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Testing whether gaze cues and arrow cues produce reflexive or volitional shifts of attention

Sara A. Stevens, Greg L. West, Naseem Al-Aidroos, Ulrich W. Weger, and Jay Pratt
University of Toronto, Toronto, Ontario, Canada

It has been suggested that two types of uninformative central cues produce reflexive orienting: gaze and arrow cues. Using the criterion that voluntary shifts of attention facilitate both response speed and perceptual accuracy, whereas reflexive shifts of attention facilitate only response speed (Prinzmetal, McCool, & Park, 2005), we tested whether these cues produce reflexive or volitional shifts of attention. A cued letter discrimination task was used with both gaze (Experiments 1A and 1B) and arrow (Experiments 2A and 2B) cues, in which participants responded to the identity of the target letter. In the response time (respond speed) tasks, participants were asked to respond as quickly as possible to the target; in the accuracy (perceptual quality) tasks, participants were asked to respond as accurately as possible. For both cue types, compatible cues were found to facilitate response speed but not perceptual accuracy, indicating that both gaze and arrow cues generate reflexive shifts in attention.

Effective interaction with our visual environment requires that individual regions of interest within the visual field be selected for deeper processing. One way that people perform this selection is to deploy attention. Stemming from initial experiments into visual attention by Posner (1980), there are two traditionally accepted ways in which attention can be oriented in the visual field. Attention can be oriented through an exogenous or reflexive system, as has typically been found in experiments that have used uninformative peripheral cues (e.g., the abrupt onset of an object in the periphery that does not provide any information regarding the location of the upcoming target; Posner, 1980). Or, attention can be oriented through an endogenous or volitional system, as has often been found in experiments using informative central cues (e.g., an arrow presented at fixation that indicates the most probable target location; Jonides, 1980, 1981). Endogenous shifts in attention are not directly triggered by physical properties of the stimuli; instead, they are goal based. Recently, however, a considerable amount of research has been conducted on cues that are centrally presented and uninformative yet generate shifts of attention to peripheral locations. From this research has emerged the proposal that two types of uninformative central cues—arrows and gaze direction—may generate reflexive or exogenous shifts in attention (e.g., Friesen, Moore, & Kingstone, 2005; Hommel, Pratt, Colzato, & Godijn, 2001; Langton & Bruce, 1999).

Many studies have now shown that the direction of gaze from a centrally presented face, be it a photograph of a real face (Driver et al., 1999) or a drawing of a schematic face (Friesen & Kingstone, 1998), can generate shifts of attention. The fact that such stimuli produce facilitation effects even when they are uninformative has led to the suggestion that they operate in a reflexive, or exogenous, manner. Indeed, facilitation effects toward the gazed-at location have also been found using counterpredictive central gaze cues (Friesen, Ristic, & Kingstone, 2004). Some evidence, however, suggests that gaze cues are not reflexive and, instead, produce endogenous shifts in attention. Specifically, Vecera and Rizzo (2006) have described a frontal lobe patient, E.V.R., who did not show facilitated response times following gaze cues and endogenous cues. E.V.R. did, however, show the normal cuing effect for peripheral exogenous cues. Because gaze cue orienting was damaged and peripheral orienting remained intact, it was suggested that gaze cues affect attentional processes in the same way that known endogenous cues do, and this type of orienting is disrupted by frontal lobe damage.

There is also evidence that central arrow cues, which, when informative, have often been used to study endogenous shifts in attention, may cause exogenous orienting. For example, Hommel et al. (2001) observed early facilitation effects with central arrow cues to targets appearing in the cued location for uninformative, as well as counterpredictive, cues. Similar findings have been obtained by Ristic, Friesen, and Kingstone (2002), Tipples (2002), and Gibson and Bryant (2005). Ristic, Wright, and Kingstone (2007) also found reflexive attentional shifts using central arrow and gaze cues but noted that gaze cues may produce stronger reflexive orienting. In contrast, there has been evidence that arrow cues do not always produce facilitation. Jonides (1981) failed to find reflexive orienting to counterpredictive arrow cues. Gibson and Bryant (2005), reexamining arrow cues, found effects similar to those of Jonides (1981) when cue duration and stimulus onset asynchrony (SOA) were relatively brief; when these durations

S. A. Stevens, sara.stevens@utoronto.ca

were increased, however, arrow cues elicited strong reflexive shifts in attention. This result suggests that the effects of arrow cues may be more susceptible to top-down control.

The majority of the aforementioned studies have been based on variations of the standard attention cuing paradigm in which reaction time (RT) is the measure of interest (Posner, 1980). Recent findings obtained by Prinzmetal, McCool, and Park (2005; also Prinzmetal, Park, & Garrett, 2005), however, provide an alternative framework for evaluating the ability of arrow and gaze cues to reflexively orient attention, beyond RT performance alone. According to these authors, the volitional deployment of attention facilitates both the perceptual quality of target representations and the speed of selecting responses made to those targets. Thus, endogenous attention will affect not only the speed of detecting a target, as measured by RT, but also the ability to identify the target, as measured by discrimination accuracy. In contrast, Prinzmetal, McCool, and Park suggested that the exogenous deployment of attention only facilitates response selection and, as such, will only affect RT measures in speed experiments. To test these predictions, they employed a variant of the cuing paradigm in which four peripheral gray boxes were presented, and one turned red, acting as a cue to orient attention. Following the brief presentation of the cue, participants were required to indicate the identity of the target stimulus (either an “F” or a “T”), which appeared in one of the placeholders. The peripheral cue was made to be either informative or uninformative regarding the target location, thus inducing participants to deploy attention endogenously or exogenously. It was found that both the informative and the uninformative cues affected RT. The accuracy of the discrimination task, however, was affected only by informative cues, not by uninformative cues. Although this framework is still being refined, and some challenges have been raised (Pestilli & Carrasco, 2005; Soto-Faraco, Sinnett, Alsius, & Kingstone, 2005), Prinzmetal, McCool, and Park provided considerable support for their framework. These data sets include findings from crossmodal cuing paradigms (which used auditory cues and visual targets), a face discrimination task, the monitoring of eye movements, and examining both informative and uninformative cue types. Using their RT and accuracy paradigms, they consistently found that endogenous attention affected both accuracy and RT measures, whereas exogenous attention only affected the RT measure.

In the present study, we investigated the proposal that central uninformative gaze cues (Experiments 1A and 1B) and arrow cues (Experiments 2A and 2B) generate reflexive shifts of attention by examining their effects on RT and on accuracy performance. We used an experimental task similar to that of Prinzmetal, McCool, and Park (2005) in order to test gaze and arrow cues; we hypothesized that there were three possible patterns that might be observed. First, the cues could affect RT only, indicating that they were purely exogenous. Second, the cues could affect both RT and accuracy, indicating that they elicited an endogenous shift in attention. If this occurred, no inferences could be made regarding exogenous shifts, since the effect on RT might reflect only an endogenous attentional shift or the combination of exogenous and endogenous shifts. Finally, the cues could fail to affect RT or accuracy, indicating that the cues did not alter attention exogenously or endogenously. By going beyond RT-based cuing paradigms, the present study allowed for a converging methods approach to be taken to the issue of how uninformative gaze and arrow cues affect the human visual attentional system.

EXPERIMENTS 1A AND 1B

In Experiments 1A and 1B, we used a cued letter discrimination task in order to determine whether reflexive or volitional orienting is elicited by gaze cues. In order to evaluate the effect of gaze cues on RT, participants in Experiment 1A were asked to respond to the target letter as quickly as possible. In order to evaluate accuracy, participants in Experiment 1B were asked to respond to the target as accurately as possible. A titration process was also applied to Experiment 1B, wherein the font size of the target letter was varied during the practice trials and between blocks, individually for each of the participants. This titration process was applied so that the average accuracy performance of each participant was approximately 75%. If gaze cues cause exogenous shifts in attention, then facilitation should only be observed in Experiment 1A, where RT is measured. If, however, gaze cues elicit endogenous attentional shifts, facilitation should be observed in both Experiments 1A and 1B.

Method

Participants

Forty-one undergraduate students (15 in Experiment 1A, 26 in Experiment 1B) from the University of Toronto participated for partial course credit. All participants were naive to the purpose of the study, gave their informed consent prior to participation, and reported having normal or corrected-to-normal vision. A larger sample was used in Experiment 1B because this was the novel perceptual accuracy experiment, and one of the predicted possible outcomes was a null result.

Apparatus and Procedure

Experiment 1A. The experiment was conducted on a PC with a VGA monitor and a chinrest was used. Each participant was tested in a dimly lit, sound-attenuated room.

The participants were instructed to respond to the target as quickly as possible while maintaining accurate performance. A typical trial sequence is shown in Figure 1A, although in the actual experiment, all stimuli appeared in white on a black background. The initial display consisted of a central gaze cue without pupils (4º in diameter), surrounded by four peripheral boxes (2.5º × 2.5º each) with a circle placeholder (1.15º in diameter) in each one. The boxes were located above, below, to the left, and to the right of the central gaze cue, 3º from fixation. Participants were instructed to remain fixated on the gaze cue for the duration of each trial. After 600 msec, pupils (filled circles, 2.8º in diameter) appeared in the eyes of the gaze cue, directed toward one of the peripheral boxes, and remained on-screen until the end of the trial. The circular placeholder in one peripheral box was then temporarily replaced by the target letter, either an “F” or a “T,” for 50 msec. The participants were instructed to respond to the identity of the target letter; if it was an “F,” they were to press the “z” key on a standard keyboard with their left index finger; if it was a “T,” they were to press the “/” key with their right index finger. Responses were to be made within 2,000 msec, after which the trial would time out. Following any incorrect responses, error feedback was provided by a tone (200 Hz). The participants were also informed that the gaze cue was uninformative of the target location.

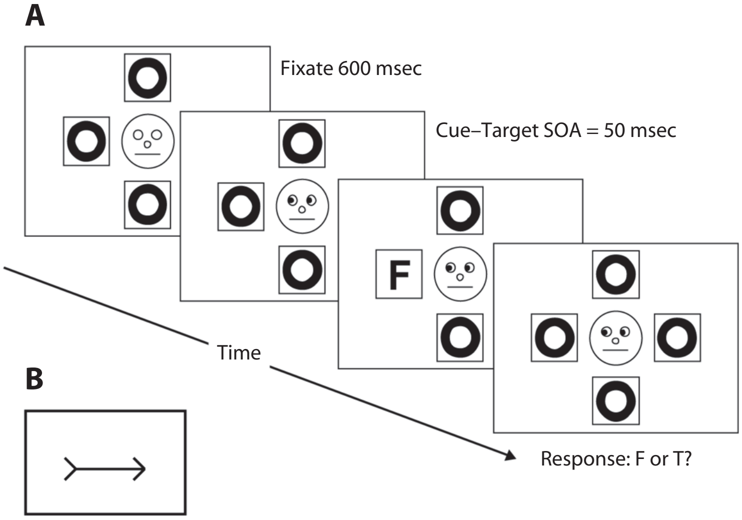

Figure 1. The basic trial sequence used in Experiments 1A–2B. Note that only left gaze cues and targets are shown (A), but gaze and targets to the right, above, and below were equally likely to occur on any trial. Experiments 2A and 2B used a central arrow cue (B), which replaced the gaze cue. Participants in the reaction time experiments were required to respond to the target stimulus as quickly as possible, whereas the participants in the accuracy experiments were required to respond as accurately as possible to the target stimulus. The actual displays of the experimental stimuli were white on a black background. SOA, stimulus onset asynchrony.

Each session consisted of 20 practice trials followed by 256 experimental trials separated into 4 blocks. On every trial, target location, target identity, and gaze direction were determined randomly.

Experiment 1B. Participants in Experiment 1B were instructed to respond as accurately as possible to the target stimulus. The procedure of Experiment 1B was identical to that of Experiment 1A, with the exception that each session began with 75 trials in which the sizes of the target letters were adjusted so that the average accuracy of each participant was approximately 75% (the font size ranged from 14–34 points, approximately 0.40º–0.64º in height). This was followed by 256 experimental trials separated into four blocks. Target size was also adjusted between blocks in order to account for practice effects. As in Experiment 1A, error feedback was provided by a 200-Hz tone following any incorrect responses.

Results and Discussion

Experiment 1A

RTs in Experiment 1A are shown on the left side of Figure 2. Cuing effects were calculated as facilitation scores (i.e., uncued RTs minus cued RTs) on the basis of correct trials, with positive numbers reflecting facilitation at cued locations. It was found that gaze cues facilitated RT. Responses were faster for targets that appeared in the cued location ($M = 538.5$ msec) than for those that appeared in the uncued locations ($M = 551.8$ msec) [$t(14) = 3.3, p < .01$]. Although this experiment emphasized RT, accuracy performance was also measured in order to ensure that there was no speed–accuracy trade-off. There was no difference between the cued ($M = 88.7\%$) and uncued ($M = 87.9\%$) trials [$t(14) < 1$].

Experiment 1B

Performance accuracies (i.e., percentages of correct responses) in Experiment 1B are shown on the right side of Figure 2. Cuing effects were calculated as facilitation scores (i.e., cued accuracy minus uncued accuracy), with positive numbers reflecting facilitation at cued locations. It was found that gaze cues did not enhance accuracy. There was no significant difference in accuracy between the cued ($M = 73.1\%$) and uncued ($M = 73.6\%$) locations [$t(25) < 1$]. For RT, which was calculated only for correct

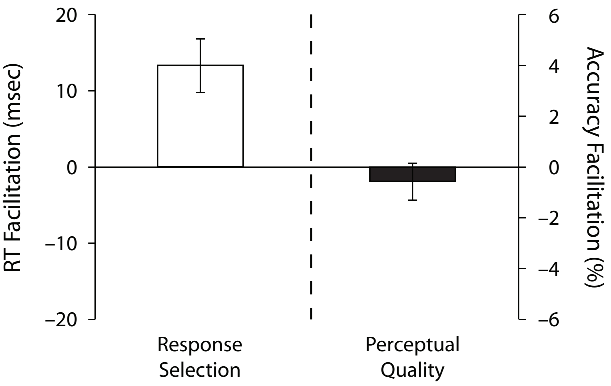

Figure 2. Facilitation scores for Experiments 1A and 1B. For reaction time (RT) measures in Experiment 1A, the cuing effect is the RT difference between the cued trials and the uncued trials, which can be observed on the left side of the graph. Responses were faster for targets at cued locations than for those at uncued locations. For Experiment 1B, the effect of perceptual quality is the accuracy difference between the cued and uncued trials, which can be observed on the right side of the graph. There was no significant effect on accuracy from the attentional orienting elicited by the central gaze cues. Error bars are the standard errors of the mean differences between cued and uncued trials.

trials, there was no significant difference between cued (M = 594.0 msec) and uncued (M = 591.2 msec) trials [$t(25) < 1$]. The absence of an effect on RT precludes the possibility that the cues affected accuracy but that the accuracy effect was traded for speed. Furthermore, note that the reflexive effect on RT from Experiment 1A was not observed here. This point is evaluated in the General Discussion section. The present results support the conclusion that uninformative gaze cues elicit reflexive attentional shifts, since such cues were found to affect RT but not accuracy.

EXPERIMENTS 2A AND 2B

Following the findings of Experiments 1A and 1B, in which uninformative gaze cues were shown to elicit exogenous attentional orienting, in Experiments 2A and 2B, we investigated the type of attentional shifts produced by uninformative arrow cues. Arrow cues were tested in the same way as were the gaze cues in Experiments 1A and 1B, with both RT and accuracy measures.

Method

Experiments 2A and 2B. Forty-two undergraduate students (16 in Experiment 2A, 26 in Experiment 2B) from the University of Toronto participated for partial course credit. Participants were naive to the purpose of the study and gave informed consent prior to their participation. All participants reported having normal or corrected-to-normal vision. As in Experiment 1B, a larger sample was used in the perceptual accuracy experiment.

Apparatus and Procedure. The apparatus and design were similar to those used in Experiments 1A and 1B. The only procedural change was that an uninformative arrow cue was used instead of a gaze cue (Figure 1B). The arrow cue was 2.0º in length and had a head and a tail. The experimental instructions were identical to those of Experiments 1A and 1B. Namely, Experiment 2A emphasized RT performance, and Experiment 2B emphasized accuracy.

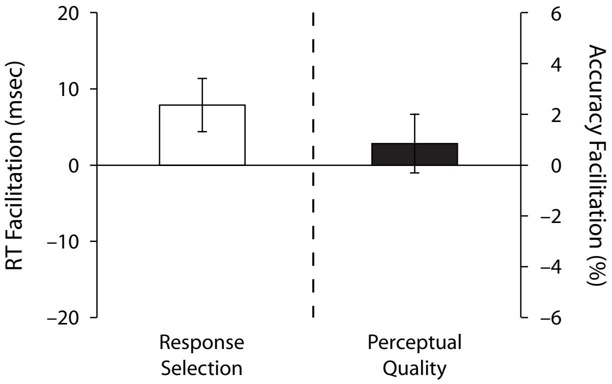

Figure 3. Facilitation scores for Experiments 2A and 2B. Cuing effects were calculated in the same fashion as they were for Experiments 1A and 1B. Central arrow cues facilitated reaction time (RT), as can be observed on the left side of the graph. Responses were faster for targets at cued locations than for those at uncued locations, similar to the results for central gaze cues. Arrow cues had no effect on accuracy performance, as is shown on the right side of the graph. Error bars are the standard errors of the mean differences between cued and uncued trials.

Results and Discussion

Experiment 2A. RTs in Experiment 2A are shown on the left side of Figure 3. As in Experiments 1A and 1B, the cuing effects were calculated as facilitation scores from correct trials. It was found that arrow cues facilitated RT. Responses were faster for targets at cued locations (M = 528.9 msec) than at uncued (M = 536.7 msec) locations [$t(15) = 2.2, p < .04$]. Although we emphasized RT in this experiment, accuracy performance was also measured. There was no difference between the cued (M = 84.4%) and uncued (M = 85.6%) trials [$t(15) = 1.7, p > .1$], indicating that there was no speed–accuracy trade-off in performance.

Experiment 2B. Performance accuracies in Experiment 2B are shown on the right side of Figure 3. Cuing effects were again calculated as facilitation scores. It was found that arrow cues did not enhance accuracy. There was no significant difference in accuracy between cued (M = 73.1%) and uncued (M = 72.2%) locations [$t(25) < 1$]. For RT, which was calculated only for correct trials, there was no significant difference between cued (M = 604.1 msec) and uncued (M = 608.4 msec) trials [$t(25) < 1$], thereby showing no speed–accuracy trade-off. The results of Experiments 2A and 2B support the view that arrow cues produce reflexive shifts in attention, because, as was found with gaze cues, uninformative arrow cues affect RT but not accuracy.

GENERAL DISCUSSION

Despite the extensive research that has been conducted on gaze direction and arrows, there continues to be conflicting evidence in regard to the type of orienting produced by these central cues. Whereas some research supports the production of endogenous attentional shifts (Jonides, 1981; Vecera & Rizzo, 2006), other research provides evidence for exogenous shifts of attention (Driver et al., 1999; Friesen & Kingstone, 1998; Gibson & Bryant, 2005; Hommel et al., 2001; Ristic et al., 2002; Tipples, 2002). By employing the differential effect of exogenous and endogenous attention on RT and accuracy, the present study used a novel approach that went beyond the probabilistic manipulations that have been used in the majority of these previous studies. Experiments 1A and 1B tested the effect of uninformative gaze cues on the measures of RT and response accuracy. Experiments 2A and 2B tested these same measures using uninformative arrow cues. For all of the present experiments, the cues were found to affect processes of response speed but did not affect the quality of perceptual representations. Based on the distinctions between exogenous and endogenous attention described by Prinzmetal, McCool, and Park (2005), our results clearly support the proposal that gaze and arrow cues affect exogenous attentional systems.

While this article was under review, it came to our attention that our results are complemented by another study also under review at the time. Conducted independently from our study, Prinzmetal, Leonhardt, and Garrett (2008) investigated whether gaze cues would affect accuracy and RT performance in target identification tasks in which the target was visually degraded. Consistent with our findings, uninformative gaze cues were shown to produce facilitation effects on RT but not on accuracy. Prinzmetal et al. (2008) also demonstrated that when the gaze cues were predictive of the target location, both RT and accuracy performance were significantly facilitated (shorter RTs and greater accuracy for targets at cued locations). These results and ours from the present study converge onto the conclusion that symbolic cues can elicit reflexive shifts in attention.

It should be noted that our conclusions rely on accepting the null hypothesis in the accuracy experiments. Because of this, we included 26 participants in each of the accuracy experiments, a substantial increase in sample size in comparison with the RT experiments. Indeed, even combining the results of the two accuracy experiments (1B and 2B) failed to show any resemblance of an effect on accuracy [$t(51) < 1$]. Furthermore, Prinzmetal, McCool, and Park (2005) and Prinzmetal et al. (2008) repeatedly observed equivalent null results. These authors went to great lengths to ensure that the null effects of their cues were representative of performance. In particular, both studies found that the cues could affect accuracy performance when the cues were made predictive. Thus, we are confident that the null results of Experiments 1B and 2B are representative of the effects on accuracy performance.

Across our study, and the recent Prinzmetal et al. (2008) study, there was strong evidence that uninformative symbolic cues act in an exogenous manner, since their effects can be seen for RT but not for accuracy. There are, however, studies that have produced dissimilar results. Soto-Faraco et al. (2005) found that uninformative gaze and arrow cues improved perceptual accuracy at cued locations. In their experiments, however, they used detection rather than identification responses, tactile rather than visual targets, and did not strictly control for overall accuracy. In addition, the significant accuracy effect was found only when the gaze and arrow experiments were combined and post hoc analyses were conducted. As was noted earlier, we did the same with the two present accuracy experiments, and the null effect remained. To the more general issue of the validity of the Prinzmetal, McCool, and Park (2005) framework, Pestilli and Carrasco (2005) used briefly presented peripheral Gabor patches and had participants report the orientation of the patch, as indicated by a subsequent response cue. When an exogenous cue preceded the target Gabor patch, Pestilli and Carrasco observed a decrease in the threshold contrast required to achieve a criterion level of performance, suggesting an effect of exogenous attention on perceptual accuracy. There is, however, a memory component in this task, because the Gabor patches disappeared before participants knew which one was the target. It may be that the reflexive cues did not enhance the perceptual quality of the target but, instead, increased the likelihood that the cued Gabor patch was stored in memory. Such a selection bias would cause an increase in performance and the reported increase in contrast sensitivity without affecting the perceptual quality. Under this argument, the effect of exogenous cues on accuracy should be eliminated when this selection bias is removed. Accordingly, Gould, Wolfgang, and Smith (2007), using a paradigm similar to that of Pestilli and Carrasco, demonstrated that exogenous cues cease to affect accuracy measures when the discrimination targets are presented concurrently with high-contrast stimuli that mark their location. Thus, although exogenous cues may bias selection, they do not appear to alter perceptual quality.

These dissociable effects of attention can be understood through models of perceptual discrimination. Typically, the RT and accuracy of perceptual discriminations are accounted for by diffusions models (e.g., random walk models; Swensson & Edwards, 1971) or by accumulator models (Usher & McClelland, 2001) of choice decisions. Such models are used in order to argue that perceptual choices are made by accumulating sensory information over time through a stochastic process, until one choice option has accrued sufficient evidence for a response to be made. Because the accumulation of information is stochastic (i.e., noisy), the reliability of a response increases over time, leading to the classic speed–accuracy trade-off (Fitts, 1954). Of particular relevance to the present article, Usher and McClelland's leaky competing accumulator model provides a useful framework for interpreting our observed effects of attention (Prinzmetal, McCool, & Park, 2005; for a review of differences and similarities between random walk models and accumulator models, see Townsend & Ashby, 1983). According to this model, a pair of accumulators (one for "F" and one for "T") would be associated with each possible target location in our task. Once the target was presented, evidence would begin to build within the accumulators for a response, with the greatest changes likely in the veridical accumulator at the target location. As soon as any accumulator reached a criterion level of evidence, the associated response would be triggered.

The effects of attention within such models are typically attributed to a reduction in the amount of noise (e.g., Graham, Kramer, & Haber, 1985) or in the speed of information accrual (e.g., Shore, Spence, & Klein, 2001) at the attended location, both of which can produce the reductions in RT and increases in accuracy observed with endogenous attention. Since exogenous attention affects only RT, it has been argued that its effect is to increase the likelihood of making a response on the basis of information at the cued location (Prinzmetal, McCool, & Park, 2005). Accordingly, exogenous attention may prime both the "F" and "T" accumulators at the cued location with a set amount of activation, leading to speeded responses without any change in discriminability. As discussed by Usher and McClelland (2001), accumulators are probably leaky, in that accumulated evidence will decay over time. Thus, the contribution of a transient attentional cue should dissipate with longer responses. This possibility is consistent with the observation that the effect of exogenous cues decreases as a task becomes more difficult (Prinzmetal, Zvinyatskovskiy, Gutierrez, & Dilem, in press) and may explain why the cues in our study did not affect RT in the accuracy experiments, in which mean RTs were considerably long. Through the leaky competing accumulator model, we see that endogenous attention increases the quality of perceived information, whereas exogenous attention speeds the process of making a decision independently of which response is made.

In conclusion, the present study employed the dissociable effects of exogenous and endogenous shifts of attention on the measures of RT and accuracy to reveal that central cues can generate exogenous shifts in attention. Although symbolic cues can be used to help volitionally guide the deployment of attention, these cues—specifically, gaze and arrow cues—also alter attention reflexively. Furthermore, the employed measures used in the present study add to the current criterion used to distinguish between exogenous and endogenous orienting. Namely, the influence of task demands and response requirements provides further insight into the differences between these forms of attention.

AUTHOR NOTE

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