The role of attentional set on attentional cueing and inhibition of return

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When people know what critical feature will define a target for a block of trials, only cues that share a critical feature with targets will capture attention. This result is taken to mean that attentional control settings play a role in target identification. To examine the validity of the attentional control settings hypothesis while controlling for potential sensory artifacts, the first experiment compared conditions in which the critical target features were either blocked or randomized. The results indicated that all cues captured attention in the random conditions, but only cues that matched targets captured attention in the attentional set condition. The second experiment used the same two conditions to examine the effect of attentional set on inhibition of return (IOR). No differences were found between the blocked and random conditions, indicating that attentional set did not impact the IOR effects. Overall, the results indicate that (1) the previous findings of attentional set effects were not due to an artifact of the method, and (2) attentional set influences and early occurring attentional cueing effects but not later-occurring IOR effects.

Attentional capture refers to the notion that attention is involuntarily allocated to certain stimuli that appear in the visual field. Because of the importance attentional capture has with regard to the selection of what portion of the visual field is processed further, it is critical to understand factors that influence attentional capture.

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field will be processed in detail, there has been considerable interest over the past several years concerning the stimulus attributes that are critical in attentional capture. Initial work by Yantis and Jonides (1984) indicated that abrupt changes in luminance in the periphery tended to automatically capture attention. Later, this notion was modified by Yantis and Hillstrom (1994) as they found evidence that attention is captured by the abrupt appearance of a new object, rather than by a change in luminance per se. In addition, research by Theeuwes (1992, 1994) has indicated that any salient feature difference in a visual display, such as a suprathreshold difference in colour or form, may produce attentional capture.

There is evidence, however, that attentional capture may not be as automatic and involuntary as first thought. Rather, there are experimental results suggesting that attentional capture is heavily influenced by top-down processes. More specifically, it appears that people have considerable control over how their attention will be allocated depending on the goals of the task they have to perform. In a series of experiments, Folk, Remington, and colleagues (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994) have used a task in which participants are asked to make a feature judgement about a target object (e.g., is the target a “+” or a “=”?). Importantly, the participants are given information about a critical stimulus attribute of the target, such as whether the target would be a white stimulus presented in isolation (an onset target) or a single red stimulus among distracting white stimuli (a colour target) (Folk et al., 1992). Prior to the presentation of the target, either a white onset cue is presented in isolation or a single red cue is presented among three white cues. The pattern of results consistently found by Folk, Remington, and colleagues is that onset cues only captured attention when participants expected an onset target, and colour cues only captured attention when participants expected a colour target. Based on these and other findings, Folk, Remington, and colleagues suggest that cues will only produce attentional capture if they have attributes consistent with the attentional control settings of the participant. If the cues do not share any attribute with the attentional set, then no attentional capture would take place despite the fact the cues might be defined by a large luminance increment, a new object, or another very salient feature difference (see Yantis, 1996 for a review of attentional capture; and Gibson & Jiang, 1998 for a recent study on attentional capture).

Although Folk, Remington, and colleagues obtained a very consistent pattern of results across experiments and studies (i.e., attentional capture only when cues match targets), it is possible that this pattern of results is at least partly due to the paradigm itself and not to any attentional control settings. This possibility arises because participants never completed the experiments in conditions prohibiting the use of attentional control. Thus, it is not clear whether the pattern of results is due to the development of an attentional set or simply due to stimulus specific artifacts of the experiment. For example, several
investigators have found little, if any, sub-threshold facilitatory interaction between colour and luminance stimuli, although such facilitation is seen within sets of colour stimuli alone or within sets of luminance stimuli alone (e.g., Mullen & Losada, 1994; Switkes, Bradley, & De Valois, 1988; Vimal, 1998). Such results have led some researchers to conclude that separate pathways exist for the detection of colour and luminance (Cole, Stromeuer, & Kronauer, 1990; Mullen & Losada, 1994). Thus, in the experiments of Folk, Remington, and colleagues, low-level visual processing might enhance the visibility of luminance targets only in the presence of a luminance cue, and of colour targets only in the presence of a colour cue. The first purpose of the present study is to provide the proper control condition from which it is possible to determine whether the pattern of results found by Folk, Remington, and others is due to stimulus factors or attentional control settings.

To address this important concern, our first experiment will replicate and extend the procedure of Experiment 3 of Folk et al. (1992). In one condition, onset cues and colour cues are equally likely to appear on any given trial; however, onset targets and colour targets will be blocked (blocked condition). Thus, participants will be informed about whether they will have to make the discrimination response of an isolated onset target or for a red colour target. The other condition will be exactly the same except that onset and colour cues and onset and colour targets will be randomly presented, and participants will be told to expect either target on any given trial (random condition). If attentional control settings did indeed produce the results reported by Folk et al., then we should replicate their pattern of results when the targets are blocked, and should find that both onset and colour cues produce attentional capture with both onset and colour targets when the targets are randomized. If stimulus specific factors were responsible for Folk et al.’s results, then we should obtain the same pattern of results in both the blocked and randomized conditions. Thus, our first experiment constitutes a stronger test of the notion of attentional control settings.

The second purpose of the present study is to extend the examination of attentional control settings beyond short-lived facilitatory effects to longer lived inhibitory effects. Posner and Cohen (1984) were the first to report that the abrupt onset of a cue stimulus in the periphery would differentially affect the time to respond to a target stimulus at the same location depending on the temporal relationship between the cue and target. If the target appeared briefly after the onset of the cue (less than 300 ms), then a target at the valid location would be responded to more quickly than a target at an invalid or novel location. This facilitation effect was assumed to occur because the onset of the cue involuntarily capture attention at that location and thus the target appeared at a currently-attended-to location. However, Posner and Cohen also found that if a longer temporal delay occurred between the onset of the cue and onset of the target (greater than 300 ms), the opposite pattern of results was found. In this case, targets that appeared at the valid location yielded longer response times
than did targets at invalid locations. This inhibitory effect has come to be known as inhibition of return (IOR) and is generally thought to reflect the output of an attentional mechanism that biases attention from returning to previously attended locations. The notion is that the long delay allows participants to move their attention from the valid location back to the fixation location, and a subsequent movement of attention back to valid location is inhibited.

Even if attentional set can influence facilitatory cueing effects at short stimulus onset synchronies (SOAs), it is important to understand the extent to which these control settings affect other aspects of attention—such as IOR. Pratt, Kingstone, and Khoe (1997) suggested that IOR is an involuntary system. If this view is correct, then one might expect attentional set to have little influence over IOR. To examine the role of attentional control settings on IOR, the same two conditions from the first experiment will be used (blocked and randomized targets) except that the SOA will be changed from the 150 ms used in the first experiment (and by Folk et al., 1992) to 850 ms. An SOA of 850 ms is typical of the delay between cues and targets that yield IOR effects (e.g., Posner & Cohen, 1984; Pratt et al., 1997). It should be noted that there has been some debate as to whether or not IOR can be found in a discrimination task (e.g., Klein & Taylor, 1994; Terry, Valdes, & Neill, 1995). However, there now appears to be considerable evidence from several different types of tasks that IOR does occur with discrimination responses (e.g., Chasteen & Pratt, 1999; Cheal, Chastain, & Lyon, 1998; Fuentes, Vivas, & Humphreys, 1999; Kingstone & Pratt, 1999; Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Pratt, 1995; Pratt & Abrams, 1999; Pratt et al., 1997). Thus, the Folk et al. (1992) paradigm is likely to produce IOR effects, so a comparison between the random set (randomized targets) and attentional set (blocked targets) conditions should determine what effect attentional control settings have on IOR.

**EXPERIMENT 1**

Experiment 1 was designed to determine the extent to which the findings reported by Folk, Remington, and others is due to attentional control or to stimulus specific interactions. As mentioned earlier, this will be done by comparing results from a condition in which the participants can set their attention for a particular target to results from a condition in which the attentional set should include all possible target stimuli.

**Methods**

*Participants.* Twenty undergraduate students from the University of Toronto participated in this experiment in return for course credit. Ten participants served in the attentional set condition, and the other ten served in the random condition.
**Apparatus and procedure.** Participants were seated directly in front of a computer monitor and standard QWERTY keyboard. The viewing distance, 44 cm, was held constant by a head/chin rest. The room was dimly lit by an incandescent light source.

The trial sequence was very similar to that used by Folk et al. (1992). Each trial began with an initial display of a central fixation box and four peripheral boxes (above, below, to the right, and to the left of the fixation box) presented in light grey (5 cd/m², IBM colour 8) on a black background (0 cd/m², IBM colour 0). Each box subtended 1.1° of visual angle and the peripheral boxes were centred 4.9° from the centre of the fixation box. After 500 ms, the centre box blinked off for 100 ms and then returned. Then, following a variable foreperiod of 1000–1400 ms (in 100 ms increments), a cue was presented for 50 ms and then removed. The cue was either an onset cue (four white dots surrounding only one of the peripheral boxes) or a colour cue (four red dots surrounding one of the peripheral boxes while four white dots surrounded the three other boxes). The white cues were bright white (77 cd/m²; IBM colour 15) and the colour cues were bright red (17 cd/m², IBM colour 12); the dots within each cue subtended 0.35°. Following a 100 ms delay, the target was presented for 50 ms and then removed. The target was either an onset target (a white “+” or “=” presented in only one of the peripheral boxes) or a colour target (a red “+” or “=” presented in one of the peripheral boxes while white “+” or “=” were presented in the three other boxes). The targets were presented in the same high-contrast white and red as the cues.

Participants were instructed to determine the identity of the target as quickly and accurately as possible. They were to press the “z” key using their left hand if the target was a “+” and the “/” key with their right hand if the target was a “=”. If they pressed the wrong key, or responded faster than 100 ms or slower than 1500 ms, the response was considered an error and a short tone (200 Hz, 200 ms) was presented. Error trials were not included in the response time analyses. The intertrial interval was 500 ms and after every 128 trials a short break was provided.

**Design.** There were a total of 512 trials in each session, with 128 trials in each of the four possible cue-target combinations (onset–onset, colour–onset, onset–colour, colour–colour). In the *blocked* condition, the order of onset cues and colour cues was randomized within each session; however, the order of onset targets and colour targets was blocked, and participants were informed about which target they should expect in a given block. The order of the blocks was counterbalanced across the participants, and after 256 trials (when the target changed from either an onset target to a colour target, or vice versa), the experimenter entered the testing room and verbally reminded the participant what type of target would occur in the remaining 256 trials. In the *random* condition, the order of the cues and targets were randomized within each session so
that any cue–target combination was equally likely on any given trial. The participants in this condition were informed that they should expect either onset or colour targets on all trials.

In both the blocked and random set conditions the location of cues and targets were completely randomized within each session. Thus, valid trials (target at the same location as the cue) occurred 25% of the time, whereas invalid trials (target at a different location than the cue) occurred 75% of the time. The participants were informed that the cue conveyed no information about the location of the target.

Results and discussion

The mean RTs from correct trials appear in the top portion of Table 1, along with the associated error rates. The mean RTs were analysed with a 2 (condition: blocked or random set) by 2 (target: onset or colour) by 2 (cue: onset or colour) by 2 (trial type: valid or invalid) analysis of variance (ANOVA). There was a main effect of condition, $F(1, 18) = 10.1, \text{MSE} = 44094, p < .006$, with the mean RT faster in the blocked condition (554 ms) than in the random condition (659 ms). This difference is probably due the higher amount of target uncertainty in the random set condition. There was also a main effect of trial type, $F(1, 18) = 38.2, \text{MSE} = 1862, p < .001$, as responses in valid trials (586 ms) were faster than in invalid trials (628 ms). This RT difference is the typical attentional cueing effect.

### Table 1

<table>
<thead>
<tr>
<th>Condition</th>
<th>Onset cue– Colour cue– Onset cue– Colour cue–</th>
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<tbody>
<tr>
<td></td>
<td>Onset target</td>
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<tr>
<td>Blocked:</td>
<td></td>
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<tr>
<td>Valid</td>
<td>520 (0.9)</td>
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<tr>
<td>Invalid</td>
<td>554 (2.0)</td>
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<tr>
<td>Random:</td>
<td></td>
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<tr>
<td>Valid</td>
<td>628 (5.5)</td>
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<tr>
<td>Invalid</td>
<td>658 (7.0)</td>
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<td>Experiment 2:</td>
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<tr>
<td>Blocked:</td>
<td></td>
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<tr>
<td>Valid</td>
<td>541 (1.5)</td>
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<tr>
<td>Invalid</td>
<td>522 (3.1)</td>
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<tr>
<td>Random:</td>
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<tr>
<td>Valid</td>
<td>665 (5.2)</td>
</tr>
<tr>
<td>Invalid</td>
<td>645 (5.6)</td>
</tr>
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Several significant interaction effects were also found. These included the condition by target interaction, $F(1, 18) = 10.3$, $MSE = 3179$, $p < .005$, and the condition by target by cue interaction, $F(1, 18) = 4.2$, $MSE = 2673$, $p < .05$. The three-way interaction of target by cue by trial type and the four-way interaction of condition by cue by target trial type were also found to be significant, $Fs(1, 18) = 16.5$, $MSE = 546$, $ps < .001$. No other significant main effects or interaction effects were found.

To gain some insight into the three- and four-way interactions, the mean cueing effects (invalid RT minus valid RT) were calculated for each cue–target combination and post-hoc $t$-tests were conducted to determine which combinations yielded significant cueing effects (see Figure 1). Overall, the results confirm that attentional control settings play a large role in early facilitatory cueing effects. When the targets were randomly presented and participants were told to equally expect onset and colour targets on any given trial (random set condition), significant cueing effects were found for all cue–target combinations. This result indicated that both onset and colour cues captured attention for both onset and colour targets. However, when the targets were blocked and participants were told that they should expect only one type of target in a given block of trials (blocked condition), only cues that matched the expected target

![Figure 1](image.png)

**Figure 1.** The mean attentional cueing effects (invalid RT–valid RT) found with the 150 ms SOA used in Experiment 1. The asterisks indicate significant cueing effects and the error bars represent standard errors.
captured attention and led to significant cueing effects. The fact different results were obtained in the blocked and random set conditions shows that Folk et al.’s original results cannot be explained by stimulus specific effects. Instead, the extent to which a cue will attract attention clearly does depend on the participant’s attentional set.

Another interesting aspect of the present data is that larger cueing effects were found with colour cues and colour targets than for onset cues and onset targets. This pattern of results is consistent with previous investigations using the Folk et al. (1992) paradigm (e.g., Folk et al., 1992; Pratt & Bellomo, 1999) and suggests that searching for the red target among the white distractors results in a greater focus of attention at the valid location than when attention is captured by a single onset stimulus. One possible reasons for the difference in attentional focus is that attending to the onset stimuli, but not the colour stimuli, can largely be accomplished with a reflexive (exogenous) orientation of attention. Because there are four onsets with the colour stimuli, exogenous attention is likely not sufficient, but rather volitional (endogenous) attention must also become involved. It should be noted that although attentional set and endogenous attention are both top-down attentional processes, they are not the same. In other words attentional set (what captures attention at a location) may exert influence on both exogenous and endogenous forms of attentional orientation (what moves attention to a location).

The error data was also analysed with a 2 (condition) by 2 (target) by 2 (cue) by 2 (trial type) ANOVA. Main effects were only found for condition, $F(1, 18) = 18.9, MSE = 55.3, p < .001$, and for trial type, $F(1, 18) = 15.9, MSE = 11.2, p < .002$, as more errors were made in the random condition and in the invalid trials. Of the interaction effects, only the target by cue interaction, $F(1, 18) = 5.2, MSE = 7.0, p < .04$, and the target by cue condition interaction, $F(1, 18) = 5.3, MSE = 7.0, p < .04$, reached significance. These interactions occurred because the colour–colour condition yielded more errors than the other conditions, and this pattern of errors was more robust in the random conditions. It is worth noting that the conditions that produced the greatest errors also produced the longest RTs, indicating that there were no speed–accuracy trade-offs present.

EXPERIMENT 2

Having found evidence that attentional control settings do have a major effect on initial facilitatory attentional cueing, Experiment 2 was conducted to determine if attentional set would also influence later occurring IOR effects. Here we replicated the methods used in the first experiment but changed the SOA from 150 ms to 850 ms to enable investigation of IOR.
Methods

Participants. Twenty undergraduate students from the University of Toronto, none of whom participated in the first experiment, participated in this experiment in return for course credit. Ten participants served in the blocked condition, and the other ten served in the random set condition.

Apparatus, procedure, and design. The experiment used exactly the same apparatus, procedure, and design as the previous experiment except that the delay between the offset of the cue(s) and the onset of the target(s) was increased to 800 ms from 100 ms, resulting in a SOA of 850 ms rather than 150 ms.

Results and discussion

The mean RTs from correct trials appear in the lower portion of Table 1, along with the associated error rates. The mean RTs were analysed with a 2 (condition) by 2 (target) by 2 (cue) by 2 (trial type) ANOVA. Similar to the findings from Experiment 1, a main effect of condition was found, $F(1, 18) = 6.1, MSE = 75396, p < .03$, with the mean RT faster in the blocked condition (561 ms) than in the random set condition (668 ms). Unlike the first experiment, however, main effects were found for target, $F_{s}(1, 18) = 66.2, MSE = 2562, p < .0001$, and for cue, $F_{s}(1, 18) = 45.3, MSE = 355, p < .0001$. These main effects occurred because responses were faster with colour cues (605 ms) than onset cues (625 ms) and faster with onset targets (582 ms) than colour targets (647 ms). No main effect was found for trial type, $F_{s}(1, 18)< 1$. The only interaction effect found was that of cue by trial type, $F_{s}(1, 18) = 10.5, MSE = 375, p < .005$. This interaction stems from the finding that only the onset cue, onset target combination yielded IOR (see the attentional cueing effects presented in Figure 2).

Figure 2 shows the cueing effects (invalid RT minus valid RT) for each of the cue–target combinations. Unlike the findings from Experiment 1, attentional control settings did not influence cueing effects. In both conditions, IOR was only found with the combination of onset cues and onset targets. Moreover, the magnitude of the IOR effect was almost identical between the two conditions. No other cue–target combination yielded any significant facilitatory or inhibitory cueing effect. It should be noted that pattern of results found in the blocked condition of the experiment closely resemble those recently found by Gibson and Amelio (in press). Using a slightly adapted version of the Folk et al. (1992) paradigm and a variety of long SOAs, they also found IOR effects only with the combination of onset cues and onset targets.

The error data was also analysed with a 2 (condition) by 2 (target) by 2 (cue) by 2 (trial type) ANOVA. No main effects or interaction effects were found.
Thus, speed–accuracy trade-offs did not influence performance in the experiment.

GENERAL DISCUSSION

The purpose of the present study was two-fold. First, to explicitly examine the role of attentional control settings on early facilitatory effects by including a critical control condition; and, second, to examine the role of these attentional settings on late IOR effects. Regarding the first purpose, the results from Experiment 1 indicate that both onset cues and colour cues capture attention when participants can not enter into an attentional set because they are unable to anticipate the stimulus characteristics of the targets. These results provide strong support for the attentional control settings hypothesis by showing that the previous results found by Folk and colleagues were not due to an artefact of their paradigm but rather were due to a manipulation of attentional set.

Regarding the second purpose of the study, the present results indicate that attentional control settings have little, if any, effect on IOR. This conclusion differs somewhat from the conclusion recently reached by Gibson and Amelio (in press) in a study that also examined attentional control settings and IOR. In a series of experiments, Gibson and Amelio used blocked target sets (onset and

![Graph showing mean IOR effects](image)
colour) with a range of SOAs (100, 700, 1000, 1100, and 1500 ms) and found results very similar to those found in the present blocked conditions. These results led Gibson and Amelio to suggest that both facilitatory cueing effects and IOR effects for the onset targets were similarly influenced by attentional control settings. However, their study did not include a condition in which all stimuli were contained within a single attentional set. As stated before, without this condition it is not possible to differentiate the effects due to stimulus-specific aspects of the experimental paradigm from those due to attentional control settings. With the addition of this condition, it is clear that attentional control settings do not influence IOR (see Figure 2).

The finding that IOR only occurred with onset cues and onset targets, regardless of whether participants were or were not in an attentional set, has some interesting implications. For one thing, the finding of IOR in the Folk et al. (1992) paradigm adds more support to the growing body of evidence that IOR can be found in discrimination tasks. In addition, the finding of IOR with the onset–onset cue–target combination but not the onset–colour combination suggests that the abrupt appearance of a new object in the periphery does not necessarily produce IOR at that location. Thus, IOR was found when attention was exogenously oriented to both a cue and a target but not when attention was endogenously oriented to either a cue or a target. Taken together, these findings support the notion that IOR is much more a phenomenon of the exogenous, involuntary orienting system than the endogenous, voluntary system (e.g., Gibson & Amelio, in press; Posner & Cohen, 1984; Pratt et al., 1997). This notion is bolstered by the finding that colour cues did not yield IOR with either type of target because the colour cue presumably involved mostly endogenous attention. Finally, the fact that Experiment 2 found no effect of attentional control on IOR is also consistent with the idea that IOR is an involuntary, bottom-up stimulus-driven attentional process.

It should be noted that Pratt et al. (1997) found a small inhibitory effect in an identification task that involved a single onset cue followed by the simultaneous presentation of a target and a distractor (i.e., requiring an endogenous orientation of attention toward the target). However, the Pratt et al. experiment only used two peripheral locations (one target and one distractor location) whereas the present study used four locations (one target location and three distractor locations). It may be that the IOR associated with endogenously attended targets is limited to relatively sparse visual displays and does not occur in more complicated scenes. This may have important implications for the notion that IOR reflects a mechanism that improves the efficiency of visual searches by biasing attention toward novel locations and away from previously attended locations (e.g., Tipper, Weaver, Jerreat, & Burak, 1994). Assuming that most visual searches we conduct occur in relatively complicated visual environments (e.g., searching for a friend in a crowd) and involve endogenous shifts of attention, the present results suggest that IOR may only
be of limited utility. However, it is also clear that IOR and the oculomotor system are intimately related (e.g., Rafal, Calabresi, Brennen, & Scioltto, 1989), and IOR may have a larger impact on endogenous eye movements that occur in visual search than on endogenous shifts of attention. Undoubtedly, future research will help clarify the relationship between IOR, eye movements, and visual search.

Related to the notion that IOR may largely reflect a bias against the exogenous orienting of attention is the suggestion based on the present findings that the relationship between early occurring facilitatory cueing effects the late occurring IOR effects may not be straightforward. Since the earlier work of Maylor (1985), it generally has been thought that IOR only occurs in conditions that yielded facilitatory attentional cueing effects at short SOAs (see also, Taylor & Klein, 1998). However, in the random set conditions of the present study, considerable cueing effects were found in all four cue–target combinations at the short SOA, but an inhibitory effect was found in only one combination at the long SOA. A similar dissociation between cueing effects and IOR effects was also found in the blocked conditions (facilitatory cueing for onset–onset and colour–colour, but IOR only for onset–onset). These findings leave open the possibility that IOR effects may be found without corresponding facilitatory cueing effects.

In summary, the present findings support the notion that attentional control settings may have a considerable impact on the manner in which cues capture attention. However, the present findings also indicate that these attentional control settings may not have any consequence on IOR. This is most likely because IOR is largely the product of the reflexive, involuntary orienting system.

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