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Inhibition of return in children and adolescents

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Abstract

Inhibition of return (IOR), slowed responding to targets at a cued location after attention is removed from this location, has been shown to occur both in adults and in infants. To explore Klein's (2000) suggestion that the timecourse of IOR depends on factors that might affect the efficiency with which attention is removed from the cued location, we compared the performance of young children (5–10-year-olds, $N = 49$, $M = 8$ years, 4 months) to older children and adolescents (11–17-year-olds, $N = 61$, $M = 14$ years) in single and double cue procedures. Cue-target interval was varied to measure the timecourse of IOR in this within-subjects localization task. Whereas no IOR was found in the young group unless a double cue procedure was used, in the older group, we found IOR at all intervals with the double cue procedure and the typical crossover pattern (cf., Posner & Cohen, 1984), with early facilitation followed by inhibition in the single cue procedure.

Keywords: Inhibition of return; Attention; Orienting; Children; Adolescents; Timecourse

Introduction

In visual attention experiments, the presentation of a spatial cue typically facilitates responding to subsequent targets at the cued location relative to other locations. Posner and Cohen (1984), however, discovered an interesting biphasic pattern in which early facilitation is replaced at long cue-target stimulus onset asynchronies (SOAs) by slowed responding to targets at a cued location. This effect was subsequently labelled "inhibition of return" (IOR) (Posner, Rafal, Choate, &

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Vaughan, 1985), reflecting the now widely adopted interpretation that attention, after being withdrawn from the cued location, is inhibited from returning to it (see Klein & Taylor, 1994 for an alternative interpretation). In recent work, Klein and his colleagues have demonstrated that by discouraging reorienting of attention to previously inspected objects or locations (Posner & Cohen, 1984), one function of IOR is improved efficiency of visual search or foraging (Klein, 1988, 2000; Klein & MacInnes, 1999; MacInnes & Klein, 2002). Considering the potential importance of IOR, researchers have been preoccupied with understanding its nature and development. Little regard, however, has been paid to how the IOR effect may vary with individual differences in the continued allocation of attention toward the cued object or location.

Accepting the idea that removal of attention from the cued location is a necessary condition for observing IOR (Posner & Cohen, 1984), Klein (2000) proposed that the timecourse of the appearance of IOR depends on factors that affect the efficiency with which attention is removed from the cued location. The choice of cueing procedure dictates whether this removal process will be controlled exogenously or left to endogenous control. As with exogenous control of attention by a peripheral cue, a flash back at central fixation should rapidly and relatively automatically pull attention away from the peripherally cued location. If a peripheral cue is not followed by another cue at central fixation, then the decision whether to remove attention from the peripheral location is optional and any such reorientation is endogenously controlled and therefore slowed. As a result any IOR effect will likely be delayed and smaller or absent. Klein's proposal was explicitly about experimental factors, such as the experimenter's choice of stimulus events and target task. Here we extend his proposal to factors within the observer. This extension predicts that there should be timecourse delays in the appearance of IOR when individuals with sub-optimal volitional control are subjected to cueing procedures wherein the removal of attention from a cued location depends on this mode of control. We anticipated that volitional control would show developmental effects and thus, so also would IOR under certain conditions.

Most studies of IOR use variations of one or both of the following peripheral cueing procedures: a single cue procedure and a double cue procedure. For both procedures the simplest version involves a central box flanked by two identical peripheral boxes, centered vertically and arranged horizontally across a computer screen (e.g., Maylor, 1985; Posner & Cohen, 1984; Rafal, Calabresi, Brennan, & Sciolto, 1989). In the most basic procedure, a single cue, consisting of the brightening of one of the peripheral boxes, is followed by a target after varying SOAs.

In the double cue procedure attention is exogenously removed from the cued location following the initial peripheral cue, by a brightening of the center box or fixation point prior to target presentation. Posner and Cohen (1984) introduced this brightening of the central location in order to ensure that participants' attention was at fixation when peripheral targets appeared at long SOAs. In this procedure, the peripheral cue is typically nonpredictive, with peripheral targets appearing equally often to the left or right of fixation.

In some early studies of IOR, both the single and double cue procedures were used, but generally at different SOAs. Specifically, a single cue procedure was used at short

SOAs and a double cue procedure was used at long SOAs (Maylor, 1985; Posner & Cohen, 1984; Posner et al., 1985; Rafal et al., 1989). Few studies (e.g., Briand, Larrison, & Sereno, 2000; Faust & Balota, 1997) have directly compared single and double cue procedures at identical SOAs. In an experiment with adult participants (Experiment 1), Briand et al. directly compared single and double cue procedures in a saccadic localization task, in which the dependent measure was RT of eye movements toward the target. One short (133 ms) and one long (1000 ms) SOA were examined, with SOA in each condition being measured from the onset of the peripheral cue to the onset of the target. In the double cue condition, the onset of the second cue (at fixation) occurred 27 ms after the 40 ms peripheral cue had been extinguished. The second cue lasted 40 ms and was followed by the remaining 26 or 893 ms of the 133 or 1000 ms SOAs, respectively. In the single cue condition, Briand et al. (2000) found the typical crossover pattern with facilitation at the short SOA and IOR at the long SOA, while in the double cue condition there was nonsignificant IOR at the 133 ms SOA and significant IOR at the 1000 ms SOA. By directly comparing the two different cueing procedures, Briand et al. unconfounded the effects of cueing procedure and SOA and demonstrated that IOR appears earlier when attention is exogenously removed from the peripherally cued location (see Pratt & Fischer, 2002).

Developmental studies of IOR

Developmental studies of IOR early in the lifespan have focused mainly on the infancy period (for a review, see Hood, 1995 or Johnson, 1994), with few studies examining this type of orienting in children. Among the few is Brodeur and Enns' (1997) study of lifespan changes in covert orienting, in which they tested groups of children with mean ages of approximately 6, 8, and 10 years, as well as young adults and older adults. Their procedure included a single nonpredictive peripheral cue at one of four locations (two on each side of fixation), with no additional cue at fixation. With this procedure, IOR was observed only in the young adults at the longest SOAs tested, with significant overall effects of facilitation in each of the other age groups. Brodeur and Enns (1997) attributed this pattern of results in part to young adults' greater capacity to ignore nonpredictive cues.

These results, however, present a conflict with the literature on IOR in infants. The similarity of infant and adult behavior demonstrated by Clohessy, Posner, Rothbart, and Vecera (1991), for example, suggests a developmental continuity in the development of IOR whereas Brodeur and Enns's (1997) study demonstrates a discontinuity. The known influence of cueing procedure on the timecourse of IOR (Briand et al., 2000; Faust & Balota, 1997) may be important here. What seems to be a conflict may simply be the result of comparing studies that examined attentional orienting in different age groups using different cueing procedures. This could be particularly problematic if the timecourse of IOR progresses differentially across development for the single and double cue procedures. A direct comparison of these two cueing procedures may resolve the apparent discontinuity. Because infants need an exogenous cue to draw their attention/gaze to fixation after cue presentation, such comparisons are not possible in studies with infants. In contrast, young children can understand verbal instructions and make saccadic or key press responses the way adults do. Yet, in the absence of a cue to remove attention from the cued location, the efficiency with which attention is removed from this location toward a more neutral state may depend on mechanisms that continue to develop even after apparently adult-like responding is possible. The lack of IOR observed by Brodeur and Enns (1997) in children tested with a single cue procedure, which produced IOR in adults, provides support for this suggestion.

Our argument is that cueing procedures in which the removal of attention from the cued location is left to the participants' endogenous control are costly, in terms of consuming energy and resources and requiring effective use of strategies. In other words, we believe that single cue procedures require some amount of controlled processing or strategic control whereas the processing required in a double cue procedure is more automated or exogenous. Results from Faust and Balota's (1997) study of older adults with DAT (dementia of the Alzheimer type) corroborate this position, in that these patients showed IOR in a double cue procedure, but not in a single cue procedure. Similarly, young children, in whom strategic control of attention is still developing, might be expected to have a delayed appearance of IOR in a cueing procedure with no cue at fixation to remove attention from the peripherally cued location. Thus, studying the development of IOR across childhood and adolescence fills a gap that exists in the literature examining the development of IOR while allowing for the comparison of cueing procedures with potentially different timecourses across development, which cannot be directly compared in studies with infants.

In the present study, we used the basic method of Briand et al. (2000), Experiment 1, as described previously, but with some adaptations for testing children ranging in age from 5 to 17 years. Also, because we are interested in comparing the timecourse of the facilitative and inhibitory effects of peripheral cues as a function of age and cueing procedure, we used intervening SOAs. A manual localization task, in which the dependent measure is the RT to press a key that corresponds to the location of the peripheral target, was chosen because it provided a happy medium between saccadic localization, in which the dependent measure is the RT to make an eye movement to the location of the peripheral target (typically used to examine IOR in infants) and manual detection, in which the dependent measure is the RT to press the spacebar upon target presentation independent of target location (typically used to examine IOR in adults). Maylor (1985) found similar patterns of facilitation and IOR for simple reaction time (RT) (manual detection) and choice manual RT (manual localization) in adults, but with slower RTs in the choice task.[1]

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[1] Furthermore, earlier in the same testing session for the present study, participants completed an experiment examining the cueing of attention by central gaze and arrow cues (cf., Ristic, Friesen, & Kingstone, 2002). A similar study with adults had previously shown that the effect of attention cueing by gaze was similar across manual detection, localization, and discrimination tasks, with a slight decrement in overall RTs as task difficulty increased (Friesen & Kingstone, 1998). Thus it was believed that employing the localization task rather than the more typical detection task would provide a more direct comparison to studies with infants, with a slight RT cost as the only drawback. Consistency across tasks was also considered important in order to avoid potential confusion caused by switching between tasks, possibly resulting in impaired performance on the latter task.

Method

Participants

Participants were 110 children and adolescents recruited from a summer Bible camp. There were 49 5–10-year-olds (31 girls, 18 boys, $M = 8$ years; 4 months, $SD = 1; 9$), and 61 11–17-year-olds (42 girls, 19 boys, $M = 14$, $SD = 1; 11$). This division at 11 years was motivated by recent studies showing that executive control improves from 5 to between 10 and 12 years of age, when it reaches adult-like levels (Casey, Durston, & Fossella, 2001; Munoz, Broughton, Goldring, & Armstrong, 1998). The number of boys and girls in each group is an accurate reflection of the gender breakdown at the camp, where the girls generally outnumber the boys.

The experimenter, a volunteer at the camp that summer and in past years, obtained the list of children registered for camp from the camp director. Informed parental consent was obtained by the experimenter, through scripted telephone calls or in person when parents dropped their children off for their week at camp.

Apparatus

Participants were seated in front of a computer at a distance of approximately 50 cm (given the breadth of the age range, the viewing distance that was comfortable varied somewhat across participants). The heights of the chair and table were 42 and 76 cm, respectively. The 17 in. (22 cm × 30 cm) NEC monitor rested on top of the Macintosh Centris CPU. The computer screen was perpendicular to the table for the majority of participants, but for younger (shorter) participants the monitor was angled downward. This arrangement was located at the back corner of the camp's dining hall. Natural light was available for most sessions, but some adolescents were tested early in the evening with fluorescent lights illuminating the dining hall.

Stimuli

Three white boxes occupying 6.4° × 6.4° of visual angle with lines about .11° in thickness were evenly spread across a black background with a distance of 3.6° between boxes. A white fixation cross measuring 1.1° × 1.1° with lines about .22 ° in thickness was centered within the central box. The cues consisted of "brightening" the outer boxes by thickening the white lines from .11° to about 1.1°, while keeping the outer dimensions constant at 6.4° × 6.4°. The central cue to fixation consisted of brightening the fixation cross by increasing the length of the lines from 1.1° to 2.0° and thickening them from .22° to about 1.1°. The targets were "Bob the Tomato" and "Larry the Cucumber," two characters from a computer-animated children's video series called "VeggieTales (Big Idea Productions, Inc.)." These characters were chosen because they were known to be familiar to most of the children attending the camp. The tomato occupied 3.3° × 4.2° and was surrounded by a pale blue background and yellow border, for a total target size of 4.5° × 5.5°. The cucumber measured 5.7° × 2.2° and was surrounded by a similar background and border for a total target size of 6.3° × 4.0°. Although they differed in shape, the target images were matched for area in pixels.

Design

The present study was a $2 \times 2 \times 2 \times 2 \times 4$ within-subjects factorial design and the task was manual localization. Participants completed eight practice trials, followed by two blocks of 64 randomly ordered trials. Each block included one each of the 64 trial types represented by the factorial combination of cueing procedure (single cue or double cue), target location (left or right), cue condition (cued or uncued), target identity (Bob or Larry) and SOA (150, 360, 570, or 780 ms). For purposes of statistical analysis, the data were collapsed across the two target identities and two target locations, thus yielding a total of eight trials per cell per observer.

Procedure

At the beginning of the experiment, the experimenter pointed to the screen and explained that there would be three boxes across the screen and that the middle box would have a white cross or plus sign in the middle of it. The children were asked to look at this cross, to keep their eyes focused on it, and not to move them. The children were also told that the boxes on the outside of the screen would flash sometimes, but that they should not pay any attention to the flashes because “they don’t mean anything and they don’t tell you where Bob or Larry will be.” The experimenter then pointed to the left side of the screen and told the child “If you see Bob or Larry on this side of the screen press this button (the ‘Z’ key marked with a blue sticker) and if you see one of them on this side (pointing to the right) press this button (the ‘M’ key marked with a blue sticker).” Finally, participants were reminded not to move their eyes. Additional instructions introducing the characters and the task and indicating what to do at the end of each block were presented on the screen in colored boxes. An image of the two target characters was presented beside the instructions. For younger children, the experimenter read these instructions aloud.[2]

The sequences of events for single cue and double cue trials are presented in Fig. 1 in the upper and lower panels, respectively. An interval of 1000 ms at the beginning of each trial was included to ensure that covert attention was at fixation. Each trial in the single cue condition began with a cue consisting of the brightening of one of the peripheral boxes for 45 ms. Then, after an interval of 105, 315, 525, or 735 ms, a peripheral target would appear (with equal probability) in either the cued or uncued location, lasting for 2000 ms or until the participant made a correct key-press re-

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[2] The instructions were: “Hello, my name is Bob the Tomato and this is my friend, Larry the Cucumber. Your job is to press a button whenever you see one of us. Please practice now!” Then after eight practice trials—“Good practicing! Now it’s time for the real game! Press a button to start Round 1!” Then after the first block—“Wow! You finished Round 1! Good for you! Press a button to start Round 2!” Finally after the second block—“That was quick! You finished Round 2! Now Amy will tell you about the next part!”

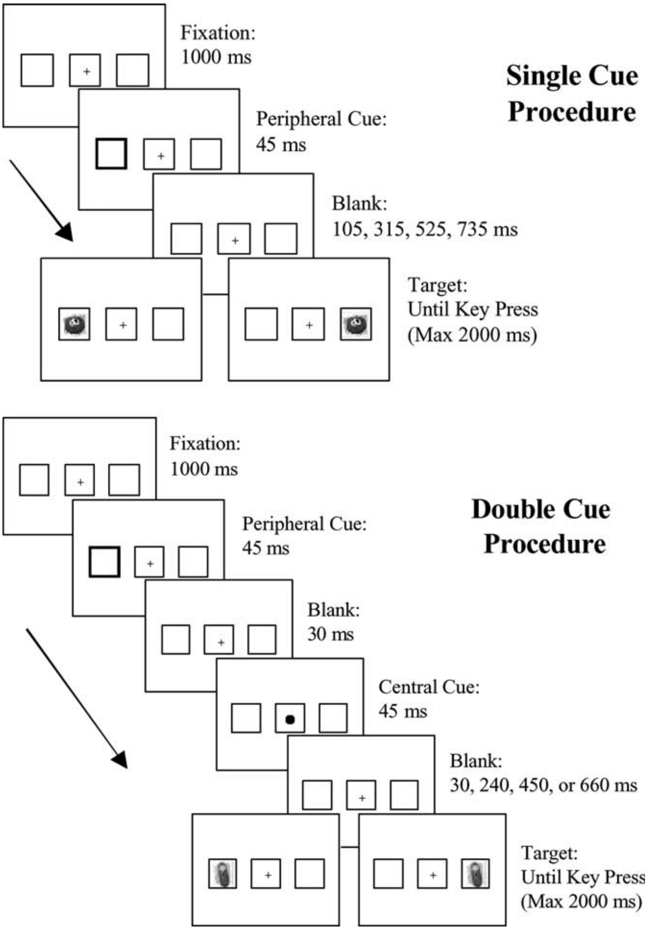

Fig. 1. Sample trial sequences illustrating the single and double cue procedures and the timings for each event, including the final event in each sequence for both cued and uncued trials. These images are phase-reversed; the actual stimuli had white boxes and cues on a black background. In addition, the targets (shown in grayscale) were in color. Images of the VeggieTales characters are used by permission of Big Idea Productions, Inc.

sponse. Each trial in the double cue condition began with a peripheral cue lasting 45 ms, followed after an interval of 30 ms by a brightening of the central fixation cross for 45 ms. After an additional interval of 30, 240, 450, or 660 ms, a peripheral target would appear in one of the peripheral boxes, just as in the single cue condition.

Results

Anticipatory responses, delayed responses, and incorrect key-press responses were excluded from the analyses. Trials with RTs shorter than 200 ms were considered anticipatory responses, and accounted for .96% of trials in the younger group and .21% in the older group. Trials with RTs longer than 1300 ms were considered delayed responses, and accounted for 5.47 and .81%, respectively, of trials in the younger and older groups. Key-press errors on trials with RTs between 200 and 1300 ms accounted for 1.85 and .85%, respectively, of trials in the two age groups.

Median[3] RTs for each trial type were calculated from the remaining trials, for each participant. These medians were analyzed in four separate 2 × 4 Repeated Measures ANOVAs to examine the interaction between cue condition and SOA for each combination of age group and cueing procedure.

In the single cue procedure for the younger age group (Fig. 2, upper left panel), a 2 (cue condition) × 4 (SOA) Repeated Measures ANOVA revealed no effect of cue condition, $F(1,48) = 1.45$, $p > .05$, and planned comparisons showed no significant effects of cue condition at individual SOAs. There was a significant effect of SOA reflecting a decrease in RT as SOA increased, $F(3,48) = 15.43$, $p < .0001$. The cue condition × SOA interaction was not significant, $F(3,48) = .23$, $p > .05$, reflecting a consistent pattern of nonsignificant facilitation across the four SOAs.

In the double cue procedure for the younger age group (Fig. 2, upper right panel), a 2 (cue condition) × 4 (SOA) Repeated Measures ANOVA revealed a significant effect of cue condition, $F(1,48) = 4.46$, $p < .05$. Planned comparisons at individual SOAs showed that this effect was due to significant IOR at the 570 ms, (−38 ms), $F(1,48) = 6.56$, $p < .05$, and 780 ms SOAs, (−42 ms), $F(1,48) = 8.09$, $p < .01$. The overall effect of SOA was significant, reflecting a decrease in RT as SOA increased, $F(3,48) = 18.70$, $p < .001$. The cue condition × SOA interaction was also significant, $F(3,48) = 3.29$, $p < .05$, reflecting the absence of a cueing effect at the earlier SOAs contrasted with significant IOR at the longer SOAs.

In the single cue procedure for the older age group (Fig. 2, lower left panel), a 2 (cue condition) × 4 (SOA) Repeated Measures ANOVA revealed no significant effect of cue condition, $F(1,60) = .55$, $p > .05$. Planned comparisons at individual SOAs showed significant facilitation at the 150 ms SOA, (27 ms), $F(1,60) = 14.68$, $p < .001$, and significant IOR at the 570 ms SOA, (−24 ms), $F(1,60) = 12.12$, $p < .001$. These opposing effects resulted in a significant interaction between SOA and cueing condition, $F(3,60) = 9.58$, $p < .001$. The effect of SOA was also significant, reflecting a decrease in RT as SOA increased, $F(3,60) = 24.12$, $p < .001$.

In the double cue procedure for the older age group (Fig. 2, lower right panel), a 2 (cue condition) × 4 (SOA) Repeated Measures ANOVA revealed a significant effect of cue condition, $F(1,60) = 28.82$, $p < .001$. Planned comparisons at individual SOAs showed significant IOR at the 360 ms, (−30 ms), $F(1,60) = 14.74$, $p < .001$ and 780 ms SOAs, (−20 ms), $F(1,60) = 6.51$, $p < .05$. Again, there was a significant effect of SOA reflecting a decrease in RT as SOA increased, $F(3,60) = 28.59$, $p < .001$. The cue condition × SOA interaction was not significant, $F(3,48) = .23$,

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[3] With variable data and a small number of trials per cell (8) the median is a more stable estimate of central tendency than is the mean, and therefore so long as the number of observations per cell is relatively homogenous (see Miller, 1988) the median is preferred.

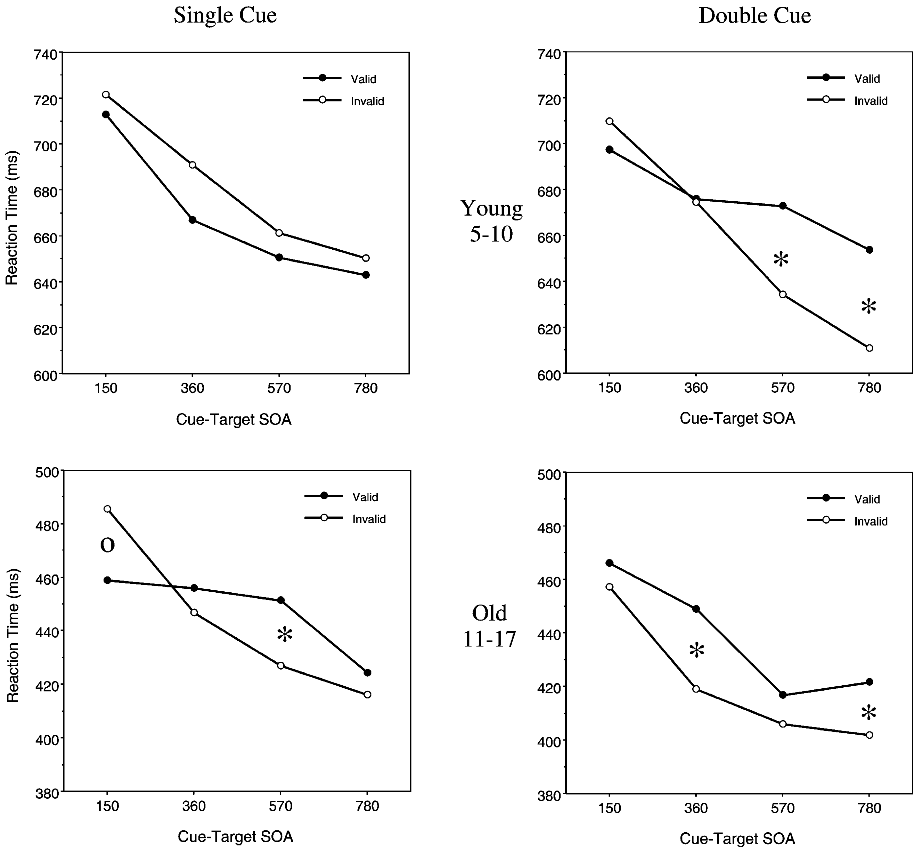

Fig. 2. Mean reaction time as a function of cue condition (cued or uncued) and SOA for each combination of cueing procedure (single cue or double cue) and age group (5–10 years or 11–17 years). Asterisks represent significant IOR, while the open circle represents significant facilitation.

$p > .05$, reflecting a fairly consistent pattern of IOR (averaging about 16 ms) across the four SOAs.

To examine results across age groups and cueing procedures, a mixed $2 \times 2 \times 2 \times 4$ Repeated Measures ANOVA was conducted with age group (5–10 or 11–17) as a between-subjects factor and cueing procedure (single cue or double cue), cue condition (cued or uncued), and SOA (150, 360, 570, or 780 ms) as within-subjects factors. This analysis revealed a significant main effect of age group, $F(1,108) = 161.40, p < .0001$, reflecting the pattern of faster RTs in the 11–17-year-olds ($M = 437.8$ ms, $SD = 80.7$ ms) compared to the 5–10-year-olds ($M = 670.5$ ms, $SD = 111.2$ ms). The main effect of cueing procedure was also significant, $F(1,108) = 12.92, p < .001$, with faster RTs in the double cue procedure ($M = 535$ ms, $SD = 165$ ms) than in the single cue procedure ($M = 548$ ms, $SD = 161$ ms). In addition, the main effect of SOA was significant, $F(3,108) = 74.86, p < .0001$, reflecting a decrease in RT with increasing SOA (150 ms SOA: $M = 575$ ms, 360 ms SOA: $M = 547$ ms, 570 ms SOA: $M = 528$ ms, 780 ms SOA: $M = 516$ ms). The main effect of cue condition was not significant, $F(1, 108) = 2.83$, $p > .05$. Cue condition did, however, interact significantly with SOA, $F(3, 108) = 5.55$, $p < .01$, and cueing procedure, $F(1, 108) = 14.21$, $p < .001$. In addition, there was a significant four-way interaction among age group, cueing procedure, cue condition, and SOA, $F(3, 108) = 3.10, p < .05$. No other interactions were significant.

The interaction between cue condition and cueing procedure occurred because responding tended to be faster on cued trials (i.e., more facilitation) in the single cue procedure and on uncued trials (i.e., more IOR) in the double cue procedure. The interaction between cue condition and SOA occurred because of the increased prevalence of IOR at long SOAs. The four-way interaction resulted from different patterns of facilitation and IOR across the four combinations of age group and cueing condition (see Fig. 2).

Discussion

The purpose of the present study was to examine the hypothesis that the timecourse of IOR may depend on the efficiency with which attention is removed from the location of a peripheral cue. Across a range of SOAs, a single cue procedure in which the removal of attention from the cued location is left to endogenous control of the participant was compared to a double cue procedure in which attention is exogenously removed from the cued location by a brightening of the fixation cross. The efficiency of removing attention from the cued location was expected to vary with age in the single cue procedure, producing a delayed appearance of IOR in younger participants, but to remain consistent in the double cue procedure. To examine this hypothesis, younger children (5–10-year-olds) were compared with older children and adolescents (11–17-year-olds). The present study is unique in that it is among the first, if not the first, to examine the timecourse of IOR in children or adolescents, and is one of only a few studies to directly compare the single and double cue procedures at identical SOAs.

As predicted, the appearance of IOR was delayed in young children when there was no cue to fixation. In fact, even at the longest SOA (780 ms), there was no evidence of IOR in 5–10-year-olds in the single cue procedure, whereas in the double cue procedure these same children showed a biphasic pattern with significant IOR appearing at 570 ms and persisting at 780 ms. This pattern of responding was similar to the adult-like pattern produced by the 11–17-year-olds who, in the single cue procedure, showed significant facilitation at 150 ms, followed by relatively homogeneous IOR at the longer SOAs. Interestingly, this pattern represents a delayed appearance of IOR in the single cue procedure in 11–17-year-olds, when compared to their performance in the double cue procedure. With the cue to fixation, this group showed a relatively homogeneous amount of IOR across the four SOAs. Facilitation at short SOAs thus seems to be specific to the single cue procedure, whereas in the double cue procedure the pattern of IOR (although not significant) is present even at very early SOAs, both in older children (present study) and in adults (Briand et al., 2000).

Providing motivation for attention to be removed from the cued location without a double cue is another effective technique for producing IOR at short SOAs (Danziger & Kingstone, 1999).

The different patterns of responding in the single and double cue procedures, particularly in the younger age group, provide support for the hypothesis that the timecourse of IOR is influenced by the efficiency with which attention is removed from the cued location. The only difference between the two cueing procedures was whether attention was removed from the cued location exogenously by a central cue or endogenously by the participant's attentional control. In 5–10-year-olds, this subtle procedural variation made the difference between an appearance of IOR at 570 ms in the double cue procedure and a complete lack of IOR in the single cue procedure. Thus, when attention was drawn efficiently from the cued location to fixation, IOR was observed, whereas the lack of IOR when the removal of attention from the cued location was left to endogenous control suggests that even at long SOAs participants were inefficient at removing attention from the cued location and directing it toward fixation. In 11–17-year-olds, for whom attentional control is considered to be more fully developed, the variation between the two procedures resulted in the opposite pattern. Just as has been observed with adult participants, they showed a biphasic pattern when a single cue was used, with early facilitation replaced by IOR by about 360 ms. In the double cue procedure the early facilitation was eliminated and the magnitude of IOR was relatively constant across SOAs, suggesting that attention had been rapidly and effectively removed from the peripherally cued location by the subsequent central cue.

Findings with children and adults support this description. Brodeur and Enns (1997) found facilitation but no IOR in a single cue procedure with children of approximately the same ages as our younger group, but found IOR at long SOAs when testing young adults with the same procedure. Briand et al. (2000), in a study with adults, found that at a short SOA of 133 ms, there was significant facilitation in the single cue procedure and nonsignificant IOR in the double cue procedure, whereas at a long SOA of 1000 ms, there was significant IOR in both cueing procedures. This is similar to the pattern found in the present study with 11–17-year-olds. These combined results suggest that in a double cue procedure IOR may be seen at early SOAs without being preceded by facilitation. These findings conflict with the biphasic pattern typically observed in adults. Studies comparing short and long SOAs tend either to use the single cue procedure at short SOAs and a double cue procedure at long SOAs or to use the single cue procedure at short and long SOAs. Thus, the single cue procedure is normally used at short SOAs in both procedures. Because the single cue procedure typically produces facilitation at short SOAs and the double cue procedure is rarely used at short SOAs, the finding of IOR at short SOAs has been rarely seen and the double cue procedure appears to be accelerating the onset of IOR.

Using a modified double cue procedure, Clohessy et al. (1991) found that infants between the ages of 6 and 18 months produced an adult-like level and timecourse of IOR. In the double cue procedure of the present study, participants in both age groups produced significant IOR, but the appearance was earlier in the older group.

These results support the claim that IOR, as measured with a double cue procedure, is present from infancy through to adulthood. These findings also indicate, however, that the timecourse of the appearance of IOR may vary with age. The majority of studies examining IOR in infants used long or variable SOAs making it difficult to determine the timecourse of the appearance of IOR. One study that used specific SOAs found facilitation at an SOA of 450 ms and IOR at 875 and 1300 ms SOAs in 20- and 26-week old infants, suggesting that the appearance of IOR in infants is between 450 and 875 ms (Richards, 2000). Considering that the appearance of significant IOR for 5–10-year-olds in the present study is between 360 and 570 ms, and between 150 and 360 ms for 11–17-year-olds it seems safe to conclude that the appearance of IOR in a double cue procedure, if not the duration of the timecourse, changes gradually across development.

In the present study, the later appearance of IOR in the single cue procedure compared to the double cue procedure is attributed to a weakness in strategic control of attention, such that the endogenous removal of attention from the cued location is typically less efficient particularly in younger participants (see Wainwright & Bryson, 2002, for a similar attribution). From the present results, younger children seem to be unreliable at removing attention from the cued location when this task is left to their endogenous control, as demonstrated by the absence of IOR at any of the four SOAs in the single cue procedure. The earliest age at which IOR can be reliably observed in a single cue procedure is unclear in the present study due to the broad age ranges in the younger and older groups. The high variability we have observed in children performing this simple RT task highlights the importance of large Ns when measuring RT in children. To refine the account of IOR in children beyond the general developmental pattern described here, it would be interesting in future studies to focus on a few specific ages thought to represent milestones of development and to test a large number of children at each of these ages. For instance, in order to determine the lower age limit for observing IOR in a single cue procedure, it would be a good idea to test a large number of children at the proposed transitional point (around 10–12 years).

Relevant data to suggest that some special transition in the development of executive control occurs between the ages of 10 and 12 years comes from two cross-sectional studies, each including participants spanning a broad range of ages (Casey et al., 2001; Munoz et al., 1998). Casey and her colleagues tested 108 children ranging in age from 4 to 18 years on a battery of three tasks across which the nature of the executive control over behavior was varied. The RT plots for all three tasks show long and highly variable RTs in the youngest children with both RT and variability decreasing gradually until the 10–12 year range and then levelling off to a consistent RT pattern with limited variability from 11 or 12 right up to 18 years of age. Munoz and his colleagues (1998) tested 168 participants between the ages of 5 and 79 in an anti-saccade task requiring them to make an eye movement to one side of the screen in response to a target appearing on the opposite side of the screen. Plots of both saccadic RT and percentage of directional errors reveal high scores and high variability in the youngest children decreasing gradually with age and levelling off around 11 or 12 years, particularly in the case of errors. Taken together, these results suggest that executive control improves considerably from 4–5 up to 11–12 years and then remains fairly consistent throughout adolescence and into adulthood. The task in the present study is different but conceptually related and the results suggest a similar developmental trajectory for strategic control of attention, with weakness and variability in the younger group, particularly in the single cue procedure, and more consistent adult-like responding in the older group.

The weakness in strategic control demonstrated by the younger group in the present study is similar to that of older adults with DAT whose spontaneous reorienting to fixation is slower than that of younger adults or healthy older adults. This weakness resulted in a delayed appearance of IOR in a single cue procedure, but not in a double cue procedure (Faust & Balota, 1997). A similar pattern of results was obtained by Sapir, Henik, Dobrusin, and Hochman (2001) who directly compared the single cue and double cue procedures in patients with schizophrenia. Thus, it seems that groups with weaknesses in strategic control of attention, including children, the aged, and patients with schizophrenia, require a double cue procedure in order for IOR to be observed.

Overall, the results of the present study indicate that the timecourse of the appearance of IOR varies with age and cueing condition. Specifically, it is delayed in the single cue procedure for both age groups and delayed for the younger group in both cueing procedures. The present findings are important on a number of different levels. From an empirical perspective, these data help to delineate the timecourse of IOR in children and adolescents and to show that at certain ages a cue at fixation to remove attention from the cued location is necessary in order for IOR to be observed. From a methodological perspective, this study emphasizes the advantage of directly comparing different cueing procedures in order to attain a more thorough understanding of the IOR effect. From a theoretical perspective these results provide support for an important transition between the ages of 10 and 12 years in the developmental function describing executive control. In addition, these results support the idea that studies of populations (e.g., schizophrenics) who may not show IOR or show it later, may not be revealing deficits in subcortical mechanisms causing IOR, but rather in the cortical mechanisms responsible for disengaging attention from an uninformative peripheral event (Klein, 2003).

Our results suggest that Klein's (2000) proposal, that the timecourse of IOR may be influenced by task factors affecting the efficiency with which attention is removed from the cued location, can be extended to individual differences in executive control. Perhaps this proposal will also hold when the efficacy of executive control is debilitated using a working memory load with the same individual. The prediction that IOR would be delayed when the cue is delivered to participants whose working memory is full has been confirmed by Klein, Castel, and Pratt (unpublished results).

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