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Attention to arrows: Pointing to a new direction

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It was long believed that central arrows needed to be spatially predictive to produce a shift in spatial attention. Recent evidence indicates, however, that central spatially nonpredictive directional cues, like arrows, will trigger reflexive shifts in attention. We asked what this recent discovery means for past studies that used predictive directional cues such as arrows. Our findings indicate that predictive arrows produce attention effects that greatly exceed the individual or summed effects of reflexive orienting to nonpredictive arrows and volitional orienting to predictive numbers. This suggests that the especially large effect produced by predictive arrows reflects an interaction between reflexive and volitional orienting. Given the broad application of the predictive arrow cueing paradigm in both past and current research, the present data shed new light on a wide range of investigations, from psychophysical studies of basic attention to behavioural and neuroimaging studies of cognition and social development.

In his seminal book "Cognition and Reality" Ulric Neisser (1976) observed that cognitive psychology had failed to deliver on its pledge to provide an understanding of human behaviour that could produce extensions of its principles beyond the specific paradigms in which they were derived. One response to this observation was the development of, and advocacy for, a "model task" research approach (Posner, 1978). This approach assumes that there are stable and isolable underlying psychological processes whose operation can be best revealed in highly controlled experimental environments. In essence experimental tasks are conceived as the "preparation" that will bring underlying psychological processes to the fore. Without question one of the most significant applications of this model task approach has been the cueing paradigm. Here human attention is conceived as a limited-capacity process that can be controlled either *exogenously* (reflexively), by external stimuli in the environment, or *endogenously* (volitionally), by internal changes in the goals and intentions of an individual. Two distinct versions of the cueing task have been developed: a *peripheral cueing task* designed to tap into exogenous attentional orienting, and a *central arrow cueing task* designed to tap into endogenous attentional orienting.

In the peripheral cueing task the characteristics of reflexive attention are thought to be revealed by

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requiring subjects to detect a target light at a peripheral location that was, or was not, brightened. Importantly, the brightening of a peripheral location, which is called the cue, does not predict spatially where the target stimulus will appear. As a result, any spatial effects of the cue on target detection are attributed to the reflexive orienting of spatial attention. The standard result is that response time (RT) to the target at the cued location is facilitated when the target appears within 300 ms of the cue, after which RT is inhibited at the cued location relative to an uncued location, reflecting the inhibition of return (IOR) phenomenon.

In the central arrow cueing task, the characteristics of volitional orienting are thought to be revealed by requiring subjects to detect a target light at a peripheral location that was, or was not, pointed at by a central arrow. Importantly, the arrow, which is called the cue, does predict spatially where the target stimulus is likely to appear. Because spatial effects of the central arrow are assumed to occur only when the arrow is spatially predictive, the observed attention effects are attributed to volitional orienting of spatial attention (Jonides, 1981). The standard result is that RT to the target at the cued location is facilitated for all cue–target intervals exceeding 300 ms with no evidence of IOR emerging.

Application of the model task

It is fair to say that the cueing paradigm has been at the very centre of modern investigations of human attention, with this paradigm being applied in all the major disciplines of cognitive and social neuroscience to investigate the brain mechanisms that subserve human attention—for example, animal models, behavioural studies, patient studies, and functional neuroimaging. For example, using the peripheral cueing task, behavioural studies with healthy and atypically developing children have mapped out the developmental time-course of exogenous attention (e.g., Brodeur, Trick, & Enns, 1997). Lesion studies with patients have identified brain structures that are specific and necessary to reflexive orienting, and functional neuroimaging studies with event-related potentials (ERPs), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI) have been applied to identify the brain structures that mediate reflexive attention (see Corbetta & Shulman, 2002, for a recent review).

Similarly, using the central arrow cueing task, behavioural studies with healthy and atypically developing children have mapped out the developmental time-course of endogenous attention over the lifespan (e.g., Goldberg, Maurer, & Lewis, 2001). Lesion studies with patients have identified the brain structures that are specific and necessary to volitional orienting, and functional neuroimaging studies with ERPs (e.g., Nobre, Sebesteyen, & Miniussi, 2000), PET (e.g., Koski, Paus, Hofle, & Petrides, 1998), and fMRI (e.g., Hopfinger, Buonocore, & Mangun, 2000) have been applied to identify the brain structures that mediate voluntary orienting.

Applications of the cueing paradigm, such as those cited above, are grounded on the assumption that each task isolates either reflexive or volitional orienting. Specifically, the peripheral task is assumed to isolate reflexive attention because orienting occurs when the cue is spatially *nonpredictive*. Conversely, the central arrow task is assumed to isolate volitional attention because orienting is thought to occur only when the cue is spatially *predictive*. Recent research, however, has demonstrated that in the central arrow task, attentional orienting occurs even when the cue is spatially nonpredictive. For example, Ristic, Friesen, and Kingstone (2002; see also Hommel, Pratt, Colzato, & Godijn, 2001; Tipples, 2002) asked preschool children and adults to detect targets appearing to the left or right of a central nonpredictive arrow cue. The results indicated that for both groups, targets were detected most quickly at the location indicated by the nonpredictive arrow cue. This was true regardless of whether the cue–target stimulus onset asynchrony (SOA) was very brief (less than 200 ms) or relatively long (600 or 1,000 ms). Similar findings emerge for other central nonpredictive directional stimuli, such as gaze direction (e.g., Driver et al., 1999;

Friesen & Kingstone, 1998), finger pointing (Langton & Bruce, 2000), head orientation (Langton & Bruce, 1999), and words with a spatial direction (e.g., "left" or "right"; Hommel et al., 2001). Thus, there is a large and growing body of evidence indicating that reflexive orienting is triggered by central spatially nonpredictive directional cues, such as arrows. Note that the attentional effects that are observed with central attentional cues are labelled *reflexive* because the attentional orienting is driven rapidly by task-irrelevant cues that are spatially nonpredictive (see Gibson & Bryant, 2005, for a recent review).

The present study

The fact that central nonpredictive arrows produce reflexive shifts of attention has important implications for the interpretation of the data from previous studies, like those outlined above, which have used the predictive central arrow cueing task to study volitional attention. Specifically, one possibility is that these studies may have been measuring reflexive attention rather than volitional attention. A second possibility is that previous investigations may have been measuring volitional attention alone when a central arrow cue is spatially predictive—that is, only volitional orienting is engaged when an arrow cue is predictive. This is the conventional wisdom. A third possibility is that a central spatially predictive arrow engages both reflexive and volitional attention, with these effects combining in an additive fashion. A fourth possibility is that a central spatially predictive arrow engages both reflexive and volitional attention, with these effects combining in an interactive manner.

The aim of the present study is to address these four alternatives. To accomplish this one needs to introduce a central cue that does not trigger reflexive shifts of attention when it is nonpredictive (we used a nonpredictive number, NN) and does engage volitional attention when it is predictive (a predictive number, PN). These effects can then be compared against the reflexive attentional effects of an arrow cue when it is nonpredictive (a nonpredictive arrow, NA) and the attentional effects of an arrow cue when it is predictive (a predictive arrow, PA). These four conditions are illustrated in Figure 1. In this way, one can determine whether a central PA engages: (a) only reflexive attention (PA = NA); (b) only volitional attention, as has been assumed in the past (PA = PN); (c) the summation of reflexive and volitional attention (PA = NA + PN); or (d) the interaction of reflexive and volitional attention (PA = NA × PN).

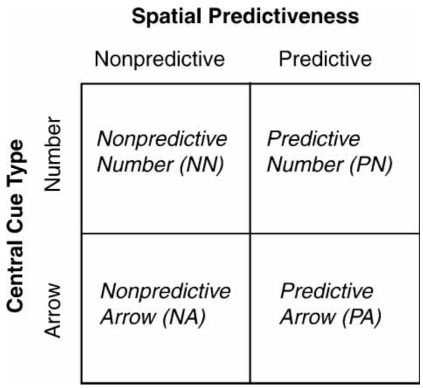

Figure 1. *Experimental conditions. A 2 × 2 matrix of the balanced within-subjects design used in the study, with cue type (arrow; number) and cue predictiveness (nonpredictive; predictive) included as factors.*

Method

Participants

A total of 48 undergraduates were recruited. Each completed two sessions on separate days, with each session lasting less than one hour.

Stimuli and design

The stimuli were black on a white background. Arrows (3.3° long) were created by combining a straight line (2.1°) with an arrowhead and an arrowtail attached to the ends. Numbers subtended 3.3°(height) × 2°(width). A fixation point subtending 1° appeared at the centre at the beginning of each trial. The target was a black asterisk, measuring 0.9°, which appeared 6.5° to

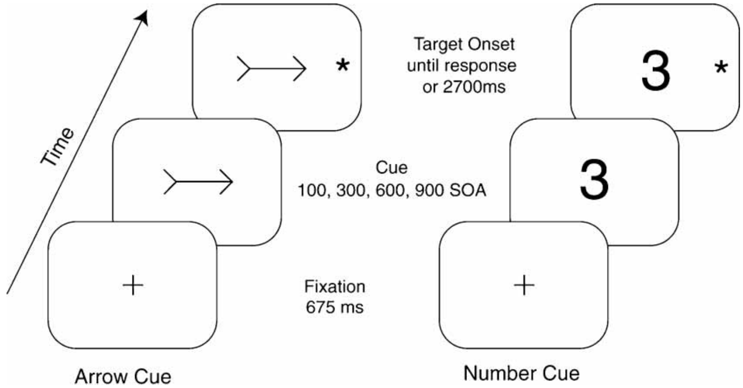

Figure 2. *Illustration of stimuli and sample sequence of events. At the start of each trial, a fixation point appeared on the screen for 675 ms. Then an arrow cue (pointing left, right, up, or down), or a central number cue (1, 3, 6, 9) appeared. The target appeared to the left, right, up, or down 100, 300, 600, or 900 ms after cue onset. Both the cue and the target remained on the screen until response was made or 2,700 ms had elapsed, whichever came first. The intertrial interval was 525 ms. Note that stimuli are not drawn to scale.*

the left/right of centre. The stimuli and a sample timing sequence are illustrated in Figure 2.

The study was a balanced within-subject design with each participant completing each of the four Cue Type × Cue Predictiveness conditions. The order of cue type (arrow; number) and cue predictiveness (nonpredictive; predictive) was counterbalanced between sessions and observers. Each participant completed a total of 1,920 experimental trials, 480 for each of the four cue type–cue predictiveness conditions. A total of 10 practice trials were run at the beginning of each condition.

There were four possible target locations: left, right, up, down. In the nonpredictive cue conditions, the target appeared at the cued location 25% of the time. In the remaining 75% of trials the target appeared with equal probability in each of the remaining locations. In the predictive cue conditions, the target appeared at the cued location 80% of the time and with equal probability in each of the remaining locations. For predictive arrow cues the most likely target location was indicated by the arrow's direction. For predictive number cues, a "1" predicted a target at the top, "3" a right target, "6" a bottom target, and "9" a left target.[1]

Procedure

Participants were seated and centred with respect to an eye-level computer screen placed approximately 57 cm away. The start of every trial was signalled by a 675-ms presentation of a central fixation cross. Then a central cue appeared. An asterisk demanding a simple detection response appeared at one of the four target locations after 100, 300, 600, or 900 ms. For each condition the cue and the cue–target SOAs varied equally and randomly. Both the cue and the target remained on the screen until a response was made or 2,700 ms had elapsed, whichever came first. The intertrial interval was 525 ms. RT to press the spacebar was measured from target onset. On

[1] To ensure that central nondirectional number cues represented a valid baseline we ran a pilot experiment with 24 additional participants who responded to the spatially nonpredictive and predictive central number cues used in the present study. Half of the participants received nonpredictive digits first, and vice versa. Each completed 960 trials: 480 for each condition. Errors were less than 1.5% of the data. Analyses of variance (ANOVAs) on RT revealed no effect of cue in the nonpredictive condition ($F < 1$) and a significant effect of cue in the predictive condition, $F(1, 23) = 30$, $p < .0001$, with shortest RTs at the cued location. When RTs in the nonpredictive and predictive cue conditions were compared in the same ANOVA, there was a significant interaction between cue predictiveness and validity, $F(1, 23) = 35.59$, $p < .0001$.

approximately 6% of all the trials a target was not presented. These catch trials were dispersed randomly across the trials.

Before starting a cue condition all participants were explicitly told, and it was confirmed that they understood, the spatial predictiveness of the cue condition. All participants were asked to respond as fast and as accurately as they could and to maintain central fixation throughout the experiment. Note that because it is well established that eye movements do not occur in tasks where suprathreshold targets must merely be detected, participants' eye movements were not monitored.

Results

Anticipations (RT < 100 ms), timed-out responses (RT $> 1{,}000$ ms), and false alarms were classified as errors and were excluded from the analysis. Response errors occurred on less than 1% of all the target trials and false alarms on less than 2.1% of the catch trials. There were no significant differences in error rates between cue conditions ($p > .05$). Mean RTs and their associated error rates for each of the conditions are presented in Table 1 and illustrated in Figure 3 as a function of SOA and validity. Figure 4 plots the difference between uncued and cued RT for each condition.

When the cues did not predict the target location ($p = .25$), as shown in Figures 3A and 3C, one sees that spatially nonpredictive number cues failed to trigger an orienting response whereas nonpredictive arrow cues were effective in triggering reflexive attention to the cued location at all SOAs. A three-way within-subject ANOVA with cue type, validity, and SOA confirmed this observation with the highest order interaction emerging between cue type and validity, $F(1, 47) = 23.24$, $p < .0001$. There was no main effect of cue type ($F < 1$), indicating that the two central stimuli were matched for RT overall.

When the cues predicted the target location ($p = .8$), as shown by Figures 3B and 3D, one sees that both spatially predictive number cues and spatially predictive arrow cues produced attentional orienting to the cued location, although the attention effect was always much larger for predictive arrows. A 3-way ANOVA with cue type, validity, and SOA confirmed these observations returning the highest-order significant interaction between cue type and validity, $F(1, 47) = 72.5$, $p < .0001$. Again, there was no main effect of cue ($p > .1$), indicating that the conditions were well matched in overall RT.[2]

Figure 4 plots the magnitude of the attention effects for each of the four cue conditions across all SOAs. Note that the magnitude of the attention effect for a predictive arrow far exceeds the magnitude of the volitional attention effect for a predictive number, and it also greatly exceeds the magnitude of the reflexive attention effect for a nonpredictive arrow. Moreover, the magnitude of the attention effect for a predictive arrow greatly exceeds the sum of the volitional attention effect for a predictive number and the reflexive attention effect for a nonpredictive arrow.

These observations were verified by an omnibus four-way within-subjects ANOVA with cue predictiveness, cue type, validity, and SOA as factors. The highest order interaction that reached significance was a three-way interaction between cue type, cue predictiveness, and validity, $F(1, 47) = 19.23$, $p < .0001$, reflecting that spatially predictive arrow cues produced significantly larger orienting effects. Indeed, when one compares the magnitudes of the predictive arrow effect against the summed average of the predictive number and nonpredictive arrow conditions, one finds a highly reliable difference between the two conditions, $F(1, 47) = 20$, $p < .0001$, confirming

[2] Although we have counterbalanced the presentation order of the four conditions, one might argue that the key interactions are due to the orienting effects being contaminated by carryover effects between conditions. To address this concern we performed the same statistical analysis as before but included only the data for those participants who received each of the experimental conditions first, thus eliminating any potential confound of carryover effects. The results of this between-subject analysis returned the same significant interaction effects as before, thus eliminating any concerns regarding within-subject cross-condition contamination.

Table 1. *Reaction times and percentage of error according to cue type and predictiveness, for different cue–target stimulus onset asynchronies*

		Arrow						*Number*					
		Nonpredictive			*Predictive*			*Nonpredictive*			*Predictive*		
SOA	*Condition*	*M*	*SD*	*%E*	*M*	*SD*	*%E*	*M*	*SD*	*%E*	*M*	*SD*	*%E*
100-ms	Cued	343.2	64.2	0.7	342.3	56.7	0.4	347.4	63.5	0.7	347	57.0	0.9
	Uncued	352.1	61.8	0.9	366.7	72.0	0.6	343.9	57.1	1.0	348	58.3	0.5
300-ms	Cued	323.2	59.6	2.7	311.5	49.7	2.7	324.7	55.6	2.2	321.5	50.2	2.5
	Uncued	332.0	57.8	2.7	354.6	55.3	2.9	324.0	49.3	2.9	334.1	57.1	3.3
600-ms	Cued	306.8	46.0	0.8	299.3	41.5	1.1	308.6	44.9	1.1	307.4	46.2	1.4
	Uncued	318.5	48.0	1.0	337.7	44.0	0.7	313.6	45.9	0.9	322.1	45.2	1.9
900-ms	Cued	313.0	48.5	0.4	308.2	40.1	0.7	316.2	46.3	1.1	311.1	41.0	1.3
	Uncued	325.1	44.2	1.2	339.4	48.3	1.0	319.8	45.5	1.1	325.6	39.3	1.0

Note: SOA = stimulus onset asynchrony. %E = percentage of error.

that the cueing effect for predictive arrows was significantly greater than the sum of the predictive number and nonpredictive arrow effects.[3]

Discussion

Our experiment examined the attentional orienting effect elicited by spatially predictive central arrow cues relative to the attentional effect elicited by spatially nonpredictive arrow cues and spatially predictive number cues. Four possible experimental outcomes were entertained. One was that the orienting effect produced by a predictive arrow was purely reflexive in nature. If this were the case, then the orienting effect of a predictive arrow would equal the orienting effect produced by a nonpredictive arrow. The results of our study did not support this hypothesis, as the orienting effect of a predictive arrow greatly exceeded the reflexive orienting effect of a nonpredictive arrow (PA > NA).

A second possibility was that the orienting effect produced by a predictive arrow was solely volitional in nature. If this were the case, then the orienting effect of a predictive arrow would match the orienting effect produced by a predictive number. The data did not support this hypothesis. The orienting effect of a predictive arrow greatly exceeded the orienting effect of a predictive number (PA > PN). This suggests that the orienting effect for a predictive arrow cue is not solely volitional in nature, as has been assumed.

A third possibility was that the orienting effect produced by a predictive arrow reflected the additive combination of reflexive orienting to a nonpredictive arrow and volitional orienting to a predictive number. Once again, the results of our study did not support this hypothesis, as the attention effect produced by a predictive arrow greatly exceed the sum of reflexive and volitional orienting (PA > NA + PN).

The fourth possibility was that the orienting effect produced by a predictive arrow reflected an interaction between reflexive and volitional orienting (PA = NA × PN). Our data support this hypothesis with the effect of a predictive arrow greatly exceeding the individual and summed measures of reflexive and volitional orienting.

We are mindful of the fact that these interpretations and conclusions are valid to the extent that

[3] A recent study by Fisher, Castel, Dodd, and Pratt (2003) reported that numerically low number cues (e.g., 1) trigger an attentional shift toward the left field, and numerically high number cues (e.g., 9) trigger a shift to the right field. Although we never observed orienting effects with nonpredictive number cues, we analysed RTs for the nonpredictive number cues as a function of SOA and target position. This analysis revealed no significant interaction involving cue type and target position, $F(9, 423) = 1.4$, $p > .15$. This was also true for the pilot experiment (see Footnote 1), $F(9, 207) = 1.79$, $p > .05$.

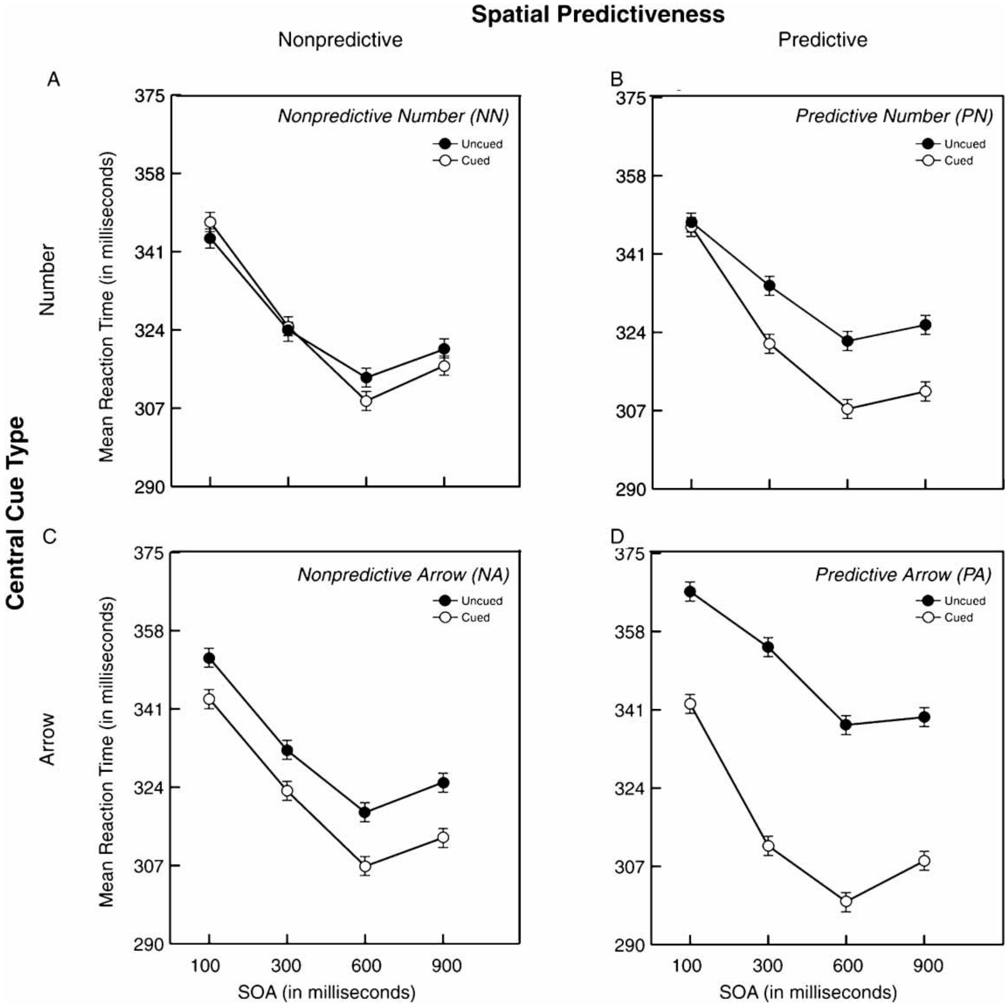

Figure 3. *Figure 3 shows mean response times (RTs) plotted as a function of cue–target stimulus onset asynchrony (SOA) and cue validity for each of the four experimental conditions. Figures 3A and 3B illustrate mean RTs as a function of SOA and cue validity for nonpredictive number and predictive number conditions, respectively. Figures 3C and 3D illustrate mean RTs as a function of SOA and validity for nonpredictive arrow and predictive arrow conditions, respectively. Error bars depict standard error of the difference of the means.*

nonpredictive arrow cues and predictive number cues provide adequate measures of reflexive and volitional orienting, respectively; and that these two cues are well matched for comparison with the predictive arrow cues. We address these issues below.

To what extent can a nonpredictive arrow cue be considered to engage reflexive spatial orienting? The standard criterion for reflexive spatial orienting is that it occurs rapidly in response to a stimulus that is task irrelevant and uninformative with regard to where in space a target is likely to appear. The best instance of this has historically been an uninformative peripheral abrupt onset cue that is understood to trigger a rapid shift of attention to the stimulated location as evidenced by the performance enhancement that occurs within 100 ms of cue onset. By these standard

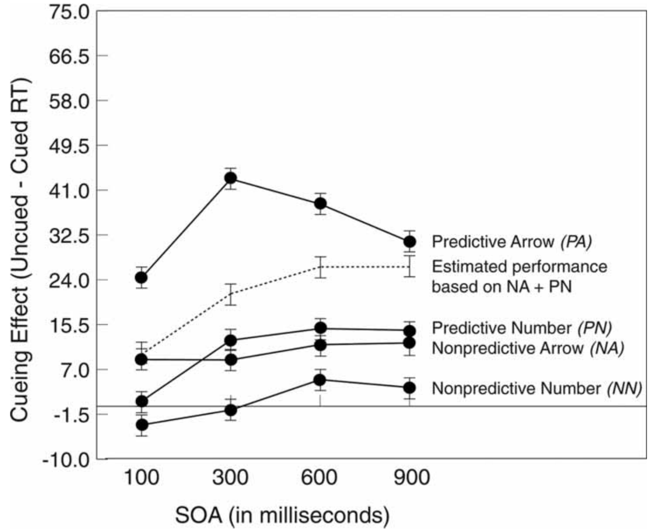

Figure 4. *Magnitudes of attentional orienting for each condition. Figure 4 shows the magnitude of attentional orienting triggered by each of the four conditions. Dotted line illustrates the magnitude of attentional orienting that would be expected by the summation of reflexive (nonpredictive arrow, NA) and volitional (predictive number, PN) effects. Error bars depict standard error of the difference of the means.*

criteria the uninformative arrow cue produces reflexive attention effects. Like the peripheral cue, the arrow is task irrelevant, is spatially uninformative with regard to the target location, and triggers an attention shift to the cued location within 100 ms. Thus, according to the traditional definition of reflexive spatial orienting, the evidence is that a nonpredictive arrow cue engages reflexive spatial attention. Moreover, because the cue is physically identical to the predictive arrow cue and only differs in terms of its predictive value, it is ideally suited as a comparison stimulus.

To what extent can a predictive number cue be considered to engage volitional spatial orienting only? The standard criteria for volitional spatial orienting is that it reflects the goals of the individual, such that the stimulus cue does not produce a shift in attention when the cue is nonpredictive and that it does produce a shift when the cue is spatially predictive (e.g., Jonides, 1981). We employed a spatially nondirectional number stimulus to measure volitional orienting, both testing and finding that this stimulus would only produce a shift in spatial attention when it was spatially predictive.

The physical differences between the predictive numbers and arrow cues, on the other hand, bring into question whether these two cues afford participants the same opportunity to engage volitional orienting. Specifically, one might reasonably argue that extracting the predicted target location from a number cue would take longer than from an arrow cue because the number–location mapping was relatively arbitrary.[4] This idea that number and arrow cues engage the same volitional attention process, but with different time courses, predicts that while the emergence of a volitional attention effect will be delayed for number cues relative to arrow cues, the magnitude of the two attention effects will ultimately converge. Looking at Figure 4, one can see that the attention effect for number cues was indeed delayed. However, the number cue effect quickly reached its maximum magnitude by the 300-ms cue–target SOA.

[4] To be fair, the mapping was not completely arbitrary in the predictive number condition. The lowest number always predicted the top location, and as the numbers increased the predicted target location progressed in a clockwise fashion.

After this SOA the number cue effect held steady for the next 700 ms. The predictive arrow cue effect emerged more rapidly, but like predictive numbers, predictive arrows produced their maximum attention effect at the 300-ms SOA. Thus, while the attention effect for predictive numbers began later than the effect for predictive arrows, the two effects peaked at the same point in time and held relatively steady thereafter. In other words, the data disagree with the proposal that the delayed attention effect for predictive numbers would grow and converge with the attention effect for predictive arrows, which was more than double the attention effect for predictive numbers across all SOAs.

In summary, the data support the idea that nonpredictive arrow cues and predictive number cues provide accurate and reliable measures of reflexive and volitional orienting, respectively, and that these cues are well matched as comparison stimuli for predictive arrow cues. The fact that predictive arrows produce an attention effect that is significantly greater than either of these two effects alone, and their sum, suggests that predictive arrows engage attentional orienting that is not merely reflexive and/or volitional in nature. Given the evidence that the directionality of a predictive arrow cue affords reflexive orienting, and its spatial predictiveness furnishes volitional orienting, the data from the present investigation suggest that the orienting effect of a predictive arrow reflects an interaction between reflexive and volitional attention.

This conclusion sheds new light on the many past and present investigations over the last three decades that have used the predictive arrow cue task as a way of engaging and examining the processes of volitional attentional orienting. To wit, the present investigation suggests that studies such as those highlighted in the Introduction may have been measuring a unique interaction between reflexive and volitional attention, rather than volitional attention alone. Thus while we and other investigators may have unintentionally collected a great deal of data in the past on how reflexive and volitional attention interact, it appears that we may not as yet have a full understanding of the individual components that make up this interaction. Indeed, the present study suggests that many fundamental questions in human attention remain unanswered. What brain mechanisms subserve volitional orienting alone? What is the nature of the dichotomy between reflexive and volitional attention? What factors determine when these networks of attention operate independently and when they interact? Does one type of orienting dominate the nature of the interaction? Discovering the answers to questions like these will not only enhance our understanding of human attention, but it will also help researchers to understand the vast amounts of data that have been collected using the predictive central arrow cue task.

Finally, we would like to propose that the present study provides a solid theoretical and empirical basis for future studies of reflexive and volitional attention. In the past, comparisons between these two forms of orienting have typically involved reflexive attention being triggered by an abrupt onset of a peripheral nonpredictive stimulus and volitional attention being engaged by the presentation of a spatially predictive central arrow stimulus. The fundamental procedural differences (a peripheral cue vs. a central cue) that were confounded with the type of attention that investigators were trying to measure (reflexive vs. volitional attention, respectively) presents an inevitable complication that fundamentally compromises attempts to make direct comparisons between reflexive and volitional orienting (e.g., Vecera & Rizzo, in press). The data from the present study suggest that a nonpredictive directional stimulus, such as an arrow, presented at fixation triggers reflexive orienting, and a predictive nondirectional stimulus, such as a number, presented at fixation, can be used to engage volitional orienting. Manipulations such as these will permit researchers to compare and contrast the behavioural and neural mechanisms of these two types of orienting on equal footing. This idea combined with a growing recognition that attention research needs to extend beyond the confines of an impoverished laboratory setting (e.g., Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003) bodes well for significant new strides in the future for attention research.

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