A new look at the developmental profile of visual endogenous orienting.

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RESEARCH HIGHLIGHTS

- Shifts in spatial attention directed by central arrow cues were examined using motor reaction times and compared to spatial shifts when monitored with eye movements.
- The two different approaches for measuring spatial shifts in attention yielded different developmental profiles.
- When orienting was measured using a manual button press target detection task, continuing development through middle childhood was found, while orienting measured by saccade-to-target showed no change between ages 6 to 12.
- These differences suggest that spatial shifts in attention are developed by age six, whereas the manual button press target detection orienting task is more likely to reflect the interaction of cognitive decision making mechanisms and motor development and maturation.
- Tasks that seek to measure orienting covertly are measuring more than just orienting, and it is those additional skills that continue to change through middle childhood.
ABSTRACT

There is a long-standing assumption that covert measurement of orienting, the shifting of the “mind’s eye” independent of a saccade to a location in space, is a more “pure” measure of underlying attention than overt measurement of orienting. Testing attention covertly often relies on target detection tasks, which depend on making a decision about when or where a target has appeared and what is the appropriate action, all of which are potential confounds in measuring attention in children. This study cross-sectionally examined developmental profiles from age 6 to 12 years of endogenous visual orienting. We used two tasks, one that measured orienting with a traditional covert attention button press response and one that measured orienting with eye-tracking to measure overt saccades. The results obtained from the two orienting tasks demonstrate that each task measures distinct underlying processes, with clear developmental profiles. Orienting, when measured by overt saccades, may be mature by age 6, while the more complex manual response selection skills required in manual reaction time covert attention tasks continue to develop through middle childhood.
Introduction

Endogenous spatial visual orienting is the voluntary goal-directed allocation of visual attention to a particular location. Information that is attended is processed to an enhanced degree over information that is not. Some researchers have used the analogy of a spotlight and/or a camera lens (capable of expanding and contracting; Eriksen & Hoffman, 1972; Eriksen & Yeh, 1985; Posner et al., 1978) to describe the prioritized nature of information within the attended location.

Visual orienting is measured in young children with overt responses, typically the turning of the head towards an event, whereas in older children and adults it is predominantly measured covertly, such as with the classic cued target-detection task (Posner, 1980), in which the shift of attention is presumed to occur in the absence of an overt eye-movement and performance is measured by manual reaction time. This latter task involves a spatial cue presented in advance of a target. For example, an arrow pointing to the right appears 300 ms before a target; if the target also appears on the right, then target detection is faster than if the cue and target were incongruent, and the inference is made that attention was deployed to the cued location in advance of the target. Target detection responses are indicated with a button press, rather than an overt shift to the target, and the task is assumed to measure orienting covertly, shifting “the mind’s eye” independent of an eye movement, for the following reasons: First, adult participants reliably detect peripheral targets that appear at short intervals after the central cue, too short to allow the participant to make an eye-movement. Second, participants are typically instructed to maintain central fixation and eye positioning is frequently
Development of orienting monitored. Target detection responses are made with a manual response (button press), and subtraction logic is used to measure orienting; namely, how fast one detects a target when it was incongruently (or misleadingly) cued minus how fast one detects a target when it was congruently cued. Researchers have also demonstrated that these covertly measured shifts of attention are closely tied to eye-movements, such that covertly measured orienting has been described as an oculomotor preparation (Klein, 1980) and both eye movements and shifts of covertly measured attention without an accompanying eye movement are controlled by similar mechanisms (Rizzolatti, Riggio, Dascola, & Umilta, 1987; Smith, Rorden, & Jackson, 2004). Thus, manual target detection as opposed to saccade onset became the standard method of measuring orienting; detection became a proxy for attention.

Yet, in his seminal paper, Posner (1980) set out the distinction between attention and detection. Evidence for this distinction was provided by a case study of a neurological patient with “blind sight” who could orient to a stimulus but was unable to verbally report its presence (Weiskrantz et al., 1974). This distinction between overtly attending and the capacity to verbally report or indicate that attention resources were directed to one location over another is particularly relevant to studies of children and clinical populations and raises questions as to if the overt orienting noted by Weiskrantz et al. (1974) was a vestigial use of the evolutionarily older subcortical superior colliculus to pulvinar and frontal eye fields system (Bridge et al., 2016; Warner et al., 2015). Posner’s task is intended to measure covert orienting, however its use with children and clinical populations is constrained by the capacity of these groups to respond reliably. The modality of response is typically a button press; the participant presses a single
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button to indicate target detection, or the participant has to make a choice among buttons to not only indicate I saw it but also to indicate location and identity of the target. While children as young as 3 years old (Ristic & Kingstone, 2009) have been tested using computer-administered attention tasks, younger children perform these tasks with significantly more errors than older children (e.g. Lewis et al., 2018; Buss et al., 2011; Rueda et al., 2004). Furthermore, the age at which children are deemed to reach “adult” performance varies as a function of response modality. This begs the question – what aspect of performance changes with age?

Age related improvements in endogenous (central-cue) orienting have been reported from age 6 years, however it remains unclear when performance reaches adult levels (Brodeur & Enns, 1997; Pearson & Lane, 1990; Wainwright & Bryson, 2005). Brodeur and Enns (1997) reported that children aged 6 to 10 years differed from adults, and argued that children’s large orienting effects were evidence that what improved through adolescence was the ability to sustain attention. Pearson and Lane (1990) also reported that 11-year-olds, but not 8-year-olds, were adult-like in their orienting. In contrast, Wainwright and Bryson (2005) reported that children 10-years and older demonstrated orienting patterns similar to those of adults. Thus, the evidence seems to converge on the finding that by age three (Ristic & Kingstone, 2009), children can show orienting on the same computerized tasks as adults, but that these orienting effects change both in magnitude and as a function of SOA with age, achieving adult-like patterns around 10-11 years old. But herein lies an important point about the role of detection. Ten year-olds orient like adults when they are required to use a single key response to indicate target present (Wainwright & Bryson, 2005) but orient like younger children
when they are required to map four cues to four potential target locations or when they also have to make target identification decisions, such as whether the target was X or O (Brodeur & Enns, 1997). The more parsimonious explanation is that the performance differences were due to task demands of the more complex response mapping, not orienting.

Further evidence that what is measured on traditional covertly measured orienting tasks may be more complex and tap skills above and beyond orienting comes from a pair of experiments by Enns and colleagues. First, Enns and Cameron (1987) demonstrated that when children could saccade to a target, there was no competition between filtering out the distractor arrows and orienting to the target arrows. Second, Akhtar and Enns (1989) demonstrated that under traditional covertly measured orienting conditions, filtering out the distractor targets competed for shared resources and this competition decreased with age. Enns and colleagues argued that these two studies demonstrate that the underlying mechanisms tapped by covertly and overtly measured orienting paradigms are differentially affected by concurrent cognitive demands in children and change as a function of age.

In the present investigation, we contrasted performance on two orienting tasks, designed to tease apart covertly and overtly measured orienting. We hypothesised that covertly measured orienting, where orienting is inferred by measuring manual button press target detection, competes for cognitive resources in the developing brain, and is thus not as simple a measure of orienting as overtly measuring orienting with a gaze shift; covert orienting involves suppressing a peripheral eye-movement, making a decision as to the appropriate response to indicate the target has been detected, and formulating the
appropriate motor plan. These issues may be irrelevant to adult research as the competing cognitive skills would be fully mature and the assumptions underlying covert orienting measured through manual response may be more appropriate. With the range of cognitive skills developing along potentially asynchronous trajectories and contributing to children’s performance on covert orienting tasks, we must question the assumption that the classic covert orienting task, which relies on a manual response, adequately represents underlying orienting performance in children.

With this in mind, we sought to contrast orienting performance in children aged 6 through 12 years, by contrasting performance on classically inspired endogenous orienting tasks, one in which eye-tracking was used to measure saccadic RT (hereafter referred to as the Gaze task), and one in which a manual button press was used to measure RT (hereafter referred to as the Manual task). While we cannot measure or control covert shifts of attention from occurring prior to an overt shift on the Gaze task, we used eye-tracking to remove any trials in which overt shifts occurred on the Manual task. We used a range of stimulus onset asynchronies (SOAs) to examine the temporal patterns of orienting and 75% congruent central arrow cues.

In accordance with previous research described above, we hypothesised that children would respond faster to targets following congruent cues on both tasks, and we hypothesised that performance would differ with age on the Manual task. If the Manual task requires additional cognitive resources above and beyond those required of the Gaze task, we would expect to see a more pronounced age-related effect on the Manual task and a muted (or null) age-related effect on the Gaze task.
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Method

Participants

Sixty children aged 6;2 (year; month) through 11;9 were recruited and tested in two public primary schools in a medium-sized regional Australian city (43% female, mean age=9.3, sd=1.6, min=6.2, max=11.8). Of these, 52 children had complete data for both experimental tasks and were included in the final analyses. Of the eight children excluded (6 male / 2 female), three did not complete the Manual task, while five had completed both tasks but were missing data in one or more cells. To examine age-related changes in performance, age was divided into quartiles of 13 participants (see Table 1). The study was approved by the Human Research Ethics Board of La Trobe University, as well as the Victorian Department of Education and Training (Australia), and was performed in accordance with the 1964 Helsinki declaration and its later amendments.

Materials

The Tobii Pro TX300 (Tobii AB, Danderyd, Sweden) system was connected to a Dell Precision M6800 mobile workstation (Dell Inc, Round Rock, TX, USA) to record eye gaze positioning over time along both the X and Y dimensions for both the Gaze and Manual tasks. The system captured 300 frames of eye gaze data per second. The screen monitor was 23 inches in size, with an aspect ratio of 16:9, and a screen resolution of 1920 x 1080 pixels. The monitor was placed at a viewing distance of 60 cm when participants were seated with a chin rest. Responses were recorded using an E-Prime compatible Chronos button box (Psychology Software Tools Inc, Pennsylvania, USA), placed centrally in front of the child, with response buttons comfortably accessible to both the child’s right and left hands.
Measures

Gaze task. Figure 1 illustrates the temporal sequence of events for a given trial. Participants were instructed to always fixate on a black X over a grey background (RGB: 192, 192, 192) that subtended 0.5° in visual angle and follow it with their eyes as it changed to different locations. A trial began with the presentation of this X in the centre of the computer screen. A white arrow cue appeared behind the X. The arrow remained visible for one of 6 different SOAs over 144 trials (150ms, 300ms, 450ms, 600ms, 750ms and 900ms) and subtended 2.5° in visual angle in width. The arrow cues were predictive of the target location with 75% congruency / 25% incongruency. The X disappeared from its central location and reappeared immediately afterwards to either the left or right hand side of the screen 9° in visual angle from the centre of the computer screen. The X was presented at this new location for 500 ms. A picture of either an animal or object, representing the target, appeared behind the X for an additional 500 ms. These images consisted of colour versions of the Snodgrass and Vanderwart (1980) dataset created by Rossion and Pourtois (2004). A total of 96 images, 48 animals and 48 objects, were used and subtended an average of 2.9° in visual angle. The selection of what picture was displayed on each trial was programmed to occur on a random basis. On average, 50% of trials were animals and 50% were objects. Participants were instructed to follow the X with their eyes. Participants were also instructed to press a button if, and only if, the target was an animal, however this instruction was only to promote engagement. Saccade reaction times were determined using the time taken to complete a saccade to the target location from the centre of the computer screen, from the onset of the X changing
location. Targets remained on the screen for 1,500 ms or until participants pressed a button. After the target disappeared, the X reappeared at the centre of the screen.

*Manual task.* Figure 2 illustrates the temporal sequence of events for a given trial. The task was adapted from the standard endogenous orienting task. This task contained the same contingency, SOAs, and number of trials as the Gaze task, however in this task the target was always a star, which subtended 2.6° in visual angle. Participants were instructed to indicate the location of the star by pressing one of two buttons on the response box. A trial began with the participant fixating on the centre of the screen on the same X as in the Gaze task. The target appeared either to the left or right of fixation, 9° in visual angle from the centre of the computer screen. The target remained present until the participant made a response. The next trial began 1,000 ms later. Reaction times were taken from this manual response.

*Procedure*

The participants were tested individually in a quiet room in their school. The order of tasks was counterbalanced across participants in an alternating order. Each task was presented to participants in three blocks of 48 trials with self-timed breaks in between. All three blocks were typically completed in less than five minutes. Each task began with a calibration series of red dots on the screen, which participants were instructed to follow with their eyes. During the Gaze task, participants were instructed to follow the X that appeared on the screen and press a button with their dominant hand if they saw an animal. The participants were instructed to do nothing if they saw any other images, just keep following the X. This instruction served to keep children engaged through the task. During the Manual task, participants were instructed to keep their eyes
on the central fixation X throughout the task. If participants had difficulty maintaining fixation, the experimenter encouraged them to try their best, however they were not penalised for saccades that occurred after target onset. The participants were not given any instructions with regards to the arrows or their contingencies. No training was provided.

**Data pre-processing and analysis**

For the Gaze task, we analysed the eye-tracking data using in-house scripts written in Matlab (Mathworks, Inc., Natick, Massachusetts, USA). For each individual, we extracted the eye gaze positioning along the X dimension. Eye-gaze positioning along the Y dimension was not analysed given we purposely designed the experiment to direct participants to make their saccades along the horizontal axis. A moving median filter with a three point window was applied to this data to remove any spiking artefacts (Martinez et al., 2008; Chouinard et al., 2017). This filter passed through each data point in the signal and replaced each entry with the median of its neighbouring entries. As illustrated in Figure 3, we plotted the eye-gaze positioning over time between 1,000 ms before target onset and 2,000 after target onset on a trial-by-trial basis. In Matlab, we manually indicated the point on the plot when the participant completed the saccade. This was defined as the first point with a 300 pixel deviation to either the left or right of fixation. A reaction time measure for completing a saccade was then calculated by subtracting this time point from the time point when the target first appeared (Figure 3). Inspection of each trial and manual definitions of saccadic onset were deemed essential to prevent any preparatory or false saccades from being recorded. To check for reliability, we had a second rater repeat these measurements in a subset of ten randomly selected individuals.
Correlating the average scores for each condition across the ten individuals yielded a high inter-rater reliability score ($r = .88$).

Eye-tracking also provided information about the efficiency of the oculomotor system as determined by calculating the peak velocity of eye movements in each trial. The rational here is the following: the oculomotor system is more efficient, and conceivably more developed, in children who can move their eyes faster from one location to another. Velocity was defined as the first derivative of position with respect to time. To obtain this measurement, the eye-gaze positioning data were first differentiated with a 3-point central difference (Bahill et al., 1982) to determine the rate of change. These data were then plotted as a function of time and the peak of this change was recorded as the peak velocity (Figure 3). This measurement was taken as an index of oculomotor development under the assumption that children who can move their eyes more efficiently have a more developed oculomotor system.

All trials in which the participant did not maintain fixation, defined as a deviation greater than 50 pixels, during the presentation of the target, including those in which a saccade was initiated before its appearance, were excluded from the analyses. Trials in which the participant made an incorrect button response during the classification task were also not considered in the analysis of saccade times. Last, trials in which the eye tracker was not recording data properly, particularly between the critical period from cue to saccade onset, were likewise excluded from the analysis. 30.52% of trials were excluded for one or a combination of the above reasons. Reaction times to the classification task, which is a Go/No-Go task, are presented following the main analyses.
For the Manual task, reaction times were calculated from the time the participant pressed the response box from the time the target appeared. We also processed and plotted the eye-tracking data on a trial-by-trial basis in the same manner as we did for the Gaze task. This was only done for the purposes of verification and no dependent variables were extracted from the eye tracking given that participants were instructed not to make saccadic eye movements. Specifically, we looked at the eye tracking data so we could flag any trials in which the participant did not maintain fixation, defined again as a deviation greater than 50 pixels, during the presentation of the target, including those in which a saccade was initiated before its appearance, so that they could be excluded from the analyses. Again, trials in which the participant made an incorrect button response and / or in which the eye tracking data was not recorded properly were likewise excluded from the analysis – 17.58% of trials were excluded for one or a combination of the above reasons.

Statistical analyses

For the Gaze task, the dependent variable was the time (ms) to complete a saccade to the target and for the Manual task the dependent variable was the reaction time (RT) (ms) of the button response to the target’s appearance. A 2 (Task) by 2 (Congruency) by 6 (SOA) by 4 (Age) Mixed ANOVA was used to examine reaction time. Interactions were examined with simple effects tests. If the cue elicited a shift of attention then this would be evidenced in a significant effect of the Congruency factor. As such, any interaction with Congruency was of interest, particularly if the Congruency effect differed as a function of Task or Age. In addition, we analysed peak velocity and both accuracy and reaction times on the classification (Go/No-Go) responses during the Gaze
task, as well as accuracy (target detection) on the Manual task. Peak velocity provided information as to how fast the eyes could move, indexing efficiency of the oculomotor system, while the accuracy measurements provided information about task difficulty. These dependent measures were each analysed with a 2 (Congruency) by 6 (SOA) by 4 (Age) Mixed ANOVA.

Results

Main analysis: Gaze vs Manual orienting tasks

Main effects were found for all four factors: Task, $F(1,48) = 656.76$, $p < .001$, $\eta^2_p = .932$, Congruency, $F(1,48) = 330.01$, $p < .001$, $\eta^2_p = .873$, SOA, $F(5,240) = 25.38$, $p < .001$, $\eta^2_p = .346$, and Age, $F(3,48) = 15.84$, $p < .001$, $\eta^2_p = .498$. Interactions were found with Task x Age, $F(3,48) = 6.35$, $p < .001$, $\eta^2_p = .284$, Congruency x Age, $F(3,48)=8.31$, p<.001, $\eta^2_p = .432$, Task x Congruency, $F(1,48)=26.45$, p<.001, $\eta^2_p = .355$, Task x SOA, $F(5,240) = 5.87$, $p < .001$, $\eta^2_p = .109$ and Congruency x SOA, $F(5,240) = 7.06$, $p < .001$, $\eta^2_p = .128$. Three-way interactions were also found with Age x Congruency x Task, $F(3,48) = 5.57$, $p = .002$, $\eta^2_p = .258$, Age x Congruency x SOA, $F(15,240) = 1.97$, $p = .018$, $\eta^2_p = .11$, and Task x Congruency x SOA, $F(5,240) = 3.18$, $p=.014$, $\eta^2_p = .062$ (Greenhouse Geisser correction applied). The three-way interactions were probed further using simple effects tests with Bonferroni corrections applied to paired comparisons, and are shown in Figures 4-6.

Age x Congruency x Task: A further evaluation of this interaction (Figure 4) reveals that congruency effects changed with age on the Manual but not the Gaze task. Specifically, the interaction was driven by congruency effects that decreased sharply with age in the
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Manual task, $F(3,48) = 8.913, p < .001, \eta^2_p = .358$, but showed little age-related change in the Gaze task, $F(3,48) = 1.943, p = .135, \eta^2_p = .108$, although significant congruency effects were found for every age on both tasks (all $ps < .001$, all congruency effects $> 34$ ms).

**Age x Congruency x SOA.** The Age by Congruency by SOA interaction (see Figure 5) was driven by differential congruency by SOA patterns across ages; the three younger groups showed benefits of congruent cues varied with SOA, whereas the costs of incongruent cues did not vary with SOA. The oldest group showed a different pattern of results, in which benefits of congruent cues did not vary with SOA, whereas the costs of incongruent cues did vary with SOA (Figure 5).

Pairwise comparisons with Bonferroni corrections for multiple comparisons showed that for the 6;2 – 8;1 group, RTs following congruent cues at 150 and 300 ms were slower than all other SOAs ($ps<.005$), which did not differ from each other. In the 8;3 – 9;3 group, RTs following congruent cues at 150 ms were slower than all other SOAs ($ps<.05$) and RTs following congruent cues at 300 ms were slower than at 450 and 750 ms ($ps < .05$), with no differences between SOAs found at the longer SOAs. In the 9;4 – 10;8 group, RTs following congruent cues at 150 ms differed from all other SOAs ($ps<.02$), which did not differ from each other. In the 10;10-11;9 group, RTs following incongruent cues at 150 and 300 ms were slower than at 900 ms ($ps<.05$), with no differences for the mid-range SOAs. Pairwise comparisons with Bonferroni adjustments for multiple comparisons also confirmed that the two youngest groups exhibited orienting (faster RTs following congruent than incongruent cues), whereas the third group did not
show a significant orienting effect at 150 ms SOA, and the oldest group did not show a significant orienting effect at 900 ms SOA.

**Task x Congruency x SOA:** The Task by Congruency by SOA interaction was driven by differential congruency by SOA effects across the two tasks. Participants responded more quickly as a function of SOA during the Manual incongruent and congruent trials and the overt congruent trials. In contrast, participants responded with similar RTs during the overt incongruent trials across the six SOAs (Figure 6). In other words, benefits of congruent cues varied with SOA in saccades, whereas both benefits and costs varied as a function of SOA in motor responses. Pairwise comparisons with Bonferroni corrections for multiple comparisons showed that on the Gaze task, responses following congruent cues at 150 and 300 ms were slower than at all other SOAs ($p$s<.04). The patterns on the Manual task were more complex. On the Manual task, responses following congruent cues at 150 ms were slower than at all other SOAs ($p$s<.003), but at 300 ms responses were slower than 450 ms and 600 ms, but not 750 ms and 900 ms ($p$s<.003); responses at SOAs from 450 ms through 900 ms were not significantly different from each other. On the Manual task, responses following incongruent cues at 150 ms were slower than at 750 ms and 900 ms ($p$s<.02), and slower at 450 ms than at 750 ms ($p$=.033).

*Additional analyses*

Peak velocity measures from the eye-tracking obtained on the Gaze task were also analysed. Peak velocity was examined with a 2 (Congruency) X 6 (SOA) X 4 (Age Group) Mixed ANOVA. There were no significant differences found.

Accuracy on the Manual task was examined with a 2 (Congruency) X 6 (SOA) X 4 (Age Group) Mixed ANOVA. There were no significant differences found. Accuracy
was in excess of 96%. Speed accuracy trade off was examined with Pearson correlation coefficient; there was no speed accuracy trade-off ($r(53) = -.076, p = .58$).

**Go/No-Go performance**

The accuracy and reaction times were also examined of the Go/No-Go classification instruction given to participants on the Gaze task to promote task engagement. Each of accuracy and reaction times were examined with a 2 (Congruency) X 6 (SOA) X 4 (Age Group) Mixed ANOVA. There were no significant differences found on accuracy. A main effect of age was found on reaction time, $F(3,28) = 3.46, p = .029, \eta^2_p = .27$. Pairwise comparisons revealed that the youngest group was significantly slower than the oldest group (mean difference = $98$ ms, $p = .032$); no other comparisons were significant.

**Discussion**

The aim of this study was to contrast performance on tasks designed to elicit endogenous orienting in children aged 6 through 12 years, by examining both performance on a classically inspired covert orienting task using a manual button press measure, and on overt orienting to a target, using eye-tracking to measure saccadic RT. We found that age-related differences in performance were only found on the task in which orienting was measured by manual button press target detection. No performance differences were found across age groups on the task in which orienting was measured by saccade to target. These findings suggest that what changes with age is not the spatial shift of attention but rather additional age-related change in other cognitive control mechanisms related to performance on the task in which orienting was measured by
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manual button press target detection; such as decision-making related to the motor response necessary to indicate target detection by using a left or right button. On the basis of previous research, younger children were argued to have less ability to sustain attention to the cued location (Brodeur & Enns, 1997) and experience greater costs of incongruent cues, as opposed to older children and adults who experience benefits of congruent cues (Pearson & Lane, 1990; Wainwright & Bryson, 2005). These previous studies, however, all employed a manual target detection task similar to our Manual task.

All children were faster to make a saccade to a target following a congruent cue than an incongruent cue, even though they were never given any instructions pertaining to the cue; the children were instructed to follow the X, the direction of which could be predicted on the basis of the cue and was an accurate predictor on 75% of trials. As expected, the magnitude of the orienting effect on the Manual task decreased as a function of age. Both the Manual and Gaze tasks were testing the endogenous orienting system because they both used the same predictive central arrow cues. The key difference between the two tasks was the manner of responding – the Manual task required a more sophisticated response in that the child had to select an action based on a learned association which otherwise would not afford that action.

In a comprehensive review of the literature pertaining to the development of attention, Ristic and Enns (2015) concluded that exogenous orienting of attention remains stable from early childhood, and instead it is the voluntary or endogenous control of attention that improves through middle childhood. We take this assertion a step further and argue that most studies have measured the endogenous orienting of attention in children using a button press response and thus were testing the development of these
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more sophisticated response mechanisms. Children were found to detect targets faster following a congruent cue, but this orienting effect only became more efficient with age in children’s fingertips, not with their eyes. We must conclude then that what becomes more efficient with age is a translation of that simple “attentional” shift into a response choice of a manual action and the inhibition of a saccade.

Indeed, the differences in profiles between the Gaze and Manual tasks leads to some interesting speculations. For millennia, people have shifted their attention with their eyes in response to learned social cues, such as the eye gaze and hand gestures of others. Although computer screens are a recent technological innovation, the Gaze task may simulate similar situations well enough to tap into the same mechanisms that mediate these behaviours in the real world (Striemer et al., 2015). Conversely, the Manual task requires an additional set of demands that are arguably even more ecologically removed. In addition to seeing visual stimuli on a computer screen, the participants are also selecting actions to learned cues by computerised button presses. Thus, it is not to say that the mechanisms are completely dissociable between our two tasks but rather that the Manual task may require additional processes. We suggest the Gaze task may be a more direct and ecological measure of endogenous orienting of attention than the Manual task. And using this approach, it may be that the endogenous orienting of attention system is as stable in early childhood as the exogenous system when one makes the task as simple and as ecological as possible using eye movements as a proxy of attention.

Possible explanations for the differences in patterns of performance between the Gaze and Manual task are as follows: First, the selection of the manual response layered over endogenous orienting may be tantamount to a dual task for the children, however,
the Gaze task contained both the orienting and a go-no task. It is thus unlikely that dual
task accounts for the age related differences on the Manual task.

Second, age related differences on the Manual task could reflect increased manual
dexterity (Gogola et al., 2013) and the development of the corticospinal tract (Eyre, 2003)
that are both known to continue to mature well into adolescence. There was an effect of
age in how fast participants responded with button pressing. In contrast, we found no
differences on the peak velocities of the saccades in the Gaze task. The lack of an effect
of age on peak velocities demonstrates how the oculomotor system was equally efficient
in moving the eyes across age groups. With this in mind, it is perhaps more sensitive to
study the mechanisms of attentional shift using eye movements, which rely on the
oculomotor system that may be fully mature in this age sample, than manual responses.
Note also how age-related changes in manual dexterity cannot explain age-related
changes in the orienting effect (i.e. differences between incongruent and congruent
reaction times). Logic would dictate that any age-related effects of manual dexterity
would equally apply to the congruent and incongruent conditions.

Some subtle age differences were observed in the SOA findings, when the data
were collapsed across the two tasks. The older the child, the greater their exhibition of the
benefits of the congruent cue at shorter SOAs up to the oldest group, for whom SOA
ceased to influence congruent cue benefit, and swapped to influencing incongruent cue
costs (Figure 5). This finding is consistent with, but more nuanced than the suggestion of
Brodeur & Enns (1997) that sustained attention improves with age. The ability of
younger children to sustain attention to the cued location improves with age, followed by
the ability to disengage and shift that attention when the cued location was a misdirection.

We also found that the benefits of congruent cues (but not the cost of incongruent cues) varied with SOA in saccades (Figure 6), whereas both benefits and costs varied with SOA in manual responses. It is possible that the slower manual response, along with the longer SOA, allowed time for cognitive feedback to operate and negate the incongruent cue effect, allowing for anticipation of the target during the Manual task. The faster eye saccade may not have afforded this time for feedback during the Gaze task.

**Methodological considerations and future directions**

In this study, the eye-tracking data was inspected for maintenance of fixation on a trial-by-trial basis and to ensure that the appropriate, as opposed to erroneous, saccades were measured. This is less of concern for adults who are more task compliant, have greater attentional focus, and typically yield cleaner data. Indeed, about 30% of trials did not meet quality control and had to be removed in the Gaze task. Our inter-subject reliability of $r = 0.88$ was quite good – providing confidence in the precision of our procedures.

We have tested responses on two separate tasks, rather than measure the saccadic and manual responding on a single task. It could be argued that overt and covert orienting were present on both tasks. We have removed overtly oriented trials on the Manual task by examining the eye-tracking data and removed trials in which the participant made a saccade in excess of 50 pixels. We cannot remove covert orienting from the Gaze task, however we are confident that we have measured separate processes given the slower
reaction times overall on the Manual task, and the different patterns of results. Manual attention is purported to be faster than eye-movements, and can only be measured when eye-movements are inhibited, but the methods used to measure it are slower than the directly measurable eye-movement. Whenever a purported cognitive mechanism can only be measured indirectly, we must remain critical of these indirect measures. Future studies, using child-friendly electroencephalography (EEG) or functional near-infrared spectroscopy (fNIRS) may be necessary to further unpack these mechanisms at a neural level.

We have estimated costs and benefits associated with incongruent and congruent cues, however we did not include neutral cues and thus cannot be sure how much of a presumed cost of an incongruent cue is in fact cost, and how much of a presumed benefit of a congruent cue is in fact benefit. The standard method of measuring cost and benefit is to measure congruent and incongruent cues relative to neutral uninformative cues. This would be an interesting additional condition for the Gaze task for future studies. We are also limited in making assertions about the developmental course of performance beyond the age range tested. We did not test children younger than 6, however, the Gaze task would be appropriate for younger children in future studies. We also did not test adults, and thus do not yet know what is adult-level performance and at what age this is achieved.

Summary

In this study, we contrasted visual orienting performance measured with saccades, and measured using traditional manual button presses. We have presented data suggesting that children’s performance on these two tasks differs and that while children exhibited
orienting on both tasks, age-related differences were only seen on the task that required manual button press responses. Developmental change as measured on the orienting task with manual button press response may incorporate a more sophisticated set of response mechanisms than do overt eye movements. We conclude that what becomes more efficient with age is a transformation of the “attentional” shift into a manual action. We propose that the endogenous orienting of attention system is as stable in early childhood as the exogenous system.


Table 1. Participant characteristics by quartile. Minimum, maximum, and mean ages are given in decimals. The quartiles are described in year;months.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>N</th>
<th>Male/Female</th>
<th>Min - Max</th>
<th>Mean</th>
<th>sd</th>
</tr>
</thead>
<tbody>
<tr>
<td>6;2 – 8;1</td>
<td>13</td>
<td>6/7</td>
<td>6.16-8.08</td>
<td>7.11</td>
<td>.66</td>
</tr>
<tr>
<td>8;3 – 9;3</td>
<td>13</td>
<td>10/3</td>
<td>8.33-9.25</td>
<td>8.84</td>
<td>.38</td>
</tr>
<tr>
<td>9;4 – 10;8</td>
<td>13</td>
<td>5/8</td>
<td>9.33-10.67</td>
<td>9.82</td>
<td>.36</td>
</tr>
<tr>
<td>10;10 – 11;9</td>
<td>13</td>
<td>7/6</td>
<td>10.92-11.75</td>
<td>11.43</td>
<td>.29</td>
</tr>
</tbody>
</table>
Figure 1. Saccade response task. Each trial began with an X presented for 1,000 ms, followed by an arrow cue presented for one of 6 SOAs, which was then followed by the X moving either to the left or right of fixation. This X was presented alone at this new location for 500 ms followed by the target behind it for 500 ms. Participants were instructed to follow the X with their eyes and press a button only if the target was an animal. They had 1,500 ms from target onset to respond. After the target disappeared, the X returned to the centre of the computer screen.
Figure 2. Manual response task. Participants were instructed to maintain central fixation to the best of their ability and press one of two buttons to indicate the location of the target when it appeared. Each trial began with an X presented for 1,000 ms followed by an arrow cue presented for one of 6 SOAs. This was immediately followed by the target presented either to the left or to the right of the X. The target remained on the screen until a response was made. The target disappeared immediately after the response was made. The next trial began 1,000 ms later.
Figure 3. Eye-tracking analysis of a sample trial in the Gaze task. To measure the reaction time in the Gaze task (in blue), the positioning of the eye along the X dimension was plotted as a function of time (A) in Matlab. A rater selected the time point when the participant completed the saccade using a cursor. The reaction time was defined as this time point minus the time point when the target appeared (in orange). To measure the peak velocity in the Gaze task (in green), the eye tracking signal was also differentiated and plotted as a function of time (B) in Matlab. A rater then selected the peak change in the signal to represent the peak velocity using a cursor. Cue onset for this trial is denoted in magenta. The data in this figure corresponds to one trial in a representative participant for the purposes of illustrating how various measures were calculated.
Figure 4. Interaction between age, task, and congruency. The graph on the top shows the reaction times, while the graph on the bottom shows the magnitude of the orienting effect (incongruent minus congruent RT). A significant congruency effect was observed at each
age on each task, as well as significant effects of task at each level of age and congruency, and significant effects of age at each level of task and congruency. The magnitude of the congruency effect, also known as the orienting effect, differed as a function of age and task. The magnitude of the orienting effect (the difference between the benefit of a congruent cue and the cost of an incongruent cue) decreased with age on the Manual task only; no age-related change was observed for the Gaze task. This pattern indicates that age-related changes in orienting performance are only occurring at the level of motor responses, as orienting effects were stable across age when measured at the level of saccades.
Figure 5. Interaction between Age, Congruency, and SOA. The three-way interaction indicates that the congruency by SOA interaction varies by age group. P-values reported on the graphs are the simple effects ANOVA for SOA within each level of Congruency and Age. The three younger groups showed benefits of congruent cues varied with SOA, whereas the costs of incongruent cues did not vary with SOA. The oldest group showed a different pattern of results, in which benefits of congruent cues did not vary with SOA, whereas the costs of incongruent cues did vary with SOA.
Figure 6. Interaction between Task, Congruency, and SOA. Simple effects tests showed that there was a significant effect of SOA on both congruent and incongruent trials in the Manual task, but only on the congruent trials in the Gaze task.