrast judgement task. In this experiment, two stimuli briefly appeared and observers judged which had greater contrast. Schneider found that gaze direction affected performance only when the targets were near the luminance of the background and hence very near threshold. Under these circumstances, observers tended to choose the stimulus in the direction indicated by the gaze as having higher contrast. When the stimuli were clearly visible (above threshold), there was no influence of the cue regardless of the difficulty of the discrimination. That is, the two stimuli could be very similar in contrast, but, as long as they could clearly be differentiated from the background, gaze direction had no influence. This paradigm, which is different from the classic spatial cueing paradigm, is clearly susceptible to bias due to location uncertainty (e.g., see Gould, Wolfgang, & Smith, 2007; Smith, Wolfgang, & Sinclair, 2004). If observers do not see anything (because the stimuli are near threshold) they

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[1] During the review process, a third paper that examined the effects of gaze direction and accuracy came to our attention (Stevens, West, Al-Aidroos, Weger, & Pratt, in press). This study was conducted independently and approximately concurrently with the present study. It will be discussed in the General Discussion.

may assume that there was something in the direction of gaze, and if there was something there, it must have higher contrast than the other unseen location.

Soto-Faraco, Sinnett, Alsius, and Kingstone (2005) examined the effects of gaze direction cues on tactile detection and discrimination tasks. The experiment was a traditional spatial cueing experiment and is therefore more similar to the experiments reported here than that of Schneider (2006). Observers viewed a face that shifted gaze either to the left or right. The gaze cues were uninformative to the target location. The target was a tactile vibration that was delivered to the little finger of either the left or right hand. The hands were placed on either side of the visual cue so that the gaze appeared to be directed to one hand or the other.

Soto-Faraco et al. (2005) conducted speeded identification (340 Hz vs. 100 Hz vibration) and detection tasks with high accuracy. In both detection and identification tasks, participants were significantly faster on valid than on invalid trials. They also performed an unspeeded detection task with the tactile stimuli near threshold. Participants were slightly more accurate on valid than invalid trials, but this difference did not reach significance with 33 participants ($p = .085$). They also conducted a separate tactile detection experiment with near threshold stimuli using noninformative arrow central cues. They found even a smaller and less consistent effect of the cue on tactile detection ($F < 1.0$). Thus neither gaze direction nor a central arrow significantly affected detection accuracy. In a post hoc analysis that combined the two experiments, there was a significant effect. It is clear that gaze direction cues affected tactile detection and discrimination RT, but with the mixed results on accuracy, it is perhaps best to suspend judgement. We will return to this issue in the General Discussion.

Even though the evidence is mixed on whether gaze direction influences perceptual accuracy, there is reason to believe that gaze direction might be different than other automatic attention cues. Gaze direction may be unique in terms of visual capture because there appears to be dedicated neural mechanisms for determining the gaze direction in primates (see Haxby, Hoffman, & Gobbini, 2002, for a review). For example, single cell recording in Macaque cortex has revealed cells sensitive to head and gaze direction in the superior temporal sulcus (e.g., Perrett, Hietanen, Oram, & Benson, 1992). Lesions to this area can cause an impairment in the discrimination of gaze direction (Campbell, Heywood, Cowey, Regard, & Landis, 1990). Functional MRI studies with humans have identified separate regions sensitive to gaze direction and these differ from regions responsible for face recognition (e.g., George, Driver, & Dolan, 2001; Hoffman & Haxby, 2000). It has been speculated that social cues, such as gaze direction and head direction, may play a special role in directing "social attention" (Perrett et al., 1992).

If gaze direction triggers a different attentional system, it may have different consequences than onset or offset cues for perception. In Experiments 1 and 2, observers made line orientation judgements. The gaze direction cue was a photograph of a face that turned its head either to the left or right. Experiment 1 was an RT experiment. Experiment 2 was an accuracy experiment; the length of the lines was reduced until observers were approximately 80% correct in the line discrimination task. Experiments 3, 4, and 5 involved a letter identification task. They used a cartoon face as a cue, and only the eyes shifted. Experiment 3 was an RT task. In Experiments 4 and 5, the contrast of parts of the letters was reduced so that observers were about 75% correct. In Experiment 4, the gaze direction was not predictive of the target location; in Experiment 5 it was predictive of the target location.

## EXPERIMENTS 1 AND 2

Experiments 1 and 2 were similar to Prinzmetal, McCool, and Park (2005), Exps 14 and 15) and to Handy, Jha, and Mangun (1999). Observers indicated whether a target line was vertical or horizontal. Prinzmetal, McCool, and Park found that with the same discrimination and masks, in an RT task with nonpredictive peripheral cues (boxes brightening), observers were faster on valid trials than invalid trials. However, when the lines were made shorter and observers were instructed to be as accurate as possible, there was no difference between valid and invalid trials. The only difference between the present experiments and Prinzmetal, McCool, and Park (2005, Exps 14 and 15) is that instead of a peripheral box brightening as a cue, we used the gaze direction of a central face as the nonpredictive cue. We used these targets and masks because Prinzmetal, McCool, and Park previously found with these stimuli that a noninformative onset cue affected RT, but not accuracy. Thus, we have a direct comparison of peripheral onset and central gaze direction cues. Furthermore, in a separate experiment, in which observers indicated the location of the target line, they were nearly 100% correct and hence there was no location uncertainty.

### Method

*Procedure.* The sequence of events is illustrated in Figure 1. Each trial began with two squares and a fixation point. Observers were instructed to maintain fixation and eye movements were monitored with a video camera (see Prinzmetal, McCool, and Park, 2005, for details). When eye movements were detected, the computer emitted a two-tone sound that was somewhat like a foghorn. After 1 s, a face appeared, staring straight ahead, for a randomly determined period from 500 to 1000 ms. The face then turned left or right and both grey boxes turned red. After 400 ms, a vertical or

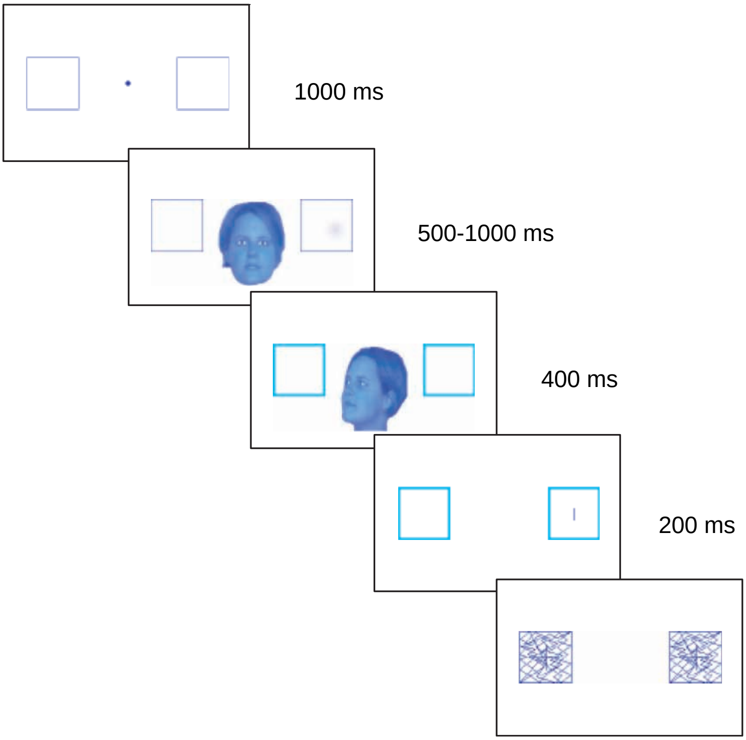

**Figure 1.** The sequence of events in Experiments 1 and 2. An invalid trial is illustrated. To view this figure in colour, please see the online issue of the Journal.

horizontal line appeared for 400 ms, and this stimulus was followed by a visual mask. The mask remained in view until the observer responded. Observers responded whether the line was vertical or horizontal by pressing one of two buttons. When the observer erred, the computer emitted a brief buzzing sound. At the end of each block, observers were told their average RT and their percent correct. In the RT version (Experiment 1) observers were encouraged to respond quickly, while maintaining at least 95% correct. In the accuracy version, observers were told to take their time and be as accurate as possible.

The stimuli used in Experiments 1 and 2 combined several different cues, in addition to gaze direction (Figure 1). Not only did the gaze change, but also the head changed direction in the direction of gaze in a dynamic manner. Gaze direction, head direction, and even body direction all contribute to orienting (Hietanen, 2002; Kylliäinen, & Hietanen, 2004; Langton, 2000). We wanted to combine as many cues as possible—working in the same direction—to maximize the probability of obtaining effects in both the RT and accuracy experiments.

Each observer began with a block of practice, and then five blocks on which data was collected. Within each block, on half of the trials the target was in the direction indicated by the gaze, and on half of the trials the target appeared in the opposite location.

*Stimuli.* The stimuli were presented on a 15-inch monitor controlled by a Macintosh G3 computer at a viewing distance of 48 cm. This distance was held constant with the use of a chinrest. Figure 1 is drawn to scale. The distance between the inside edges of the squares was 4 cm, subtending a visual angle of 4.75 degrees. In the RT version of the task (Experiment 1) the horizontal or vertical line was 15 pixels in length (0.5 cm), subtending a visual angle of 0.6 degrees, and 1 pixel wide. In the accuracy version of the task, the length of the target line was adjusted so that observers were approximately 80% correct. For most observers, the length of the line was 2 pixels in length (.067 cm), subtending a visual angle of only .08 degrees.

*Participants.* There were 12 observers in Experiment 1 (RT) and 20 observers in Experiment 2 (accuracy). We ran more observers in the accuracy version because we wanted to make sure that the accuracy experiment was at least as powerful as the RT experiment. Observers were recruited from the University of California, Berkeley Research Participation subject pool.

## Results and discussion

In the analysis of RT in Experiment 1, trials on which eye movements were detected ($<1\%$) were eliminated, as were RTs under 100 ms. and over 2000 ms. Observers were significantly faster on valid trials than on invalid trials (470 ms. vs. 482), $t(11)=2.83$, $p<.01$. Observers were quite accurate; the percentage correct for valid and invalid trials was 97.6% and 97.1%, respectively. Thus, we replicated the gaze direction effect in RT.

In Experiment 2, trials on which eye movements were made constituted less than 1% of trials and were removed from the analysis. In Experiment 2, there was no significant difference in accuracy between valid and invalid trials. The average percentage correct for valid and invalid trials was 80.9% vs. 80.2%, $t(19)=0.61$. Only 12 of the 20 observers were more accurate on valid than invalid trials.

Although Experiment 2 was designed around accuracy and observers were instructed to take their time, we also examined RT. The mean of the correct RT for valid and invalid trials was 879 ms. vs. 900 ms, $t(19)=2.07$,

$p < .05$, replicating Experiment 1. However, an analysis of correct trials when observers have made a substantial proportion of errors might be misleading because many of the correct trials are correct guesses. An analysis of all trials, including incorrect trials, also yielded faster RTs for valid than invalid trials (879 ms. vs. 900 ms), but this difference was not reliable, $t(19) = 0.63$.

In Experiment 1 we obtained the usual gaze direction effect in RT, but in Experiment 2, with degraded input, we obtained no effect on accuracy. Hence, it appears that involuntary attention, directed by gaze direction, has the same consequences on performance as involuntary attention directed by onset cues. The purpose of Experiments 3–5 was to test the generality of this finding with other gaze cues and stimuli. These experiments used a cartoon face and the task was letter identification. Experiment 3 was an RT experiment with stimuli that were easy to discriminate. In Experiments 4 and 5 the targets were made more similar so that observers could only be about 75% correct. In Experiments 3 and 4, the gaze direction was not predictive of the target location; in Experiment 5 it was predictive of the target location. The purpose of Experiment 5 was to determine whether we would obtain an effect with accuracy when the cue was predictive of the target location. Prinzmetal, McCool, and Park (2005) found that if the cue was not predictive of the target location, it had no effect on accuracy. However, if it was predictive, observers were more accurate on valid than on invalid trials.

## EXPERIMENTS 3, 4, AND 5

### Method

*Procedure.* The sequence of events is illustrated in Figure 2. Each trial began with a face gazing straight ahead. Observers were instructed to fixate between the eyes and eye movements were monitored as before. After a random period of 500 to 1000 ms, the gaze shifted to the left or right. Subsequently, a target letter appeared. The target was either the letter H or S made of straight-line segments. The exposure duration was 40 ms. After the observer responded, the screen became blank. Feedback was provided as before. There were two blocks of 18 trials of practice and data was collected on four blocks of 72 trials. In Experiments 3 and 4, the cue was not predictive of the target location. In Experiment 5, the target appeared in the location indicated by the gaze cue on 80% of the trials. Observers were told the proportion of valid and invalid trials. In Experiment 3, observers were given the same speed–accuracy instructions as in Experiment 1, and in Experiments 4 and 5 they were given the same accuracy instructions as in Experiment 2.

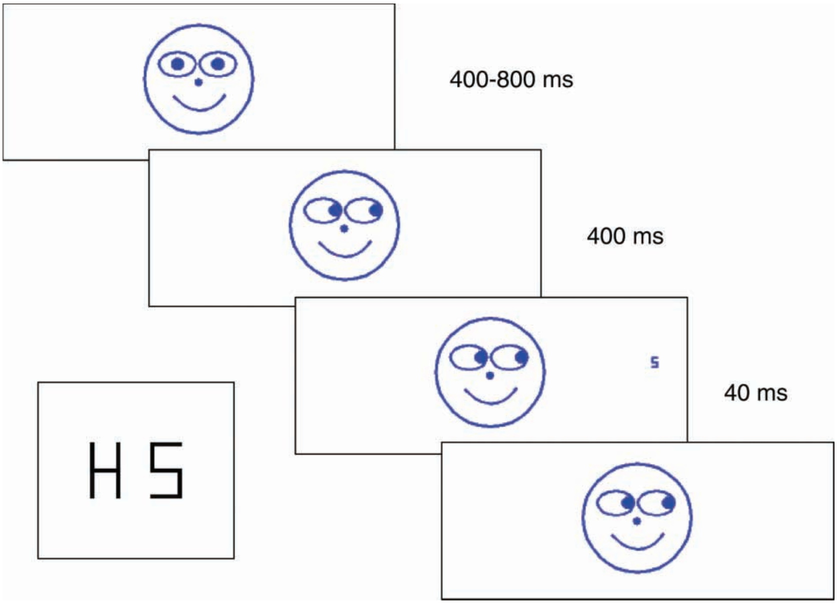

**Figure 2.** The sequence of events in Experiments 3, 4, and 5. The task was made difficult in Experiments 4 and 5 by reducing the contrast of those line segments that discriminate the target letters H and S (see box, bottom left). To view this figure in colour, please see the online issue of the Journal.

*Stimuli.* The stimuli were presented as in the previous experiments. Figure 2 is drawn to scale. The distance from the fixation location (between the eyes) to the inside edge of the target letters subtended a visual angle of 8.9°. The target letters (H and S) subtended a visual angle of approximately 0.50° high and 0.36° wide. In Experiments 4 and 5 the line segments that distinguished the target were reduced in contrast, between blocks, so that observers were approximately 75% correct (see Figure 2). The contrast of these segments was 100% in the RT experiment (black lines on a white background), but averaged 18% in the accuracy experiments. The line segments that are shared by the targets were 100% contrast (i.e., black). There were two advantages to these stimuli. First, due to the fact that the stimuli always contained high contrast lines, observers could easily see where the target was, but not which target was present. Thus, there was no location uncertainty. Second, compared to Experiment 2, there was more latitude in controlling the difficulty of target discrimination as there were 256 levels of contrast. There were 12 observers in Experiment 3 and 5. There were 24 observers in Experiment 4 (nonpredictive accuracy experiment). Eye movements were monitored as in Experiments 1 and 2.

## Results and discussion

*Experiment 3.* RTs were analysed as in Experiment 1. One observer made an excessive proportion of eye movements (11%) and was replaced. Trials on which eye movements were made were removed from analysis (1.6% of trials). Observers were significantly faster on valid trials than on invalid trials (506 ms vs. 519 ms), $t(11) = 3.78$, $p < .01$. Observers were slightly more accurate on valid trials than invalid trials (96.5% vs. 95.6%), but this difference was not reliable, $t(11) = 1.30$, $p > .05$.

*Experiment 4.* Trials on which observers made eye movements were eliminated from the analysis (1% of trials). With nonpredictive gaze cues, observers were not more accurate on valid trials than invalid trials. The accuracy for valid and invalid trials was 75.4% vs. 75.7% for valid and invalid trials, respectively, $t(23) = 0.85$, $p > .05$. Only 11 of the 24 observers were more accurate on valid than invalid trials.

Although accuracy was emphasized over speed in this experiment, we did analyse RT as in Experiment 2. The average RT for correct valid and invalid trials was 754 ms vs. 795 ms, respectively, but this difference was not reliable, $t(23) = 0.96$, $p > .05$. Considering all trials (correct and incorrect), the RT for valid and invalid trials was 784 vs. 795, $t(23) = 0.96$.

*Experiment 5.* Trials on which eye movements were made ($< 1\%$) were eliminated from analysis. With predictive gaze cues, unlike the previous experiments, observers were more accurate on valid trials than invalid trials. The percentage correct for valid and invalid trials, respectively, was 81.6% vs. 76.9%, $t(11) = 2.76$, $p < .01$. Thus, it is possible to obtain an accuracy effect with these stimuli, but only if the gaze direction is predictive of the target location.

In the analysis of RTs, considering only correct trials, observers were significantly faster on valid trials than on invalid trials (595 ms. vs. 632 ms), $t(11) = 3.46$, $p < .05$. In an analysis considering all trials, this difference was also reliable (620 ms. vs. 669 ms), $t(11) = 6.28$, $p < .01$.

In summary, in the RT experiment, we obtained the usual gaze direction effect with a nonpredictive gaze cue. When the target discrimination was made more difficult and observers were urged to be as accurate as possible, there was no automatic gaze effect on accuracy. Finally, when the gaze cue was made predictive of the target location, gaze direction did affect accuracy. This pattern of results was precisely the same as Prinzmetal, McCool, and Park (2005) found with peripheral visual onset cues and spatial auditory cues.

# GENERAL DISCUSSION

Prinzmetal, McCool, and Park (2005); also see Prinzmetal, Park, & Garrett, 2005) reported that involuntary attention (nonpredictive spatial cues) affected RT, but not accuracy under conditions without location uncertainty and without speed pressure. The effect of gaze direction seems to be similar: we readily obtained effects on RT, but we only obtained an effect on accuracy when the gaze cue was predictive of the target location. Although we cannot claim that gaze direction will never affect accuracy, our two experimental preparations were reasonably diverse, using different cues (photographs and cartoon faces), different discriminations (line orientation vs. letter identification), with and without poststimulus masks, different temporal parameters, and different methods of impoverishing the target.

One might object that the gaze direction effects in RT that we obtained in Experiments 1 and 3 were rather small and that somehow accuracy is a less sensitive measure than RT. Hence, we took a small effect and made it disappear by using a less sensitive measure. There are two points to make in response to this criticism. First, the gaze direction effect is typically small. For example, we found seven studies in the literature where eye movements were monitored. These studies tested 33 separate conditions and the effect averaged 13 ms (for a similar analysis, see McKee, Christie, & Klein, 2008). We also conducted 10 pilot RT experiments with nonpredictive gaze cues to see if we could obtain a larger RT effect. However, in all of these pilot experiments, the effect averaged about 11 ms. Thus, the effects reported here are typical. Second, it is not the case that RT is a more sensitive measure than accuracy. The effect size for Experiment 5 (accuracy with a predictive cue) was larger than Experiment 3 (RT with a nonpredictive cue), Cohen's *d* of 0.12 vs. 0.06, respectively.[2]

One might question whether our null result with accuracy and nonpredictive gaze was due to lack of power. We do not think that this was the case. Combining Experiments 2 and 4, only 23 of the 44 observers were more accurate on valid than on invalid trials. This null result is in contrast to the significant results in the RT experiments (Experiments 1 and 3) and accuracy in the predictive cue experiment (Experiment 5).

Recently, it has come to our attention that Stevens et al. (in press) independently (and as far as we can determine, concurrently) conducted experiments similar to ours. Each trial began with the outline of a cartoon face at fixation. Fifty milliseconds before the target appeared, the eyes were filled such that the gaze was directed to one of four locations. A target (the

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[2] These values were calculated from the individual condition standard deviations as if the experiment was an independent group's experiment, as suggested by Dunlap, Cortina, Vaslow, and Burke (1996).

letter F or T) would appear either in the cued or an uncued location. The gaze cue was not predictive of the target location. In one experiment, RT was the dependent variable and the target letters were fairly large. In another experiment, accuracy was emphasized and the size of the letters was reduced until observers were about 75% correct. Although in the RT experiment observers were significantly faster on valid trials than invalid trials (539 ms vs. 552 ms, respectively), there was no difference in accuracy (73.1% vs. 73.6%, for valid and invalid, respectively), $t(25) < 1.0$, $p = .41$. They found the same pattern of results for central nonpredictive arrow cues.

One might wonder how to explain discrepant results between Soto-Faraco et al. (2005), on the one hand, compared to the current results and those of Stevens et al. (in press) on the other. We can think of at least two possibilities for this discrepancy.

The first possibility is that the results are not discrepant. Soto-Faraco et al. (2005) reported significant effects of gaze direction on RT in speeded tactile detection and identification tasks, but the effect of gaze direction on detection accuracy was not significant. They also failed to find a significant difference in tactile detection accuracy with nonpredictive arrow cues. By this view, the post hoc uncorrected analysis that combined experiments inflated Type 1 error. (See LeLorier, Gregoire, Benhaddad, Lapierre, & Derderian, 1997, for a dramatic example of post hoc meta-analysis inflating Type I error.) Given that the gaze direction effect in accuracy reported by Soto-Faraco et al. was small (and not significant), and the failures to find an effect by Stevens et al. (in press) and in the current experiments, this is the possibility we favour. By this view, the results are congruent.[3]

A second possibility is that there is a fundamental difference between cross-modal cueing and within-modality cueing such that nonpredictive cues (such as gaze direction) affect accuracy in the cross-modal case, but not the within-modality case. The most general version of the view is probably not correct. Prinzmetal, McCool & Parks (2005) investigated the effects of nonpredictive auditory cues on a visual discrimination task and found that although the auditory cues affected RT, they did not affect accuracy. It is possible that tactile cues and visual targets are in some way different from auditory cues and visual targets. However, we do not favour this explanation because we can think of no reason why controlling tactile attention with vision should be different than controlling auditory attention with vision.

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[3] Given that Soto-Faraco et al.'s (2005) conclusion was based on a post hoc analysis, an independent replication of the effect seems warranted, especially in light of the present results and those of Stevens et al. (in press). To be equivalent to the present experiments, the following condition would be important: (1) Trial-by-trial feedback is given to ensure observers know the cue is noninformative; (2) it is clear there is no speed pressure whatsoever; (3) independently it is ascertained that observers know the location of the stimulus with nearly 100% accuracy.

We have suggested that accuracy and RT are sensitive to different aspects of performance. Perceptual effects should be reflected in both accuracy and RT, whereas effects determined by nonperceptual stages, such as response selection, may be reflected only in RT (Santee & Egeth, 1982). Prinzmetal, McCool, and Park (2005) hypothesized that involuntary attention affects the selection of which location contains the target (channel selection), whereas voluntary attention affects the perceptual processing of the target. The involuntary gaze direction effect appears to be relevant to channel selection, which, when there is no location uncertainty, is only manifest in RT, and not in accuracy.

In spatial cueing experiments that follow the four strictures outlined in the introduction, we have found that voluntary attention affects performance both in studies designed around RT and those designed around accuracy. Involuntary attention seems to affect performance only in RT experiments, whether directed by the sudden appearance of an object, a sound, or an arrow (i.e., Stevens et al., in press). We have concluded that voluntary attention affects perceptual accuracy; involuntary attention does not. Three issues are raised by this research.

First, it has been pointed out to us by several reviewers that there seems to be a discrepancy between our results and physiological results using EEG. There have been two studies using nonpredictive gaze direction cues that have found enhanced P1 on valid trials compared to invalid trials over occipital sites (Schuller & Rossion, 2001; Tipper, Handy, Giesbrecht, & Kingstone, 2008). The argument goes that enhanced P1 represents enhanced perceptual processing, and so observers must be more accurate on valid trials than invalid trials.

Questions about perceptual accuracy are most directly answered by examining perceptual accuracy and not a physiological correlate of accuracy. There are probably many reasons why activation reflected by P1 might not be translated into accuracy. For example, event-related potentials reflect time and phase locked activity. The cue may synchronize activity leading to a higher P1, without altering the total neural response. Alternatively, the P1 activation could be due to the thick stripes in V2 (Livingstone & Hubel, 1987). From the EEG results, it is impossible to tell whether the response is due to all of the cortical cells or a subset of them. Information from the thick stripes is preferentially projected to dorsal areas that affect action, but is not projected to ventral areas that are responsible for recognition. Consistent with this hypothesis, we have recently conducted a spatial cueing task with faces as stimuli using fMRI (Esterman et al., 2008). We used faces because we could examine the activity in the FFA (fusiform face area), a ventral area important for face recognition. We found that voluntary attention modulated the FFA while involuntary attention did not. Using the same task, we found striking differences in the EEG activity associated with voluntary and involuntary attention (Landau, Esterman, Robertson, Bentin, & Prinzmetal, 2007). However, despite all of the physiological findings notwithstanding to the contrary, the best gage of accuracy of perception is a participant's accuracy.

The second issue is whether the effects of gaze direction are mediated by the same or different mechanisms as other automatic attentional cues, such as peripheral stimuli (Jonides, 1976, 1981) or nonsocial central stimuli, such as arrows (e.g., Downing et al., 2004; Ristic et al., 2002; Tipples, 2002). Note that one can distinguish mechanisms for directing attention from mechanisms that are responsible for the effects of attention after it has been directed. Our results indicate that the *consequences* of directing attention with gaze direction are similar to other cues.

However, special mechanisms may exist for directing attention with gaze direction. For example, functional imaging studies have indicated that there may be distinct neural mechanisms for gaze direction (e.g., George et al., 2001; Hoffman & Haxby, 2000; Tipper et al., 2008). On the other hand, the electrophysiological (EEG) response to gaze cues (Schuller & Rossion, 2001) is similar to other kinds of exogenous cues (Hopfinger & Mangun, 1998). A single study is not going to answer the question of whether gaze direction and other forms of stimulus-driven capture involve the same mechanisms for directing attention, and whether they involve the same mechanisms once attention is directed. Our results only point out that gaze direction and other forms of stimulus-driven capture have similar behavioural consequences in that they can affect RT while not affecting accuracy.

The third issue is what kind of mechanism would cause effects in experiments designed around RT, but not those designed around accuracy. We are not claiming that gaze direction will never affect accuracy. However, in cases such as the present experiments, where it does not affect accuracy, one might ask what mechanism could affect performance in an experiment designed around RT, but not an experiment designed around accuracy?

Prinzmetal and Landau (in press; also Prinzmetal, 2006) describe two mechanisms whereby a nonpredictive cue could affect RT in a speeded identification task without affecting accuracy in an unspeeded task. We will briefly describe one of these mechanisms. The idea was inspired by the leaky accumulator model of Usher and McClelland (2001) and is illustrated in Figure 3 (also see Brown & Heathcote, 2005; Klein & Hansen, 1990). The theory proposes that there is an evidence counter (or accumulator) for each target in each location. When the evidence in an accumulator reaches a threshold (Figure 3), the observer responds. A gaze shift to one location primes both target accumulators for the cued location (grey in figure). When the target appears, information accrues in the accumulator corresponding to that target until the threshold is reached. The target-related activity is indicated with the arrow in Figure 3. RTs are faster on valid trials because

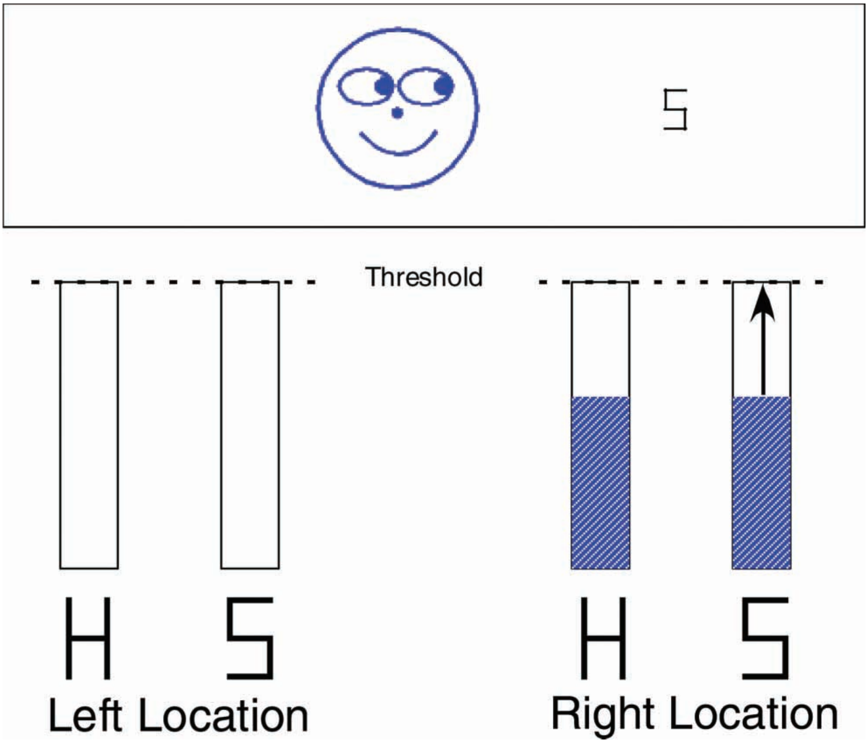

**Figure 3.** Accumulator model applied to a valid trial in Experiment 3. There is an accumulator for each potential target (H and S) in each potential location. When activation reaches threshold, the observer responds. The shaded area represents activation from the cue, the arrow represents activation due to target identity. To view this figure in colour, please see the online issue of the Journal.

the accumulators are already filled part way to the threshold. Note that, for involuntary attention, information related to the target identity accumulates at the same rate in both the cued and uncued locations. This location priming does not affect performance in unspeeded accuracy experiments because the accumulators are "leaky" and the priming activation dissipates before observers respond. Thus, the accumulator model predicts differences in RT experiments, but not in unspeeded accuracy experiments.

The accumulator model makes another prediction. In speeded tasks (as opposed to unspeeded tasks), observers are often more accurate on valid trials than invalid trials (e.g., Prinzmetal, McCool, and Park, 2005, Exp. 5). Under speed pressure, on some invalid trials, activation from the accumulator will erroneously trigger a response. Such responses must be at chance with respect to target identity because there is no target information in the cued location on invalid trials. This is because the location priming is not specific to target identity, but primes both accumulators related to the cued location. On valid trials, however, there is activation from the cue and from the target, so responses will not be random. The accumulator model is one way of accounting for affects in tasks designed around RT, but not tasks designed around accuracy.

In summary, we have demonstrated that the gaze direction effect can have an effect on RT without influencing accuracy. Gaze direction did not affect perception such that observers were more accurate in target identification when a target appeared in the direction of gaze than when it did not, unless the gaze was predictive of the target location. Like other forms of involuntary attention, gaze direction automatically affects RT without enhancing perceptional accuracy.

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*Manuscript received June 2007*
*Manuscript accepted January 2008*
*First published online April 2008*