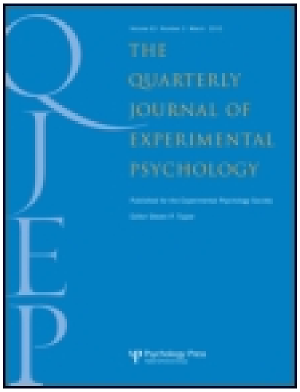

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Developmental changes in the control of saccadic eye movements in response to directional eye gaze and arrows

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We investigated developmental differences in oculomotor control between 10-year-old children and adults using a central interference task. In this task, the colour of a fixation point instructed participants to saccade either to the left or to the right. These saccade directions were either congruent or incongruent with two types of distractor cue: either the direction of eye gaze of a centrally presented schematic face, or the direction of arrows. Children had greater difficulties inhibiting the distractor cues than did adults, which revealed itself in longer saccade latencies for saccades that were incongruent with the distractor cues as well as more errors on these incongruent trials than on congruent trials. Counter to our prediction, in terms of saccade latencies, both children and adults had greater difficulties inhibiting the arrow than the eye gaze distractors.

Keywords: Gaze cueing; Oculomotor control; Inhibition; Development; Social attention.

As children develop, they make remarkable improvements in their ability to ignore irrelevant information and in orienting attention to relevant stimuli. Even as late as adolescence, children show a striking improvement in cognitive control, with growing ability to inhibit reflexive or proponent responses (Dempster, 1992). These changes in higher level cognitive control correspond to changes in oculomotor control, which also develops across childhood through to late adolescence (Casey et al., 1997; Paus et al., 1999). Research on the neural mechanism of oculomotor control indicates that development of frontal areas, including the dorsolateral prefrontal cortex, and the frontal eye fields (Munoz & Everling, 2004) may explain these changes.

The type of developmental change observed in children's oculomotor control depends on what kind of task is used. For example, in the antisaccade (AS) task, goal-directed and stimulus-driven control are set in opposition. Several studies using the AS task have shown that participants' oculomotor control dramatically improves during adolescence (8–20 years; Klein & Foerster, 2001; Kramer, de Sather, & Cassavaugh, 2005; Munoz, Broughton, Goldring, & Armstrong, 1998).

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However, other oculomotor control tasks have revealed somewhat different results. For example, in the oculomotor capture (OC) task, participants were required to make a voluntary saccade towards a colour-singleton target, which was presented simultaneously with an abrupt onset that appeared somewhere else in the display (Theeuwes, Kramer, Hahn, & Irwin, 1998). This onsetting object was entirely task irrelevant yet participants frequently saccaded towards it, thus demonstrating oculomotor capture. Although the OC task involves inhibition of a reflexive response, unlike in the AS task, participants' performance on the OC task has been shown to be age irrelevant (8–25 years).

A proposal made by Kramer et al. (2005) is that different inhibitory mechanisms guide these two tasks. In the AS task, participants must actively attend to the new object, as they will otherwise not know where to move their eyes. In contrast, in the OC task, the new distractor does not predict the target location, and there is no need to actively attend to this new object. It has therefore been suggested that these two tasks measure two qualitatively different types of inhibition with an automatic and implicit form of inhibition playing a central role in the OC task compared to an intentional and effortful inhibition process in the AS task (Kramer et al., 2005). Moreover, it was suggested that these two inhibitory mechanisms might show different developmental trajectories.

The proposed distinction between automatic and intentional inhibitory mechanisms, indicated by these two different oculomotor tasks, needs to be considered in the light of more recent evidence. Until fairly recently, it was assumed that peripheral cues, such as the onset of a new object, were unique in their ability to capture attention exogenously. However, it has now become apparent that central directional cues, such as the direction in which another person is looking, result in attentional orienting that shares similarities with typical exogenous cues, and that these effects are found for both covert as well as overt attention (Frischen, Bayliss, & Tipper, 2007; Langton, Watt, & Bruce, 2000). For example, in the central interference (CI) task, adult participants are presented with an image of a face and are required to fixate a fixation point in the centre of the face (Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002). After 1.5 seconds, the eyes of the face look either to the left or to the right. Simultaneously with this change in gaze direction, the colour of the fixation point changes, indicating the direction in which participants are required to saccade. Importantly, participants are just as likely to be instructed to saccade in the same direction that the eyes are looking (congruent trials) as they are to the opposite direction (incongruent trials), and they are encouraged to ignore the distractor cue of the eye direction. As in the AS and the OC tasks, the goal-directed eye movements and stimulus-driven control are set either in conflict (incongruent trials), or in agreement (congruent trials). Indeed, several studies with adult participants have now demonstrated that saccade latencies on congruent trials are faster, and saccade errors are fewer (Kuhn & Benson, 2007; Kuhn et al., 2010; Kuhn & Kingstone, 2009; Ricciardelli et al., 2002), thus demonstrating difficulties in inhibiting these eye gaze cues.

Using these kinds of central interference task, it was initially suggested that automatic attentional orienting in response to eye gaze was unique to biologically relevant stimuli (Friesen & Kingstone, 1998). Indeed, Ricciardelli et al. (2002) showed that whilst eye gaze cues resulted in a failure to inhibit reflexive saccades (as measured by saccade errors), no such effects were found for arrow cues (<< vs. >>). However, more recent replications of these findings using more controlled stimuli have found identical effects for both arrow and eye gaze cues (Kuhn & Benson, 2007; Kuhn et al., 2010; Kuhn & Kingstone, 2009), thus suggesting that these cueing effects occur for both eye gaze as well as symbolic cues. It has, however, been suggested that whilst arrows and eye gaze may result in identical behavioural effects, the neural mechanism underlying these two forms of attentional orienting may differ (Hietanen, Nummenmaa, Nyman, Parkkola, & Hamalainen, 2006; although see Tipper, Handy, Giesbrecht, & Kingstone, 2008, for a different view).

All the aforementioned research has been carried out with adults. Faces, and in particular the eyes, have a particular evolutionary significance, and it has indeed been suggested that we are born with an innate eye gaze detector (Baron-Cohen, 1995). Given that children have a more limited experience with arrow cues than with eyes, it is possible that the eye gaze cues might have greater attentional saliency for children than nonbiologically relevant arrow cues. One would therefore expect smaller orienting effects for arrow than for eye gaze cues in children. In support of this hypothesis, it has been shown that children (mean age 9.6 years; range, 7.6–12.3 years) orient covert attention (attentional orienting without eye movements) in response to counterpredictive eye gaze, but not counterpredictive arrow cues (Senju, Tojo, Dairoku, & Hasegawa, 2004). This suggests that children have greater difficulties inhibiting eyes than arrows (for similar debate in adults, see Friesen, Ristic, & Kingstone, 2004; Tipples, 2008). However, given that covert attentional orienting in response to nonpredictive arrows has been found in preschool children (3–5 years), it is likely that this form of attentional orienting is learnt fairly early in development (Ristic, Friesen, & Kingstone, 2002).

Most of the developmental work comparing the inhibition of eye gaze and arrows has focused on covert attention. The aim of the current study was to investigate the developmental change in oculomotor control in response to these cues. One of the advantages of using an overt attention task over manual reaction time tasks is the opportunity to use a naturalistic task; then we usually move our eyes towards objects that we attend to. Moreover, eye movements allow us to investigate both the speed by which attention has been allocated (saccade latencies) and the direction in which attention has been deployed (saccade errors). We predict that the eye gaze distractor cue should be more salient for children than the arrow distractor cue and thus should result in greater interference. Senju et al. (2004) suggested that the difference in cueing between arrows and eyes may occur in those ages ranging from 7.6 to 12.3 years of age. We therefore decided to compare interference of arrows and eyes within this age group using the CI oculomotor inhibition task and compared the performance of children to the performance of adults.

Method

Participants

Two groups of participants took part in the study. There were 42 primary school children (20 males, 22 females) aged 7–11 years ($M = 9$ years, 3.5 months, $SD = 1.02$), who were recruited through a local primary school, and written consent was obtained from their parents. Past research has demonstrated that the cueing effect found in typical adult populations is very consistent and reliable (Kuhn & Benson, 2007; Kuhn & Kingstone, 2009). We, therefore, felt justified in using a smaller sample for the adult population, which consisted of 24 adults (6 male, 18 female) aged 21–51 years ($M = 39$ years, $SD = 11.8$), who were recruited from the local (non-University) population. All participants had normal or corrected-to-normal vision and were naive to the purpose of the experiment. Moreover, prior to the experiment we ensured that each of the participants clearly understood the instructions and was able to discriminate the colour of the central fixation point.

Materials and procedure

Eye movements were monitored using an EyeLink II and an EyeLink 1000 eye tracker (remote; SR Research Ltd, Osgoode, Canada), and eye movements were recorded monocularly at 500 Hz. For both the experiments run on the EyeLink 1000 and the EyeLink II, the head was fixed using a chin rest. The adult population was run on the EyeLink 1000 whilst children were run on the EyeLink II.[1] The experiment was run on a Pentium D and was displayed on a 20″ CRT monitor (viewing distance was 63 cm). The experiment was compiled and run using Experiment

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[1] Adults and children were run on the same monitor, and the experiments were compiled using the same software (Experiment Builder). As the two eyetracking systems (EyeLink II and 1000) share the same internal data-filtering and event-parsing algorithms, they result in the identical saccade latency sensitivities (J. Shen, personal communication with SR Research March 14, 2011).

Builder (SR Research Ltd, Osgoode, Canada). Each trial started with a central black fixation point (0.63° in diameter) on a grey background (see Figure 1). Participants were asked to fixate on this central spot. Once fixation was achieved, the trial was initiated by the experimenter. This procedure allowed us to perform a drift correction and ensured that participants fixated the centre of the screen. In the eye gaze condition, the display consisted of a schematic face (8.57° in diameter) with two eyes (2.27° in diameter) flanked by two solid black target circles (0.91° in diameter, 10° from fixation). In this condition, there was a small black spot between the eyes that acted as a fixation point (0.45° in diameter). After 1,000 ms, pupils (0.45° in diameter) appeared inside the eyes, which could look either to the left or to the right, and the black fixation point turned red or green. The arrow condition was identical to the eye gaze condition with the exception that the directional eye gaze stimulus in the eye gaze condition was replaced by a directional arrow. For the arrow condition, the face was replaced with a horizontal line (3.8° in length), and arrow heads appeared at either end (see Figure 1).

Half of the participants were instructed to move their eyes to the right when the fixation point turned red and to the left when it turned green. For the other half of the participants, the colour commands were reversed. The colour change of the fixation spot, therefore, informed each participant of the target to which they had to saccade. For the children group, special care was taken to ensure that participants could distinguish between right and left. After every 8 trials, participants were asked to repeat the instructions and indicate the appropriate direction by pointing. Moreover, visual aids on the side of the computer prompted participants about the correct target-direction/colour contingency. Congruent trials were those where the saccade target direction and the eye gaze direction were the same; incongruent trials were conditions in which the target and the eye gaze direction were opposite. After 1,000 ms, the display was replaced with a blank screen for 1,500 ms. For each block (eye gaze, arrow) there were 32 trials, equally divided between congruent and incongruent trials. Prior to each block, all participants were given 4 practice trials.

Prior to each experimental block, participants performed a 3-point horizontal calibration, followed by a validation procedure. The calibration was accepted if the average error was below 0.5°. Participants were then asked to fixate on the central fixation point at the beginning of each trial and to press the space bar when they had done so. Once the trial was initiated, they were asked to look at the target to the left or the right of fixation, as indicated by the colour switch of the fixation point, and to ignore the distractor cues. Participants were instructed to move their eyes as quickly as possible to the target and to avoid making any mistakes. Moreover, participants were asked to ignore the eyes and the arrows, because these cues indicated the correct target location for only half of the trials. The instructions for the children were simplified, by presenting them verbally and using visual aids to illustrate the procedure. Prior to the experiment, each child was asked to repeat the instructions, and the experiment was only started once the instructions were fully understood. We also ensured that the children were comfortable with wearing the eye tracker. The children were tested in a quiet room in their school.

Results

Eye movements were analysed using Dataviewer (SR Research Ltd, Osgoode, Canada). The dependent variables were saccade onset latencies and directional errors. Eye movement onset latency was defined as the time that elapsed from the fixation point colour change (direction cue) to the initiation of the first saccade. The first saccade was defined as the first eye movement with a velocity and acceleration exceeding 30° s^{-1} and 8,000° s^{-2}, respectively. Only saccades greater than 1° were analysed. All saccades that went in the intended direction were defined as correct saccades, and those that went in the opposite direction were defined as saccade errors. Data from 4 child participants were discarded, as they made errors on more than 10% of the trials without correcting

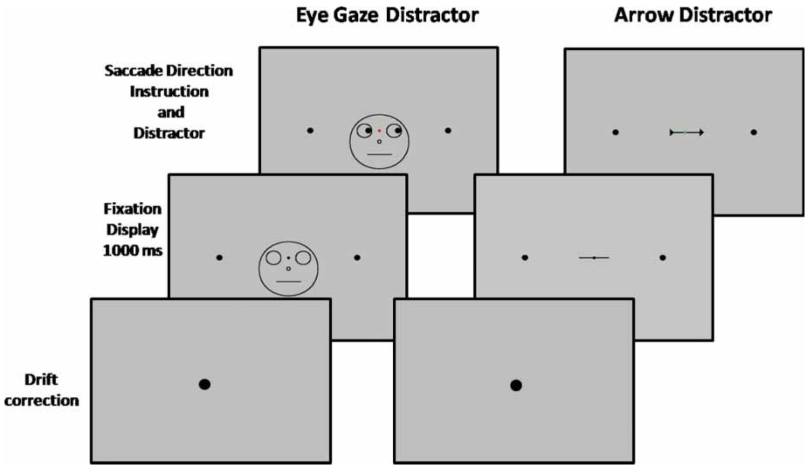

Figure 1. *Each trial started with a fixation point that acted as a drift correction. Once fixation was achieved, participants were presented with a fixation display. After 1,000 ms, the fixation point changed colour (red or green), which indicated the direction in which participants were required to saccade. Simultaneously with the change in fixation point, the distractors appeared. In the eye gaze distractor condition, the distractors consisted of onsetting pupils looking either left or right. In the arrow distractor condition, the distractors consisted of onsetting arrow heads pointing either left or right. To view a colour version of this figure, please see the online issue of the Journal.*

them. One of the participants in the adult group failed to complete the study as she developed a headache. Trials on which tracker loss occurred were excluded from the analysis, as were those on which participants failed to move their eyes. These errors accounted for a total of 0.32% of all trials in the adult group and 1.9% of trials in the children group. Trials on which saccade latencies were less than 80 ms (anticipatory saccades) or greater than 1,000 ms were classified as outliers and were also removed prior to analysis (0.32% in adults; 4.39% in children).

Saccade latencies

Figure 2 shows the distributions of the saccade latencies as proportion of the total number of saccades for the eye gaze and the arrow task for correct and incorrect saccades. Using an antisaccade (AS) task, Munoz et al. (1998) showed that saccades were distributed into at least two modes. The first mode comprised saccade latencies between 90 and 140 ms believed to be *express saccades* and a more gradual distribution of "normal saccade". Our distributions do not reveal the presence of any express saccades.[2] However, the distributions of the children are much flatter than those for the adults, suggesting larger within-group variability. In the children's group, the overall saccade latencies did not correlate with age ($r = -.11$, $p = .52$), thus suggesting that this increased within-group variability was not systematically related to age.

Figure 3 shows mean saccade latencies on correct trials for congruent and incongruent trials for both groups and distractor types. An analysis of variance (ANOVA) with age group (children vs. adults) as between-participant factor and congruency (congruent vs. incongruent) and distractor type (arrow vs. eyes) as within-participant factors found a significant main effect of congruency, $F(1, 60) = 57.3$, $p < .0005$. Saccade latencies on congruent trials were significantly faster than those on incongruent trials, thus demonstrating a typical interference effect. There was a significant congruency by group interaction, $F(1, 60) = 4.24$, $p = .044$, indicating that the interference for the

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[2] These results concur with previous findings in which only a very low percentage of express saccades were observed (Kuhn & Benson, 2007; Kuhn et al., 2010; Kuhn & Kingstone, 2009).

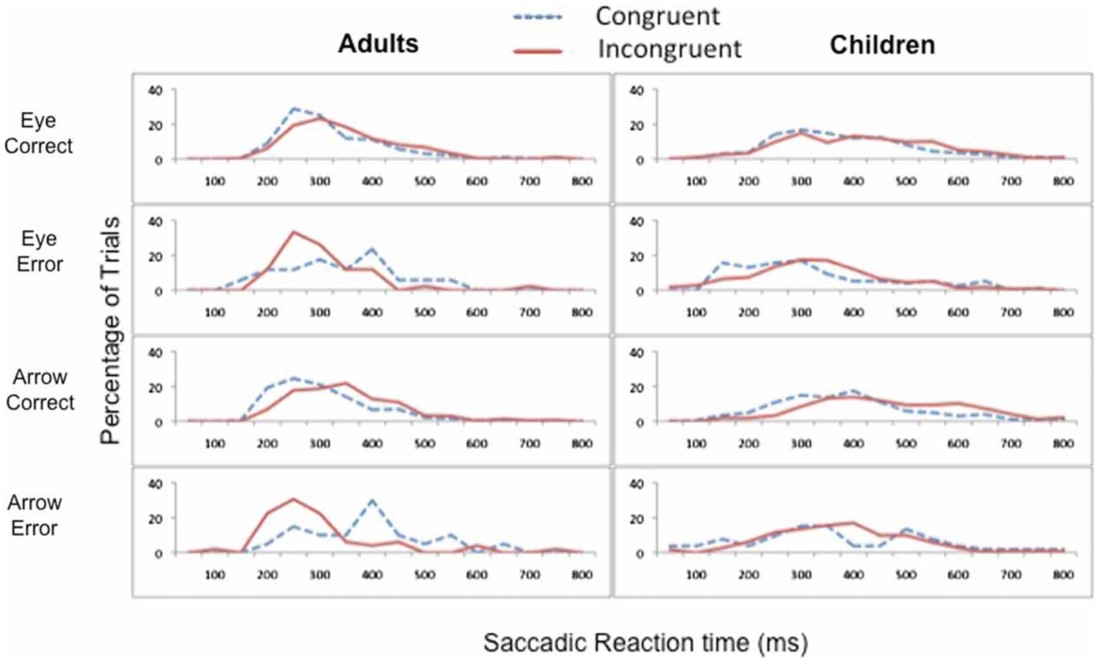

Figure 2. *The distributions for correct and incorrect responses for both distractor types (eyes, arrows) and age groups (children, adults). The solid lines denote incongruent trials and the dotted lines congruent trials. The distributions varied systematically, by which the response times for the children were more varied (flatter distributions) than those for the adults. To view a colour version of this figure, please see the online issue of the Journal.*

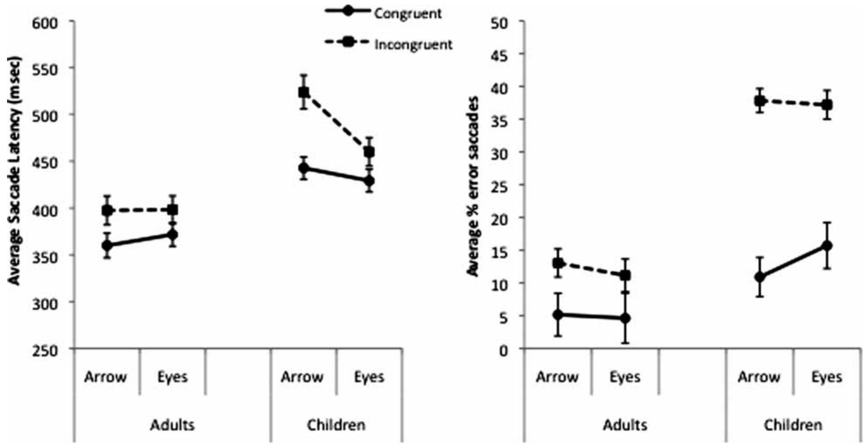

Figure 3. *Left panel shows average saccade latencies for the children and adults for correct saccades executed in the arrow distractor and the eye gaze distractor conditions as a function of congruency. Right panel shows average percentage of saccade errors for the children and adults in the arrow distractor and the eye gaze distractor conditions as a function of congruency. Error bars denote standard errors.*

children was greater than that for the adults. Moreover, there was a significant main effect of group, $F(1, 60) = 23.2$, $p < .0005$, whereby the adults were significantly faster to initiate saccades than the children. Rather surprisingly, there was a significant distractor type by congruency interaction, $F(1, 60) = 4.25$, $p = .029$, demonstrating that arrow cues resulted in a stronger cueing effect than did the eye gaze cues. These results are counter to previous findings using undergraduate populations (Kuhn & Benson, 2007; Kuhn et al., 2010; Kuhn & Kingstone, 2009). Although the graph suggested that this trend is stronger in the children than in the adults, there was no significant congruency by distractor type by group interaction, $F(1, 60) = 2.08$, $p = .16$, thus suggesting that it is not age specific. Within the children group, there was no significant correlation between age and overall interference (mean saccade latency incongruent trials – mean saccade latency congruent trials; $r = -.21$, $p = .20$), thus suggesting that the interference within this group was not systematically related to age. There was no main effect of distractor type, $F(1, 60) = 2.65$, $p = .11$, but there was a significant group by distractor type interaction, $F(1, 60) = 5.10$, $p = .028$, whereby children were faster to initiate saccades on eye trials than on arrow trials. However, in light of the significant distractor cue by congruency interaction in the children group, $F(1, 38) = 6.59$, $p = .014$, this effect is a likely artefact of the interaction.

Saccade errors

Errors were defined as trials on which the first saccade was contrary to the saccade instruction. Figure 3 shows the percentage of errors for congruent and incongruent trials for each of the groups and distractor types. An ANOVA with age group (children vs. adults) as between-participant factor and congruency (congruent vs. incongruent) and distractor type (arrow vs. eyes) as within-participant factors found a significant main effect of congruency, $F(1, 60) = 90.2$, $p < .0005$, thus demonstrating that more errors were made on incongruent than on congruent trials. Moreover, there was a significant group by congruency interaction, $F(1, 60) = 26.4$, $p < .0005$, illustrating that the interference for the children was greater than that for the adults. The significant main effect of group, $F(1, 60) = 41.7$, $p < .0005$, demonstrated that the children made more errors than the adults. None of the other main effects or interactions were significant (all ps $< .25$). Within the children's group, there was no significant correlation between age and overall interference (mean saccade errors incongruent trials – mean saccade errors congruent trials; $r = -.01$, $p = .94$), thus suggesting that the interference within this group was not systematically related to age.

So far the results demonstrate stronger interference for the children than for the adults. One possible reason for this is that the stronger interference found for children than adults resulted from a difficulty in understanding the task instruction. If this were the case, we would expect participants not to correct a saccade once an error has been made. However, the children corrected errors on 67.4% ($SD = 21$) of the trials, which, although the result is smaller than that for the adults (86.1%; $SD = 21.3$), clearly demonstrates that they did indeed understand the task. Moreover, even when only trials on which an error correction was made are analysed, a similar pattern of results is found.

Reflexive nature of errors

Table 1 shows the mean saccade latencies for correct and error saccades on incongruent trials for each of the distractor types. Previous studies using AS, OC, and the CI task have shown that reflexive saccades are faster than voluntary saccades (Kramer et al., 2005; Kuhn & Benson, 2007; Kuhn & Kingstone, 2009). In our task, error saccades on incongruent trials represent saccades that were reflexive, whilst correct saccades on incongruent trials are purely volitional saccades. Table 1 shows the saccade latencies for error and correct saccades for each age group and distractor type. An ANOVA with age group (children vs. adults) as between-participants factor and distractor type (arrow vs. eyes) and saccade type (error vs. correct) as within-participants factors found a significant main effect of saccade type, $F(1, 54) = 35.8$, $p < .0005$, indicating that saccade latencies

Table 1. *Mean saccade latencies for correct and error saccades for incongruent trials*

			Distractor type			
			Arrow		*Eyes*	
Age group	*N*	*Saccade type*	*M*	*SD*	*M*	*SD*
Adults	18	Correct	397	72	396	72.4
	18	Error	333	63.4	363	106
Children	38	Correct	520	112	458	95.6
	38	Error	439	99.1	398	91.6

Note: Data from participants who made no saccade errors were excluded. Latencies in ms.

for error saccades were indeed faster than those for correct saccades. Moreover, as expected, there was a significant main effect of age group, $F(1, 54) = 18.1$, $p < .0005$, as children were slower. There was a significant group by distractor type interaction, $F(1, 54) = 8.05$, $p = .006$. None of the other main effects or interactions were significant (all ps > .11). As in previous research, we demonstrated that error saccades have shorter saccade latencies than saccades that are purely volitional and that this effect is not age related. Moreover, averaged across distractor type, saccade latencies for error saccades on incongruent trials ($M = 394$, $SD = 79.9$) were also marginally shorter than those for correct saccades on congruent trials ($M = 410$, $SD = 67$), $t(56) = 1.89$, $p = .06$. However, this also did not interact with distractor type or age group (all ps > .2).

Discussion

Our aim was to investigate developmental differences between adults and children in terms of oculomotor control using a central interference (CI) task. In particular, we were interested in investigating differences between directional arrow and eye gaze cues. We found a marked developmental change/difference in the interference experienced by children compared with adults. This difficulty in inhibiting the central cue revealed itself in terms of shorter saccade latencies and fewer errors on trials in which the saccade direction was congruent with that of the distractor cues than on trials on which the voluntary saccade direction was incongruent with that of the distractor cue. Crucially, however, this interference was significantly stronger for the children than for the adults, thus indicating a developmental change in the ability to control attention and eye movements between the ages of 10 years to adulthood. Correlational analysis found no systematic relationship between age and interference within the children group, thus suggesting that improvements in the control of attention occur after the age of 10. This is the first study to report developmental change in people's ability to inhibit eye gaze, by demonstrating that children are much more likely to follow another person's gaze than are adults.

However, this following of the distractor cue was not unique to eye direction stimuli. As in previous findings using saccade error measures (Kuhn & Benson, 2007; Kuhn et al., 2010; Kuhn & Kingstone, 2009), the current study showed that adults had as much difficulty in inhibiting directional arrows as eye direction (cf. Ricciardelli et al., 2002). However, we predicted that given the evolutionary relevance of eyes, as well as the fact that children have less experience with arrows, they would find arrows less salient than eyes and thus easier to inhibit. The results did not support this prediction. We found that in terms of saccade errors, the interference of eyes and arrows were identical for both adults and children. In terms of saccade latencies, however, we found the opposite result than expected. Both children and adults had greater difficulties in inhibiting arrows than eyes.

Arrows have been specifically designed to convey directional information. Their almost universal use, as well as their strong attentional effects, implies that arrows are very good at this. Previous work using a covert attention task (Senju et al., 2004) has found developmental differences between arrows and eyes using counterpredictive, rather than nonpredictive cues. In adult populations, counterpredictive arrows and eyes result in identical overt cueing effects (Kuhn & Kingstone, 2009), but future research could assess whether the same applies to children. Moreover, this is the first data to our knowledge that has found stronger cueing (in terms of saccade latencies) for arrows than for eyes. Contrary to most previous eye movement studies, our participants were sampled from a nonuniversity population, which suggests that these types of attentional effects could potentially be influenced by educational levels.

The present results are consistent with the general finding that across a number of different tasks, the development of effective inhibitory processes coincide with the maturation of the prefrontal regions of the brain (Cepeda, Kramer, & Gonzalez de Sather, 2001; Fischer, Biscaldi, & Gezeck, 1997; Klein & Foerster, 2001; Kramer et al., 2005; Munoz et al., 1998). The children also had significantly slower overall saccade latencies than adults, which is consistent with this previous research. Moreover, there was generally more within-group variability in the saccade latencies for the children than for adults. For both the adults as well as the children, saccades that went in the cued but unintended direction were significantly faster than those that went in the cued and intended or uncued and unintended direction, thus suggesting that these error saccades may have been reflexive (see also Kuhn & Benson, 2007; Kuhn et al., 2010; Kuhn & Kingstone, 2009). However, whilst other studies using AS and OC tasks have demonstrated the existence of very rapid express saccades (80–140 ms) we found very few saccades within this saccade latency. This may be because in the current task the volitional saccades are initiated from a central fixation point, rather than having to look at a peripheral target. Moreover, the reflexive nature of these saccades was age irrelevant and independent of distractor type.

Previous research suggests that different types of inhibition processes may develop at different ages. One such difference is whether individuals actively attend to the distractor cue compared to when the interference occurs automatically. In the antisaccade (AS) task, participants must actively attend to the distractor stimulus in order to obtain the target of the goal-directed saccade. In the oculomotor capture (OC) task, the distractor cue is entirely task irrelevant, and, unlike in the AS task, there is no need to actively attend to the distractor stimulus. Previous research shows that whilst younger children show strong impairments on the AS task, their performance on the OC task is "adult-like". This "adult-like" performance on the OC task suggests that by the age of 8, children do indeed have an ability to exert top-down control in opposition to attentional capture by salient "attention-grabbing" stimuli, and it was therefore suggested that "automatic inhibitory processes may develop earlier than intentional, effortful inhibition" (Kramer et al., 2005, p. 770). In the CI task, the distractor cue is entirely task irrelevant, and, unlike in the AS task, there is no need to actively attend to the distractor stimulus. Indeed, participants were strongly encouraged to ignore the distractor cues, thus suggesting that this interference by eyes and arrows occurs automatically. What, therefore, do our results using the CI task contribute to our understanding of the development of oculomotor control and higher level inhibitory control processes?

One answer to this question is that they may point to links between the development of oculomotor control and working memory. It has been suggested that improvements in inhibitory control are a direct consequence of enhanced working memory capacity (Conway & Engle, 1994, 1996; Roberts, Hager, & Heron, 1994), and there is much evidence to suggest that working memory capacity improves during adolescence (Gathercole, 1999). This would imply that older individuals, who have larger working memory capacities, have more attentional resources available to perform the task and thus will be less disturbed by a salient, yet task-irrelevant, distractor. More recently, Eenshuistra, Ridderinkhof, Weidema, and van der Molen (2007) have demonstrated that in younger children (8 years old) the available functional working memory capacity is indeed engaged in oculomotor inhibition. In addition to accounting for the general improvement in inhibition that is typically found during adolescence, limitations in working memory capacity may also partly explain the diverse age effects that are found for different inhibition tasks. In the AS task, participants must maintain several top-down goals, such as inhibiting eye movements towards a salient stimulus as well as moving the eyes in the opposite direction. In the OC task, on the other hand, participants only need to maintain one task in working memory—namely, to saccade towards the red target, which may be within the capacity of the children. Kramer et al. (2005) suggested that children may have particular problems in maintaining multiple goals in working memory and that the increased interference in the AS task, compared to the OC task, is related to holding these goals in working memory. A failure in retaining these goals may reduce the effectiveness of inhibiting the cue-directed saccade and thus result in oculomotor capture by the cue. The CI task requires participants to hold two goals in working memory; "red go left" and "green go right", compared to only one instruction in the OC task (i.e., look at the colour singleton). The stark developmental change in inhibition found in the CI task may therefore be a result of requiring participants to retain multiple goals in working memory. However, it is important to note that most of the children successfully completed the task, as indicated by the fact that most of the errors were subsequently corrected. Whilst they had greater difficulties inhibiting the distractor cues, they were perfectly capable of correcting these mistakes. The higher level of overall errors and slower saccade latencies suggest that the children may have found the primary task more challenging than the adults did, which may have led to greater interference. To understand more fully the role that multiple goal instructions play on oculomotor control, it would be interesting to compare performances in all three tasks (OC, AS, and CI), across different ages. More generally, our results illustrate that developmental changes in oculomotor control vary greatly depending on the type of task that is being used. This finding raises important questions about how best to measure oculomotor control, especially in relation to brain development.

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