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PAPER

Developmental changes in attention: the effects of endogenous cueing and of distractors

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Abstract

We used two reaction time tasks to examine age differences in the ability to use an endogenous cue to shift attention covertly and to ignore distractors. In Experiment 1, 8-year-olds, 10-year-olds and adults (n = 24 per age) were asked to push a button as soon as they detected a target that was presented in a cued, miscued or non-cued peripheral location at 100, 400 or 800 ms after the appearance of a central cue. In Experiment 2, 10-year-olds and adults (n = 24 per age) were asked to indicate which of two shapes appeared in the periphery 400 ms after a central cue, with those shapes surrounded by compatible or incompatible distractors. Unlike previous studies, the data were corrected for a reaction time bias that can inflate the apparent effect of cueing. Children were slower and more variable than adults overall. However, there were no age differences in the effects of the cues in either experiment: at all ages, the speed of responding was increased similarly by correct cueing and slowed similarly by incorrect cueing. Thus, under these conditions, the ability to use endogenous cues to orient covertly to the periphery is already adult-like by 8–10 years of age, although there may be subsequent changes in the consistency of responding. In Experiment 2, 10-year-olds were slowed more than adults by incompatible distractors. Thus, the ability to ignore distracting information is not adult-like even by 10 years of age. The findings suggest different rates of development for the ability to shift attention following an endogenous cue and for the ability to filter out irrelevant information.

Introduction

No matter how they are tested, adults are more skilled at redirecting and focusing attention than are young children (e.g. Akhtar & Enns, 1989; Enns & Brodeur, 1989; Pearson & Lane, 1990; Brodeur, 1993; Wainwright-Sharp, 1995; Brodeur, Trick & Enns, 1997). For example, when adults are asked to press a button as soon as a target appears in the periphery, they respond more quickly if a visual marker cues the location of the upcoming target during the 200 ms preceding it than if the wrong location is cued, even when they must shift attention covertly because eye movements are not allowed (e.g. Akhtar & Enns, 1989; Enns & Brodeur, 1989). Such cues at the location of the upcoming target have been labeled exogenous and are believed to draw attention automatically to their location, probably on the basis of midbrain processing (e.g. Jonides, 1981). Like adults, children also show a validity effect, i.e. they respond faster when the target appears at the cued location on valid trials than when it appears at an unexpected location on invalid trials (Akhtar & Enns, 1989; Enns & Brodeur, 1989; Brodeur, 1993; Wainwright-Sharp, 1995; Brodeur *et al.*, 1997). However, all studies using exogenous cues agree that children aged 5–9 years show a larger validity effect than do adults, presumably because they are less well able to shift attention from the incorrectly cued location to the position where the target appears.

The current studies were designed to investigate developmental differences in the ability to use an endogenous cue to shift attention. An endogenous cue is typically presented centrally and contains information about the likely location of the upcoming target. An endogenous cue does not automatically draw attention to the cued location; instead it prompts a voluntary shift in attention (Jonides, 1981). Many investigators argue that endogenous cues are more

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likely than exogenous cues to tap cortical aspects of attention, particularly the posterior-parietal attentional system (Posner, Cohen & Rafal, 1982; Posner, Walker, Friedrich & Rafal, 1984).

There are some suggestions that children aged 6–10 years show a larger validity effect than adults when tested with endogenous cues (Pearson & Lane, 1990; Brodeur, 1993; Brodeur *et al*., 1997), especially when the target appears between 83 and 300 ms after the cue (Pearson & Lane, 1990). However, one study found no difference in the size of the validity effect in adults and children aged 6–14 years (Wainwright-Sharp, 1995). Moreover, problems limit the interpretation of all previous studies using endogenous cues with children. In one study (Pearson & Lane, 1990), the data from tasks with endogenous and exogenous cues were combined in the *post hoc* analyses of age differences. In another study (Brodeur, 1993; Brodeur *et al*., 1997), the endogenous cues appeared at different intervals before the target (SOAs) for adults than for children, and the SOA is known to affect the strength of the validity effect in adults (Shulman, Remington & McLean, 1979; Posner & Cohen, 1984; Remington & Pierce, 1984; Shepherd & Müller, 1989; Sorensen, Martin & Robertson, 1994). In the study that failed to find age differences with endogenous cues (Wainwright-Sharp, 1995), participants were allowed to make eye movements and hence the investigators may have measured the effect of the cues on eye movements rather than on attention. Children as young as age 6 may be as skilled as adults in using endogenous cues to program an eye movement toward the expected location of the target but differ from adults in their ability to make voluntary shifts of attention without eye movements.

Previous data on age differences in the size of the validity effect may also have been misinterpreted because outlying (long) reaction times are likely to be more common in children than adults and have an especially biasing effect in the invalid condition (van Selst & Jolicoeur, 1994). Both the mean and median are biased toward large values when the distribution of reaction times is positively skewed by long reaction times, especially when the sample of reaction times is small, as it is in the invalid condition (Miller, 1988, 1991). When the sample is larger, as it is in the valid condition, there is less bias. Thus, with positively skewed distributions, estimates of the size of the validity effect (the difference in reaction time between the invalid and valid conditions) based on either the mean or the median are inflated, and would be inflated more in children than in adults if their reaction times are more variable. Although there are a number of statistical procedures for removing outliers (e.g. Stevens, 1984), van Selst and Jolicoeur (1994) describe a procedure designed specifically for removing the bias from comparisons of conditions with unequal numbers of trials, such as the comparison of invalid and valid trials. Specifically, it uses a moving criterion to remove outliers from the mean, with the criterion adjusted relative to the number of observations being averaged. For example, for a condition with 50 observations (a typical number for a valid condition), reaction times lying 2.48 standard deviations or more away from the mean are eliminated while, for a condition with only 10 observations (e.g. an invalid condition), reaction times lying 2.17 standard deviations or more away from the mean are eliminated. Van Selst and Jolicoeur showed that this procedure removes the bias from the comparison of the means.

One purpose of the present experiments was to re-examine age differences in the ability to use endogenous cues to shift attention covertly, while using van Selst and Jolicoeur's procedure for removing reaction time bias. In Experiment 1, 8-year-olds, 10-year-olds and adults were asked to detect a peripheral target that appeared at various intervals after a central endogenous cue. We kept the time interval between the cue and target (SOA) constant within each block of trials because, when SOAs are intermixed, the participant's expectation that a target is about to appear may change between the cue and the time when the target appears. If the procedure includes catch trials (as it does here), then the longer the interval after the cue, the more likely that the trial is a catch trial and the less likely that a target is about to appear. Such changes in expectancy during the course of a trial may change with age and obscure understanding of developmental changes in attentional control. To avoid that problem, in Experiment 1 we kept the SOA constant within each block of trials. In Experiment 2 there was only one SOA and participants (10-year-olds and adults) were asked to signal which of two targets appeared in the peripheral location.

A second purpose of these studies was to compare children's ability to use endogenous cues with their ability to ignore distractors surrounding the target. Previous studies using a number of paradigms including Stroop color–word naming, same/different judgments and speeded classification suggest that children have more difficulty ignoring distractors than do adults (Strutt, Anderson & Well, 1975; Well, Lorch & Anderson, 1980; Lane & Pearson, 1982; Enns & Cameron, 1987; Enns & Akhtar, 1989; Tipper, Bourque, Anderson & Brehaut, 1989; Enns, 1990; Plude, Enns & Brodeur, 1994; Ridderinkhof & van der Molen, 1995). For example, in a speeded classification task, children aged 4–7 years (Enns & Akhtar, 1989) and 5–9 years (Ridderinkhof & van der Molen, 1995) were slowed much more than adults by incompatible information. In adults, the ability to ignore distractors is influenced little, if at all, by where the subject is attending (Akhtar & Enns, 1989) and appears to be governed more by an anterior-frontal inhibitory system than by the posterior-parietal attentional system (e.g. Knight & Grabowecky, 1995). The one published study with children that combined distractors with exogenous cueing reported that there were developmental differences in the effect of distractors only on invalid trials: on those trials, incompatible distractors (i.e. distractors that signaled an inappropriate response) slowed the responses of children 5–9 years old more than those of adults. That finding suggests that children are especially disadvantaged when they have to ignore distractors in an unattended location. There are no published developmental studies on the combination of distractors and endogenous cueing. In Experiment 2, we examined differences between children and adults in the influence of endogenous cues on the ability to ignore distractors.

In summary, the purpose of these experiments was to characterize the development of two attentional processes: covert shifts of attention and ignoring distractors. From a developmental neuropsychological perspective, these experiments tap the functioning of the posterior-parietal attention network and the anterior-frontal inhibitory system (Posner & Petersen, 1990).

Experiment 1

Experiment 1 was designed to examine age differences in the effect of central, endogenous cues on the time to detect a peripheral target. We chose to test 8-year-olds, 10-year-olds and adults because (1) 8 years was the youngest age at which children could perform the task reliably and (2) previous studies suggest that attentional skills are not adult-like at 8 years of age but may become so by 9–12 years (Pearson & Lane, 1990). To aid interpretation of any age differences, we included catch trials during which no target appeared following the cues and neutral trials in which the central cues were matched in area to cues on other trials (Jonides & Mack, 1984) but shaped so that the subject knew they were uninformative. Eye movements were monitored and trials with eye movements were eliminated so that differences in reaction times between conditions would reflect covert attentional shifts. Testing was monocular so that the data could be used as norms for later evaluating the performance of children with unilateral eye problems. Testing was along the vertical rather than along the horizontal meridian because patients with bilateral eye problems often have a spontaneous horizontal nystagmus that prevents accurate fixation on the horizontal meridian. To assure that participants had normal vision, we included a visual screening examination.

Because shifts of attention are influenced by SOA in adults (Shulman *et al.*, 1979; Remington & Pierce, 1984; Shepherd & Müller, 1989; Sorensen *et al.*, 1994) and, at least under some conditions, in children (Pearson & Lane, 1990; Brodeur, 1993; Wainwright-Sharp, 1995), we tested at three different SOAs: 100, 400 and 800 ms. We included a 100 ms SOA because in a previous study using the same procedure we found that it is a relatively short SOA at which adults usually show a small validity effect, a 400 ms SOA because it is the SOA at which adults showed a large validity effect, and an 800 ms SOA because it is when the validity effect declined in adults (Goldberg, Maurer & Lewis, 1996; Goldberg, 1998). To keep the predictive validity of the cue constant across SOAs (see Introduction), the three SOAs were tested in separate blocks of trials.

Method

Participants

The participants were groups of 24 8-year-olds (mean age 8.1 years, range 7.9–8.2 years), 10-year-olds (mean age 10.0 years, range 9.8–10.3 years) and adults (mean age 20.2 years, range 18.8–29.6 years). An additional nine participants were excluded from the final sample because they failed a vision screening examination (four 8-year-olds, two 10-year-olds, two adults; see Procedure) or were taking medication to control seizures (one 8-year-old).

Apparatus and stimuli

At the beginning of each trial, participants saw a central fixation stimulus between two square boxes where targets could appear. The central fixation stimulus was a solid black diamond, 5.6° (3.6 cm) high and wide when viewed from 36 cm. As illustrated in Figure 1, the boxes were 7.6° (4.8 cm) in diameter, formed from lines 1.3° (0.8 cm) thick, and began 5° (3.2 cm) above and below the center of the central fixation stimulus. Targets were 2×2 black-and-white checkerboards appearing inside the boxes and were formed from checks 2.5° (1.6 cm) in diameter. Cues were white shapes appearing inside the central fixation stimulus. Informative cues were solid triangles and were 2.8° (1.8 cm) wide by 1.4° (0.9 cm) high pointing up or down. Neutral cues

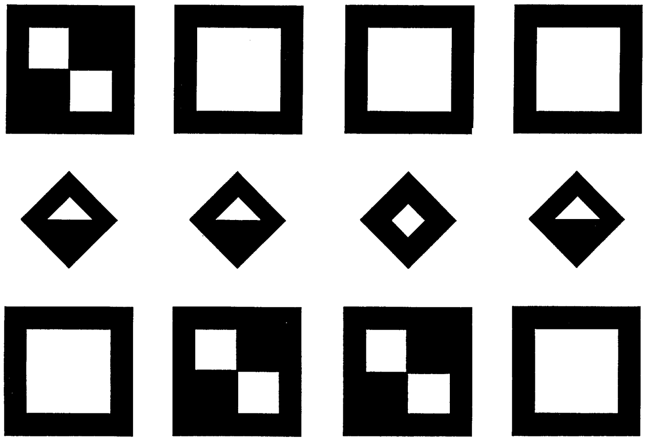

Figure 1 *Covert orienting task with endogenous cues used in Experiment 1. Examples of a valid, invalid, neutral and catch trial are shown.*

(2° high and wide) were diamonds providing no information about the location of the target and were matched in area to the informative cues (7.9 cm^2). Black stimuli were 9.0 cd/m^2; white stimuli were 46.7 cd/m^2.

Stimuli were presented by a Macintosh Powerbook 160 onto an Apple 12 inch monitor (25.3° high and 35.4° wide). SuperLab software, with a 3.96 ms time accuracy and a 20 μs timing resolution, controlled the presentation of visual stimuli, the time interval from the onset of a cue to the onset of a target (SOA) and the measurement of reaction time.

Procedure

For participants to be included in the final sample they had to pass a visual screening examination without optical correction, including tests of visual acuity, fusion and stereopsis (Bowering, Maurer, Lewis & Brent, 1993). Each participant was tested monocularly by having the non-tested eye covered by an eye patch made from a double layer of Micropore tape (3M, London, Ontario, Canada). Half of the participants in each age group were tested with the right eye, and half were tested with the left eye.

Each participant sat 36 cm from the screen with the non-patched eye aligned with the central fixation stimulus, which they were instructed to fixate. When the experimenter judged that the participant was fixating on the center of the black diamond, she pressed a key to present a cue. Participants were instructed to maintain central fixation and to respond by pressing the letter B on a computer keyboard in front of them as soon as they detected the target. At the end of each trial, the experimenter coded whether or not an eye movement had occurred.[1]

There were 160 trials at each of three SOAs (100, 400, 800 ms): 104 valid trials, during which the central arrow correctly signaled the location of the upcoming target; 20 invalid trials, during which the arrow incorrectly signaled the location of the upcoming target; 20 neutral trials, during which the diamond provided no information about the location of the upcoming target; and 16 catch trials, during which no target appeared following the cue. These catch trials provided a measure of false positive responding, i.e. the participant's tendency to push the button simply because a target was expected. The cue and target remained on the screen until a key press response occurred or until 2 s elapsed. On valid, invalid and neutral trials, half of the targets appeared in the upper visual field and half in the lower visual field (in a random order).

The procedure began with a demonstration followed by practice trials at the 800 ms SOA that continued until the participant completed 10 consecutive trials without an eye movement, anticipatory response before the onset of the target, or false positive response on a catch trial. This typically took about 20 trials.

Data analyses

The dependent variable was reaction time, measured as the latency between the appearance of a target and the participant's response. Trials on which participants made eye movements or anticipated the appearance of the target were eliminated before the analysis. Table 1 shows the number of these trials for each group. Mean reaction times for the remaining trials were calculated for each participant for each condition after outliers were removed using a moving criterion (see Table 4 of van Selst & Jolicoeur, 1994). The percentage of scores eliminated by the moving criterion was 3.19% for 8-year-olds, 3.13% for 10-year-olds and 3.01% for adult participants. An analysis of variance (ANOVA) was then performed on the mean reaction times with one

[1] To evaluate the accuracy of the experimenter's judgments of central fixation, an adult fixated the center of the central stimulus or 1°, 2° or 3° above or below the center on 35 randomly ordered trials. The experimenter was accurate 100% of the time in judging whether fixation was center, up or down, and accurate 88% of the time in judging which of the six locations off center was being fixated. To evaluate the accuracy of the experimenter's judgments of eye movements off center, the adult fixated centrally and then either made no eye movement or moved her eyes 0.5°, 1°, 1.5°, 2°, 2.5° or 3° above or below center on 65 randomly ordered trials. The experimenter detected all of the eye movements off center and judged their direction and size correctly 92% of the time.

Table 1 *Mean percentage (standard error) of trials with eye movements, responses on catch trials, and anticipations of the target*

Study	Age	Eye movements (%)	Responses on catch trials (%)	Anticipations of the target (%)
1	8	4.6 (0.5)	15.1 (2.4)	0.6 (0.2)
	10	4.4 (0.5)	21.1 (2.5)	0.7 (0.2)
	Adult	1.0 (0.3)	5.4 (1.4)	0.5 (0.2)
2	10	8.0 (1.4)		
	Adult	2.6 (0.9)		

between-subject factor, age (8-year-olds, 10-year-olds, adults), and three within-subject factors: SOA (100, 400, 800 ms), cue type (valid, neutral, invalid) and visual field (lower, upper).

Results

Adults made fewer eye movements and responded on fewer catch trials than 8-year-olds or 10-year-olds, who did not differ significantly from each other (separate ANOVAs on eye movements and catch trials, main effects of age, Tukey post-tests, all $ps < 0.05$). Participants rarely anticipated the appearance of the target, with no significant age differences (see Table 1).

Effects of age and its interactions

The ANOVA on reaction times indicated that adults responded faster than 8-year-olds and 10-year-olds (main effect of age, $F(2, 69) = 19.16$, $p < 0.000001$, and Tukey post-tests, $ps < 0.05$), who did not differ from each other (Tukey post-tests, $ps > 0.05$). However, there was no age difference in the effect of the cues (nonsignificant interaction between cue and age, $F(4, 138) = 1.21$, $p > 0.10$), nor in the way cues interacted with SOA (nonsignificant interaction between age, SOA and cue, $F(8, 276) = 0.91$, $p > 0.10$). Figure 2 illustrates the mean reaction times on valid, invalid and neutral trials at each SOA for each age group.

Age interacted with visual field ($F(2, 69) = 4.52$, $p < 0.05$). Reaction times were faster for targets in the upper visual field than the lower visual field in 8-year-olds but not in older participants (analyses of simple effects, $p < 0.05$). There was a trend for an age by cue by visual field interaction ($F(4, 138) = 2.31$, $p = 0.07$) because 8- and 10-year-olds tended to show larger validity effects in the lower visual field than in the upper visual field and adults tended to do the opposite. There was no significant interaction between age and SOA or any significant three-way interactions involving age.

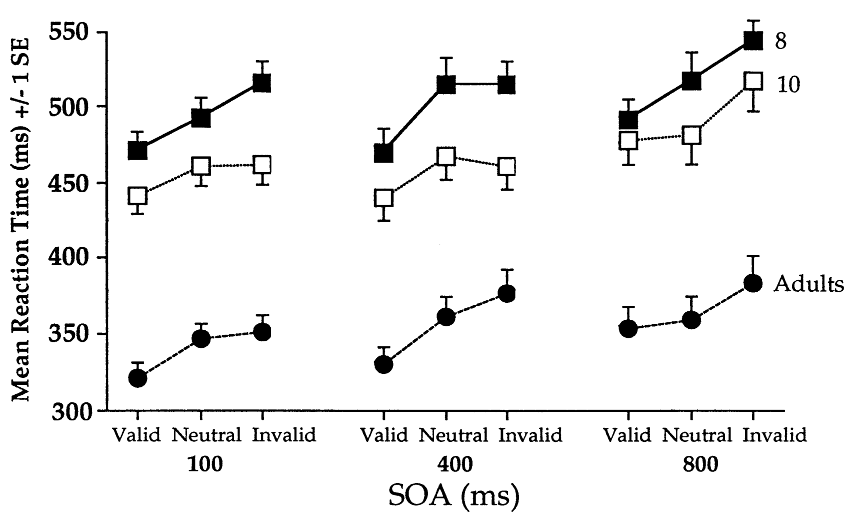

Figure 2 *Mean reaction time (±1 standard error) as a function of cue type and SOA for 8-year-olds (filled squares) 10-year-olds (open squares) and adults (filled circles) in Experiment 1. Means are connected to facilitate comparisons of the effects of the cues at different ages.*

Effects of cue and its interactions

There was a main effect of cue ($F(2, 138)$ 45.97, $p < 0.000001$). Reaction times were significantly slower on invalid trials than on neutral trials (Tukey post-test, $p < 0.001$, cost = 14.0 ms) and valid trials (Tukey post-test, $p < 0.001$, validity effect = 36.8 ms). Reaction times were significantly faster on valid trials than on neutral trials (Tukey post-test, $p < 0.001$, benefit = 22.7 ms). Cue interacted with SOA ($F(4, 276) = 3.69$, $p < 0.01$). Figure 3 shows that at the 100 ms and 400 ms SOAs, reaction times were significantly faster on valid trials than on neutral trials and invalid trials; reaction times on neutral and invalid trials did not differ significantly from each other. At the 800 ms SOA the pattern was different: reaction times on valid and neutral trials did not differ significantly from each other but reaction times were significantly slower on invalid trials than on neutral trials and valid trials (analyses of simple effects and Tukey post-tests, $ps < 0.05$). Cue did not interact with visual field ($F(2, 138) = 1.32$, $p > 0.10$) nor with visual field and SOA ($F(4, 276) = 0.88$, $p > 0.10$).

Effects of SOA and its interactions

There was a main effect of SOA ($F(2, 138) = 6.33$, $p < 0.01$). Reaction times were faster at the 100 ms and 400 ms SOAs than at the 800 ms SOA (Tukey post-tests, $ps < 0.01$). SOA did not interact with visual field ($F(2, 138) = 1.25$, $p > 0.10$).

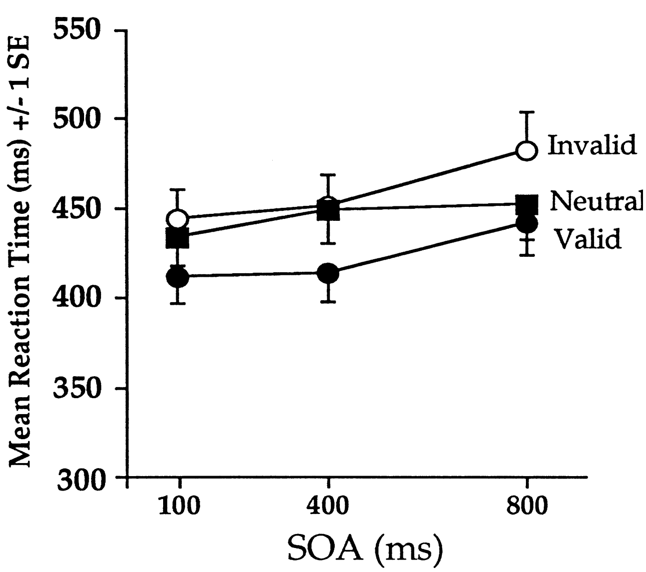

Figure 3 *Mean reaction time (±1 standard error) on valid trials (filled circles), invalid trials (open circles) and neutral trials (filled squares) as a function of SOA in Experiment 1, collapsed across age. Means are connected to facilitate comparison of the effects at different SOAs.*

Discussion

In this procedure, children were slower overall than adults. This could occur because children are slower to detect the target, program a response, and/or execute that response. More interesting is the finding that children appeared to be adult-like in the influence of the endogenous cues in changing reaction time between conditions: regardless of age, participants responded about 37 ms more quickly on trials during which the target was preceded by a valid cue than on trials with an invalid cue. The analyses involving neutral trials (and the absence of an interaction between cue and age) indicated that participants at all ages were slowed by about 14 ms by invalid cueing and profited by about 23 ms from valid cueing. Moreover, at all ages, the benefit of valid cueing was larger at the earlier SOAs, while the cost of invalid cueing was largest at the longest SOA. Thus, under these conditions, 8- and 10-year-old children use endogenous cues as well as adults to covertly orient attention.

Our results differ from those in the one previous study that examined the effects of endogenous cueing without eye movements (and that inadvertently tested adults and children at different SOAs): the overall pattern of results in that study suggested that children 6, 8 and 10 years old are slowed more than adults by invalid cueing (Brodeur, 1993; Brodeur *et al.*, 1997).[2] There are at least three possible explanations. First, Brodeur's study required the subject to recognize which of two targets occurred in an unexpected location on invalid trials rather than simply to detect that something – a large target – had occurred there. Children may be able to shift attention from the location invalidly predicted by an endogenous cue as quickly as adults when they have only to detect a large target, as was true in Experiment 1, but be much slower than adults to recognize what that target is when it appears in the unexpected location, as was true in Brodeur's procedure. Second, Brodeur's targets were presented along the horizontal meridian, whereas the targets in Experiment 1 fell on the vertical meridian. It is possible that covert orienting in response to endogenous cues develops differently along different meridia. Third, Brodeur did not correct for the bias in the mean or median reaction time that can arise when

[2] We have ignored a study that combined the results from tasks with endogenous and exogenous cues in the *post hoc* analysis of age differences (Pearson & Lane, 1990) and a study in which participants were allowed to make eye movements (Wainwright-Sharp, 1995).

there are a different number of trials in the conditions being compared. Erroneously, we also thought we had found age differences in the size of the validity effect when we did not correct the data for a reaction time bias. The results based on uncorrected medians showed that the validity effect was larger in 8-year-olds than in 10-year-olds and adults (Goldberg *et al.*, 1996).

To better understand how reaction time bias might have affected the uncorrected medians, we examined the variability of each individual's reaction times in each condition (indexed by the standard error for that individual in that condition). An ANOVA with age group, cue and SOA as factors indicated that children's reaction times were more variable than adults' reaction times (main effect of group, $F(2, 69) = 22.19$, $p < 0.001$; Tukey post-tests, $p\text{s} < 0.01$), especially in the invalid condition (group by cue type interaction, $F(2, 69) = 10.9$, $p < 0.001$; analysis of simple effects, $p < 0.001$). Thus, reaction time bias would cause the greatest inflation of the median (or mean) for children in the invalid condition because (1) those responses were the most variable, (2) that condition contained the smallest number of trials and (3) the distributions of reaction times are likely to have been positively skewed for most individuals. That inflation, in turn, would increase the size of the validity effect for children and lead to the erroneous conclusion that there are age differences in the effect of these endogenous cues. If this argument is correct, then by age 8 children are able to shift attention from a location invalidly signaled by an endogenous cue as quickly as adults on most trials. What develops after age 8 is the ability to do so consistently.

In summary, the results of Experiment 1 suggest that the neural mechanisms for covert orienting with endogenous cues are functional by age 8, but are perhaps limited to certain parts of the visual field (i.e. the vertical meridian) or easily detected stimuli, or are not used as consistently as in adults. In Experiment 2 we explored whether there are age differences even after age 8 when the task is more difficult.

Experiment 2

In Experiment 2, we made the task more difficult by requiring discrimination between two possible targets and by surrounding the target with two distractors. The purpose of requiring discrimination was to test the hypothesis that the effectiveness of endogenous cues is adult-like by 8–10 years of age only for an easy task like detection of the large target used in Experiment 1. The purpose of adding distractors was to test whether with endogenous cues, as has been reported with exogenous cues (Akhtar & Enns, 1989), there is an interaction between invalid cueing and incompatible distractors. In addition, we wished to test the generality of the claim that the ability to orient attention develops more rapidly than the ability to filter out irrelevant information (e.g. Plude *et al.*, 1994). Although there is much evidence for the protracted development of the ability to filter out irrelevant information (e.g. Ridderinkhof & van der Molen, 1995), there has been no previous study of its relationship to the orienting of attention controlled by endogenous cues.

The procedure was similar to that used in Experiment 1 except that participants had to indicate which of two shapes appeared on each trial, and consequently, we were able to measure accuracy as well as reaction time. Surrounding each target were two distractors that were either (1) compatible, identical to the target shape and hence mapped to the same response as the target, or (2) incompatible, identical to the other shape and hence mapped to the opposite response from the current target. We will refer to these as compatible and incompatible distractors, respectively. Thus, in Experiment 2, the participant was asked to shift attention covertly before the target appeared, to ignore distracting stimuli surrounding the target, and to recognize which of the two target shapes appeared.

We began by testing 10-year-olds and adults, with the intention of testing younger subjects if 10-year-olds proved to be adult-like. In order to obtain as much data as possible in each condition, we restricted testing to a 400 ms SOA, the SOA at which previous studies have shown the largest validity effect in adults with endogenous cues (Müller & Findlay, 1988; Goldberg *et al.*, 1996; Goldberg, 1998).

Method

Participants

The sample consisted of 24 10-year-old children (mean age 10.0 years, range 9.8–10.2 years) and 24 adults (mean age 20.4 years, range 18.6–26.2 years). The inclusion criteria were the same as those described in Experiment 1. An additional five participants were excluded from the final sample because they failed the vision screening examination (two 10-year-olds, one adult), made errors on more than 50% of the trials (one 10-year-old) or reported fatigue during the task (one adult).

Apparatus and stimuli

The apparatus and endogenous cues were the same as in Experiment 1. The targets, a plus sign and a circle, were centered 9.0° (5.7 cm) directly above or below the center of the central stimulus and appeared in the same locations as the boxes in Experiment 1 (see Figure 1). The distractor shapes were identical to the targets and were aligned horizontally beginning 1.6° (1.0 cm) from the nearest edge of the target. The nearest edges of the targets and distractors were 5° and 7.4° (3.2 and 4.7 cm), respectively, from the center of the central stimulus.

Procedure

The procedure was the same as in Experiment 1 with the following exceptions. There were a total of 200 trials with one of two targets (plus sign or circle) presented randomly on each trial under a combination of one of three cue conditions (120 valid trials, 40 invalid trials, 40 neutral trials) and one of two distractor conditions (100 trials with compatible distractors; 100 with incompatible distractors). Participants were asked to indicate whether a target was a plus sign or a circle by pressing one of two designated buttons on a keyboard. Participants were tested only at a 400 ms SOA and were provided with auditory feedback ('great' or 'whoops') regarding the accuracy of their responses. The feedback was auditory in order not to interfere with the processing of visual information. Participants were given practice until they completed 10 consecutive trials correctly without eye movements. Participants took about 20 practice trials.

Data analyses

Trials on which participants made eye movements were eliminated before conducting analyses of accuracy and reaction time. Adults made eye movements on fewer trials than 10-year-old children (two-tailed t test, $p < 0.05$; see Table 1).

Accuracy was greater than 96% in all conditions at both ages. For the analyses of reaction time, we included only correct trials and, because there were more trials in the valid condition than the other two conditions, used van Selst and Jolicoeur's (1994) procedure for removing outliers from the mean for each participant in each condition. The percentage of scores eliminated by the moving criterion was 2.99% for 10-year-olds and 2.43% for adult participants. Because there were so few errors, we did not adjust the reaction times on correct trials for the number of errors (see Akhtar & Enns, 1989). The data on accuracy and reaction time were subjected to an ANOVA with one between-subject factor, age (adults, 10-year-olds), and three within-subject factors: cue type (valid, neutral, invalid), distractor type (compatible, incompatible) and visual field (lower, upper).

Results

Reaction time

Effects of age and its interactions There was a significant main effect of age ($F(1,46) = 121.48$, $p < 0.0001$). Adults responded faster than 10-year-old children. Age interacted with distractor type ($F(1,46) = 5.75$, $p < 0.05$). Analyses of simple effects failed to identify the source of this interaction. As illustrated in Figure 4, participants at both ages were slower on trials with incompatible distractors than on trials with compatible distractors (main effect of distractor type, $F(1,46) = 49.65$, $p < 0.0001$, and analysis of simple effects, $p\text{s} < 0.05$). A t test comparing the difference in reaction time for trials with incompatible and compatible distractors for the two ages revealed that 10-year-olds were slowed significantly more (50.3 ms) than adults (24.8 ms) by incompatible distractors ($p < 0.01$). This is shown in Figure 4 by the larger gap between the two lines for 10-year-olds than for adults.

Compatible and incompatible distractors did not influence reaction time differentially on valid, invalid or neutral trials at either age (nonsignificant interaction of distractor type by cue type, $F(2,92) = 2.09$, $p > 0.10$; and of age by distractor type by cue type, $F(2,92) = 0.65$, $p > 0.10$). There were also no age differences in

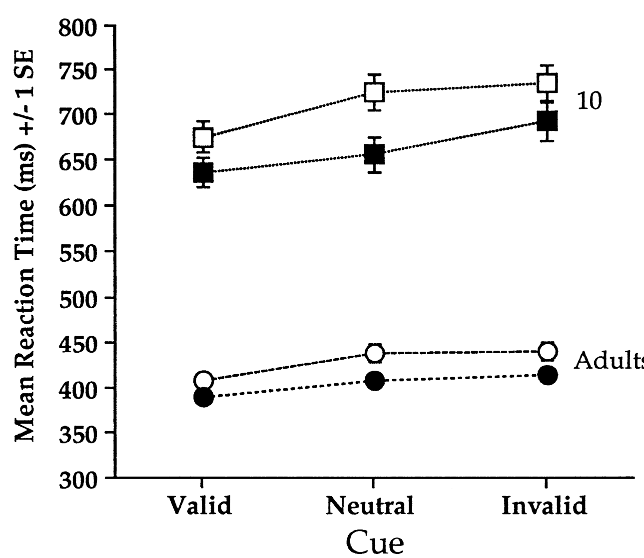

Figure 4 *Mean reaction time (±1 standard error) for 10-year-olds (squares) and adults (circles) on trials with incompatible distractors (open symbols) and compatible distractors (filled symbols) as a function of cue type in Experiment 2. Where not shown, standard error bars are smaller than the data points. Results for different cue types are connected to facilitate comparison.*

how cue informativeness altered reaction time (non-significant interaction of age by cue type, $F(2,92) = 2.46$, $p > 0.05$).

Effects of cue and its interactions There was a significant main effect of cue ($F(2,92) = 21.17$, $p < 0.0001$). As illustrated in Figure 4, participants at both ages were significantly faster on valid trials than on neutral trials and on invalid trials (Tukey post-tests, ps < 0.01, benefit = 29.0 ms; validity effect = 43.0 ms), but not significantly slower on invalid trials than on neutral trials ($p > 0.05$, cost = 13.6 ms).

Effects of visual field and its interactions Participants were faster to respond to targets in the upper visual field (519.4 ms) than the lower visual field (582.2 ms) (main effect of visual field, $F(1,46) = 166.07$, $p < 0.0001$). Visual field did not interact with any other factor ($p > 0.05$).

Accuracy

The ANOVA indicated that 10-year-olds were as accurate as adults (main effect of age, $F(1,46) = 2.76$, $p = 0.10$). Adults were more accurate when the target was in the lower visual field than when it was in the upper visual field (age by field interaction, $F(1,46) = 6.67$, $p < 0.05$; analysis of simple effects, $p < 0.05$). Ten-year-olds' accuracy was the same for targets in the upper and lower visual fields (analysis of simple effects, $p > 0.05$). None of the other interactions with age was significant (all ps > 0.05). In particular, children were not less accurate than adults on invalid trials with incompatible distractors (age by cue by distractor, $F(2,92) = 2.36$, $p = 0.10$). There was no effect on accuracy of cue type (main effect of cue, $F(2,92) = 0.42$, $p > 0.10$) or distractor type (main effect of distractor, $F(1,46) = 3.13$, $p > 0.05$).

Discussion

As in Experiment 1, 10-year-olds were slower than adults, but they showed a validity effect of comparable size: at both ages participants were approximately 43 ms slower when the endogenous cue was invalid than when it was valid. Even with this harder task, the attentional mechanisms controlled by endogenous cues appear to be adult-like by 10 years of age, at least when the targets are presented on the vertical meridian and when the reaction time distributions are corrected for outliers.

The analyses involving distractors indicated, however, that not all aspects of attention are adult-like by 10 years of age. At both ages, responses were slower when the distractors were incompatible than when they were compatible, but the effect was stronger in 10-year-olds. The difference could have arisen because incompatible distractors had a more deleterious effect on 10-year-olds than adults and/or because compatible distractors had a more facilitory effect on adults (see Enns & Akhtar, 1989, for a discussion). Whatever the explanation, our results with 10-year-olds are consistent with those of Akhtar and Enns (1989), who found that children aged 5, 7 and 9 years were slowed more than adults by distracting information surrounding targets in exogenously cued locations. In contrast, a study that required ignoring distractors but without also requiring covert orienting showed the same effect of distractors in children 10–12 years of age as in adults (Ridderinkhof & van der Molen, 1995). The comparison suggests that 10-year-olds are able to ignore distractors as well as adults under some conditions, but not if they must also covertly orient.

The effect of distractors was not altered by the informativeness of the cue (i.e. valid, neutral, invalid) at either age. These findings contrast with those from the study mentioned previously with younger children aged 5, 7 and 9 using exogenous cues and smaller stimuli oriented horizontally (Akhtar & Enns, 1989). The results from that study showed that children were slowed considerably more than adults by incompatible distractors but only on invalid trials. There are several possible explanations of the discrepant results. First, Akhtar and Enns (1989) did not correct their data for a reaction time bias, which might be most likely to inflate the mean for the most variable groups (children) tested in the condition with the smallest number of trials (invalid condition). Second, it is possible that the interaction between the validity of the cue and distractors decreases between 9 years of age (the age of the oldest group of children in Akhtar & Enns, 1989) and 10 years of age (the age of the children in Experiment 2). Third, Eriksen and Eriksen (1974) found that the greatest slowing from incompatible distractors in adults occurred at the smallest spacing (0.5°) between the target and the distractors. Therefore, it is possible that Akhtar and Enns (1989) found significant slowing by incompatible distractors on invalid trials because they used relatively small spacing between the target and the distractors (0.2° compared with 1.6° in Experiment 2), and at that spacing the effect of distractors interacts with the validity of the cue, at least for children. Finally, Akhtar and Enns (1989) tested along the horizontal meridian with exogenous cues while we tested along the vertical meridian with endogenous cues. The developmental patterns are likely to be different for exogenous and endogenous cues (Jonides, 1981) and may be different for different meridia (Previc, 1990). Whatever the explanation for the lack of interaction between the validity of the cue and the effect of the distractors in Experiment 2, our results agree with those of Akhtar and Enns that children are slowed more than adults when they have to both shift attention and ignore distractors.

In summary, under these conditions, there appear to be different developmental patterns for the ability to shift attention following endogenous cueing (Experiments 1 and 2) and the ability to ignore distractors (Experiment 2). The ability to shift attention covertly following endogenous cueing is nearly adult-like by 8–10 years of age, with any subsequent development involving the consistency of attentional responses and/or certain parts of the field. In contrast, even at age 10, the ability to ignore distractors is still immature. This pattern is consistent with other evidence of the relatively late development of the ability to filter out irrelevant information and keep attention focused on important stimuli. For example, until early adolescence children make more perseverative errors than adults and are more likely to respond to irrelevant stimuli (Levin *et al*., 1991). The relatively slow development of the ability to filter out irrelevant information is consistent with evidence that the frontal cortex, which is important for ignoring distractors in adults (Duncan, 1986; Richer *et al*., 1993; Denckla, 1996; Godefroy, Lhullier & Rousseaux, 1996; Godefroy & Rousseaux, 1996; Richer & LePage, 1996; Husain & Kennard, 1997), does not reach adult levels of synaptic density until about age 15 (Huttenlocher, 1979, 1990; Huttenlocher, DeCourten, Garey & Van der Loos, 1982–1983), much later than the parietal, occipital and temporal cortices, which are important for covert shifts of attention controlled by endogenous cues (Chugani, 1994; Huttenlocher & Dabholkar, 1997). It is also consistent with the relatively slow development of adult-like glucose metabolism in the frontal cortex (Chugani, 1994). Thus, the ability to voluntarily shift attention (controlled by endogenous cues) and to filter out distractors may develop at different rates because filtering is affected much more by the relatively slow development of the frontal cortex.

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