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Attentional capture in goal-directed action during childhood, adolescence, and early adulthood

Christopher D. Erb [a,*], Jeff Moher [b], Stuart Marcovitch [c]

[a] School of Psychology, University of Auckland, Auckland 1010, New Zealand
[b] Department of Psychology, Connecticut College, New London, CT 06320, USA
[c] Department of Psychology, University of North Carolina at Greensboro, Greensboro, NC 27412, USA

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ABSTRACT

Attentional capture occurs when salient but task-irrelevant information disrupts our ability to respond to task-relevant information. Although attentional capture costs have been found to decrease between childhood and adulthood, it is currently unclear the extent to which such age-related changes reflect an improved ability to recover from attentional capture or to avoid attentional capture. In addition, recent research using hand-tracking techniques with adults indicates that attentional capture by a distractor can generate response activations corresponding to the distractor's location, consistent with action-centered models of attention. However, it is unknown whether attentional capture can also result in the capture of action in children and adolescents. Therefore, we presented 5-year-olds, 9-year-olds, 13- and 14-year-olds, and adults ($N = 96$) with a singleton search task in which participants responded by reaching to touch targets on a digital display. Consistent with action-centered models of attention, distractor effects were evident in each age group's movement trajectories. In contrast to movement trajectories, movement times revealed significant age-related reductions in the costs of attentional capture, suggesting that age-related improvements in attentional control may be driven in part by an enhanced ability to recover from—as opposed to avoid—attentional capture. Children's performance was also significantly affected by response repetition effects, indicating that children may be more susceptible to interference from a wider range of task-irrelevant factors than

* Corresponding author.
E-mail address: christopher.erb@auckland.ac.nz (C.D. Erb).

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adults. In addition to presenting novel insights into the development of attention and action, these results highlight the benefits of incorporating hand-tracking techniques into developmental research.

Introduction

Adaptive behavior requires the ability to filter out distractions and focus one's attention on the task at hand. The term *attentional capture* refers to instances in which salient but task-irrelevant information disrupts our ability to respond to task-relevant information (e.g., Theeuwes, 1992). Although this interference is often innocuous, lapses of attention can have real-world impacts ranging from impaired classroom learning (Fisher, Godwin, & Seltman, 2014) to fatal auto accidents (National Center for Statistics and Analysis, 2019). A central topic in the attentional capture literature therefore concerns the extent to which individuals can use top-down control to avoid or recover from capture.

Although attentional capture has been investigated in detail in adults, comparatively few studies have explored how the ability to avoid or recover from attentional capture changes across development (see, e.g., Gaspelin, Margett-Jordan, & Ruthruff, 2015). Similarly, hand-tracking techniques are commonly used in adult research to study how the processes underlying attentional capture and recovery from capture unfold over the course of a trial (*within-trial dynamics*) and are modulated by qualities of the previous trials (*cross-trial dynamics*) (e.g., Kerzel & Schönhammer, 2013; Moher, Anderson, & Song, 2015; Moher & Song, 2013; Welsh, 2011). Yet, few studies have used hand-tracking techniques to explore how these processes change as a function of age and experience (*developmental dynamics*). Therefore, the current study aimed to investigate the within-trial, cross-trial, and developmental dynamics of attentional capture by measuring the reaching behavior of children, adolescents, and young adults as they perform a visually guided reaching task designed to elicit attentional capture on select trials. In addition to providing a detailed window into the dynamics of attentional capture across development, this approach offers a unique perspective on current debates regarding (a) the extent to which developmental differences in attentional capture reflect the ability to avoid or recover from capture and (b) the extent to which attentional capture results in the automatic activation of a task-irrelevant response.

Attentional capture, top-down control, and development

Developmental and individual differences in attentional capture are generally interpreted in terms of two theoretical accounts. According to the *susceptibility account,* top-down control enables us to *avoid* attentional capture under certain conditions, particularly when the attention-capturing stimulus is known to be irrelevant to the task at hand (e.g., Folk, Leber, & Egeth, 2002; Folk, Remington, & Johnston, 1992; Fukuda & Vogel, 2009; Gaspelin, Ruthruff, Lien, & Jung, 2012; Lien, Ruthruff, & Johnston, 2010). Early evidence in favor of the susceptibility account was offered by Folk et al. (1992), who observed that capture costs in adults were modulated by the relation between an attention-capturing cue and a target stimulus. For instance, the researchers found that when participants were instructed to search for a target that appeared abruptly in one of four possible locations, cues that appeared abruptly 100 ms before the target would capture the participant's attention, resulting in slower response times on trials in which the cue appeared at a different location than the target (*invalid-cue trials*) relative to trials in which no cue appeared before the target (*no-cue trials*). However, when the identity of the target was signaled by color (rather than abrupt onset), abrupt onset cues did not appear to capture attention given that no response time difference was observed between the invalid-cue and no-cue trials. This finding suggests that adults were able to use top-down control to avoid attentional capture when the dimension used to identify the target (color) differed from the dimension used to capture attention with the cue (abrupt onset).

In contrast to the susceptibility account, the *recovery account* proposes that top-down control may help individuals to efficiently *overcome* attentional capture (e.g., Fukuda & Vogel, 2011; Theeuwes, Atchley, & Kramer, 2000).[1] Evidence in favor of the recovery account was offered by Fukuda and Vogel (2011), who investigated how individual differences in adult working memory capacity (WMC) relate to one's ability to avoid and recover from attentional capture. The researchers found that adults showed equivalent capture costs on trials in which the attention-capturing stimulus appeared 50 ms before the target array regardless of their WMC level (low or high), suggesting that normal variations in WMC are not strongly related to an individual's capacity to avoid attentional capture. However, when the attention-capturing stimulus appeared 150 ms before the target array, individuals with higher WMC exhibited significantly smaller capture costs than individuals with lower WMC. Taken together, the results of Fukuda and Vogel (2011) indicate that low- and high-capacity individuals were equally susceptible to capture, but individuals with higher WMC were able to recover more rapidly from attentional capture than those with lower WMC.

Given that top-down control and related constructs such as WMC are known to undergo significant development between childhood and adulthood (e.g., Bedard et al., 2002; Davidson, Amso, Anderson, & Diamond, 2006; Fry & Hale, 1996; Luciana, Conklin, Hooper, & Yarger, 2005; Luna, Padmanabhan, & O'Hearn, 2010; Velanova, Wheeler, & Luna, 2008), how might the ability to avoid or recover from attentional capture change across development? A number of studies have explored this question, including research with typically developing children (Gaspelin, Margett-Jordan, et al., 2015; Iarocci, Enns, Randolph, & Burack, 2009; Leclercq & Siéroff, 2013; Oh-uchi, Kawahara, & Sugano, 2010; Wainwright & Bryson, 2002) as well as children diagnosed with attention-deficit/hyperactivity disorder (Mason, Humphreys, & Kent, 2004), autism spectrum disorder (Greenaway & Plaisted, 2005), and epilepsy (Deltour et al., 2007). Although these studies vary across a number of dimensions (e.g., tasks used to assess attentional capture, number and range of age groups, analytic strategies employed), the existing data generally indicate that attentional capture costs decrease between the preschool years and early adulthood (see Gaspelin, Margett-Jordan, et al., 2015). This improvement is widely interpreted to reflect age-related gains in top-down control and is frequently linked to the development of the frontal cortex (Gaspelin, Margett-Jordan, et al., 2015; Leclercq & Siéroff, 2013; Mason et al., 2004). However, it is currently unclear whether the decrease in attentional capture costs observed between childhood and adulthood reflects age-related reductions in the *susceptibility* of attention to capture, age-related improvements in the ability to *recover* from capture, or a combination of the two.

The majority of previous studies investigating developmental differences in attentional capture have featured pre-cueing tasks in which the target was presented after a distractor or cue (Gaspelin, Margett-Jordan, et al., 2015; Iarocci et al., 2009; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2002). For example, Gaspelin, Margett-Jordan, et al. (2015) found that children aged 4 and 5 years exhibited larger attentional capture costs in a pre-cueing task than adults and interpreted this difference in terms of the susceptibility account. Given that the target is presented after the distractor in pre-cueing tasks, it is possible that the age-related differences observed in pre-cueing tasks partly reflect an improved ability to recover from capture before the target was presented rather than an improved ability to block capture altogether. Interestingly, Oh-uchi et al. (2010) used a search task in which the target and distractor appeared simultaneously and concluded that the costs of capture were equivalent in 5- and 6-year-olds and adults, suggesting that the developmental differences observed in pre-cueing tasks may have partly reflected age-related differences in recovery. One of the central questions to be addressed in the current study therefore concerns the extent to which developmental differences in attentional capture are observed across childhood, adolescence, and early adulthood when the target and distractor are presented simultaneously.

[1] Note that these accounts are not mutually exclusive; top-down control may both reduce one's susceptibility to attention capture and enhance one's recovery from attentional capture under certain conditions

Targeting the dynamics of attentional capture with reach tracking

Attentional capture has traditionally been assessed with button-press measures of accuracy and response time (the time elapsed between target presentation and response completion). Although button-press measures have provided foundational insights into attentional capture and its development, accuracy and response time offer relatively limited insight into how the tension between attentional capture and top-down control unfolds over the course of a trial (Song & Nakayama, 2009). To shed light on these within-trial dynamics, researchers studying attentional capture and related topics have turned to motion-tracking techniques to record the temporal and spatial dynamics of participants' hand movements as participants perform tasks by (a) reaching to touch targets on a digital display (e.g., Chapman, Gallivan, Wong, Wispinski, & Enns, 2015; Erb, Touron, & Marcovitch, 2020; Erb et al., 2021; Gallivan, Barton, Chapman, Wolpert, & Flanagan, 2015; Gallivan & Chapman, 2014; Kerzel & Schönhammer, 2013; Moher, Sit, & Song, 2015; Welsh, 2011) or (b) navigating a cursor to targets on a screen using a computer mouse (e.g., Freeman, 2018; Freeman, Dale, & Farmer, 2011; Scherbaum, Dshemuchadse, Fischer, & Goschke, 2010).

For instance, Welsh (2011) used reach tracking to investigate the extent to which attention and action are linked in visually guided action during adulthood. The question of particular interest concerned whether attentional capture by an item would automatically generate response activations corresponding to the item. In other words, can attentional capture also result in action capture? Welsh found that participants' reach movements were curved toward the location of an attention-capturing cue on invalid-cue trials, indicating that attentional capture generated response activations corresponding to the cue's location. Notably, this effect was observed in reach trajectories only when the salient dimension of the cue (abrupt onset or color) matched the salient dimension of the target, mirroring the effects previously observed in response times (e.g., Folk et al., 1992). The observed impact of attention capture on reach movements is consistent with action-centered models of attention (e.g., Rizzolatti, Riggio, & Sheliga, 1994; Tipper, Lortie, & Baylis, 1992), which propose that action and attention are reciprocally linked such that to-be-performed actions influence the distribution of attention and, conversely, the distribution of attention influences the production of actions (Welsh & Zbinden, 2009).

The results of Welsh (2011) also presented early evidence that reach tracking can be used to shed light on how attention is captured and top-down control is implemented over the course of a trial. This interpretation is consistent with a growing body of hand-tracking research indicating that distractor items can generate early response activations for incorrect responses and that the activation of incorrect responses can be supplanted by activation of the correct response over the course of a hand movement (Erb, Moher, Sobel, & Song, 2016; Moher, Anderson, et al., 2015; Resulaj, Kiani, Wolpert, & Shadlen, 2009; Scherbaum et al., 2010; Schmidt, 2002).[2] However, little research has used hand-tracking techniques to investigate the interplay of attentional capture and top-down control in children and adolescents. Consequently, it is currently unclear whether the link between attention and action observed in adults is present to the same degree at earlier points during development.

In addition to providing insight into the within-trial dynamics of attention, distraction, and control, reach tracking presents new opportunities to explore how attentional capture is modulated by trial sequence effects in which qualities of a previous trial influence performance on the current trial. The cross-trial dynamics of top-down control have become a major focus of research during recent years as researchers have become increasingly aware of the impact that trial sequence effects can have on performance (Braem et al., 2019; Chapman, Gallivan, & Enns, 2015; Chapman et al., 2010; Egner, 2007, 2017), including within the domain of attentional capture (e.g., Kumada & Humphreys, 2002; Olivers & Humphreys, 2003). For example, previous work investigating pop-out effects in visual search tasks has demonstrated priming effects in which responses are facilitated if the target position on the current trial repeats that of the previous trial (Maljkovic & Nakayama, 1994, 1996). Similar effects of selection history have been observed in eye movements (e.g., McPeek, Maljkovic, & Nakayama, 1999;

[2] A similar idea has been explored in eye-tracking studies with double-step tasks (e.g., McPeek, Han, & Keller, 2003; McPeek, Skavenski, & Nakayama, 2000). This work indicates that saccadic eye movements may also reflect competition between targets and distractors.

Talcott & Gaspelin, 2020; Walthew & Gilchrist, 2006) and hand movements (Song & Nakayama, 2006) as well. Although researchers have begun to explore trial sequence effects in congruency tasks such as the Eriksen flanker task (Eriksen & Eriksen, 1974) and the Simon task (Simon, 1969) from a developmental perspective (e.g., Ambrosi, Servant, Blaye, & Burle, 2019; Cragg, 2016; Erb & Marcovitch, 2018, 2019; Erb, Moher, Song, & Sobel, 2017, 2018), comparatively little research has explored how target location repetitions affect attentional capture across development.

The current study

The preceding sections raised three open questions concerning the development of attentional capture and top-down control:

1. To what extent are age-related differences in attentional capture observed when the target and distractor are presented simultaneously?
2. Does attentional capture automatically bias response activations in children and adolescents as in adults?
3. How do the cross-trial dynamics of attentional capture change across development?

To address these questions, we presented children, adolescents, and young adults with a reach-tracking version of a visual search task adapted from Theeuwes (1992; see also, e.g., Moher, Anderson, et al., 2015). Participants were instructed to touch a circle that appeared simultaneously with three diamonds on a digital display. On half the trials, all the shapes appeared in the same color (*distractor-absent trials*). On the other half, one of the diamonds appeared in a different color than the other shapes (*distractor-present trials*).

This task was particularly well suited to address the questions outlined above for three reasons. First, the simultaneous presentation of the target and distractor increases the likelihood that the effects of attentional capture would be detected if capture were to occur, thereby allowing for a richer comparison of the susceptibility and recovery accounts. Strong evidence in favor of the susceptibility account would be provided if attentional capture effects were observed in the younger but not older age groups. If attentional capture effects were present in each age group but decreased with age, this would suggest that older participants (a) avoided capture more frequently than younger participants, (b) recovered from capture more rapidly than younger participants, or (c) both avoided capture more frequently and recovered from capture more rapidly than younger participants.

Second, in contrast to pre-cueing tasks, the task used in the current study did not feature cues that occasionally provided task-relevant information. Similarly, the task-relevant dimension (i.e., shape) and the task-irrelevant dimension (i.e., color) remained constant throughout the task. Consequently, if reach curvatures were to reveal a significant distractor effect in children, it would be unlikely that the effect resulted from confusion regarding the relevance of the distractor or switch costs associated with transitioning between different task-relevant dimensions. Third, the stimuli appeared at a small number of locations, resulting in a relatively high proportion of trials in which the location of the target matched that of the previous trial. Consequently, the task was well suited to identify how the cross-trial dynamics of attentional capture are influenced by repetitions of target location at different points during development.

Method

Participants

A total of 96 right-handed individuals with normal or corrected-to-normal vision participated in the study, with 24 participants in each of four age groups: 5-year-olds (M_{age} = 5.5 years, *SD* = 0.3; 37.5% female), 9-year-olds (M_{age} = 9.5 years, *SD* = 0.3; 58% female), 13- and 14-year-olds (M_{age} = 13.8-years, *SD* = 0.6; 58% female), and adults (M_{age} = 18.6 years, *SD* = 1.3; 71% female). An additional 4 participants were tested but excluded from the final sample due to difficulty in following the task instructions (1 5-year-old), failure to complete the experimental task (1 5-year-old), and equipment failure (1 9-year-old and 1 13-year-old). Child and adolescent racial and ethnic identification were as follows: 75% White, 14% African American, and 7% multiple racial backgrounds (4% preferred not to respond); 89% non-Hispanic and 8% Hispanic (3% preferred not to respond). Of child and adolescent participants, 37% came from households making less than $60,000 a year and 57% came from households making more than $60,000 a year (6% of parents or legal guardians did not wish to state household income). Of adult participants, 42% identified as White, 38% identified as African American, 8% identified as Asian American, 4% identified as Native Hawaiian or other Pacific Islander, and 4% identified as other (4% preferred not to respond). No measures of personal or family income were collected for adult participants.

All participants were right-handed with normal or corrected-to-normal vision. Child participants received a small prize for participating, whereas adult participants received course credit. Data collection took place at the University of North Carolina at Greensboro between June and December 2016. The institutional review board at the University of North Carolina at Greensboro approved the protocol.

Materials

The experiment was conducted using a rear-mounted projector to display the task on a Plexiglass screen (e.g., Erb et al., 2016; Moher & Song, 2013). The projector, screen, and an electromagnetic source were affixed to a wooden board that was mounted to a table (91.4 by 152.4 cm) (see Fig. 1A). The projected display on the Plexiglass screen was 38 by 50 cm. The apparatus was designed so that the screen could be positioned at one of three locations on the table to accommodate participants of different ages. A square marker (2 by 2 cm) was placed 27 cm in front of the screen, with the placement of the square changing based on the position of the screen. The square served as a starting marker from which participants initiated their movements. Reach movements and response selections were measured at a rate of approximately 160 Hz with an electromagnetic position and orientation recording system (Polhemus Liberty, Colchester, VT, USA). A small motion-tracking sensor was secured to participants' right index finger with a Velcro strap. The sensor was 2.26 cm long, 1.27 cm wide, and 1.14 cm high and weighed 3.7 g. The task was programmed in MATLAB (MathWorks, Natick, MA, USA).

Participants completed an attentional capture task in which a circle (3.9 cm in diameter) and three diamonds (each 3.9 cm wide by 3.9 cm tall) appeared on a digital display simultaneously. Participants were instructed to touch the circle (i.e., the *target* or *shape singleton*) regardless of its color. On *distractor-absent* trials, each of the four shapes appeared in the same color: green (0, 255, 0) or red (255, 0, 0). On *distractor-present* trials, one of the diamonds appeared in a different color from the other three shapes (i.e., the *distractor* or *color singleton*). Consequently, the target was never presented as a color singleton. The images appeared against a black background at the same four locations on each trial (12.25 cm above, below, to the left of, and to the right of the center of the display) (see Fig. 1B). To be registered as a response at each of the four response locations, the sensor needed to be within 62 pixels of the x and y dimensions of the center of the target shape and within 0.5 cm of the display along the z dimension.

A distractor was present on a randomly selected half of all trials. Distractor-present and distractor-absent trials was randomly intermixed, and the target and distractor locations were randomly selected for each trial with equal probability of appearing at the top, left, and right locations. The bottom location was not used to simplify trajectory analyses because movements to the bottom location would be shorter and would not pass any nontargets along the y axis and thus it would be harder to detect the influence of distractors for reaches to that location. We did, however, include an object at that location to increase the contrast of both the target and distractor at other locations. The color of the target was randomly selected for each trial to be either red or green with equal probability. The distractor, when present, was presented in whichever of those two colors was not selected for the target on that trial.

Participants initiated each trial by resting their finger on the starting marker located on the table between participants and the display. A crosshair measuring 0.7 by 0.7 cm appeared in the center of the display for either 0.50 or 0.75 s before the four shap appeared. Each duration occurred equally

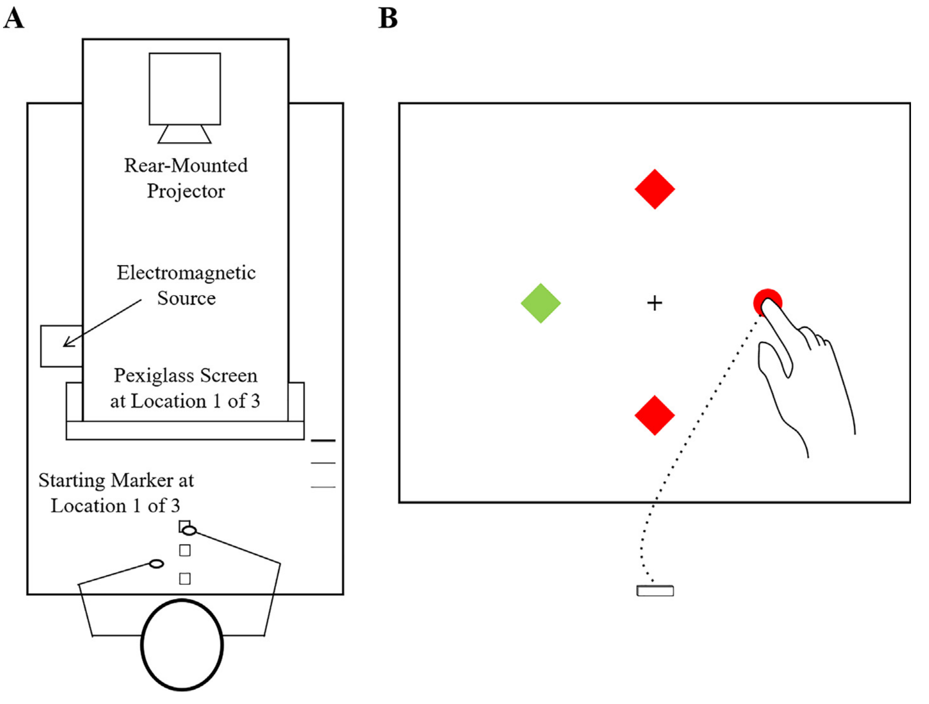


Fig. 1. (A) Diagram of experimental setup from aerial view. The task was displayed on a Plexiglass screen mounted upright on the table in front of the participant. The position of the screen was adjustable to three different locations to accommodate participants of different ages. All movements were initiated from a starting marker mounted on the table 27 cm in front of the screen. (B) Illustration of a distractor-present trial from the perspective of the participant. Participants were instructed to touch the circle (the shape singleton) regardless of its color. On distractor-present trials, one of the diamonds appeared in a different color from the remaining shapes (the color singleton). On distractor-absent trials, each of the shapes appeared in the same color (red or green). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.) (Adapted with permission from Erb & Marcovitch, 2018.)

often, and the durations were randomly intermixed to avoid a predictable target onset. If participants' hand moved from the starting marker before the shapes appeared, the task was paused and did not resume until participants returned their hand to the starting block, at which point the wait time was reset for that trial such that participants needed to stay in the starting position for either 0.50 or 0.75 s. No time limit was placed on responses, although participants were encouraged to perform the task quickly. A high tone sounded for correct responses (600 Hz for 200 ms), and a low tone sounded for incorrect responses (300 Hz for 200 ms).

Procedure

Testing took place in a dimly lit room. Participants first completed a nine-point calibration sequence followed by 10 baseline trials that required participants to reach a target that appeared alone at the top, left, or right location. Participants then received a practice block consisting of 10 trials in which they were instructed to touch the circle when it appeared. If performance was less than 70% during this practice block, participants were asked to repeat the block. The experiment consisted of four blocks of 40 trials. Before each of the experimental blocks, participants were encouraged to respond quickly and to remain focused, and they were reminded that it was "okay" if they made some mistakes.

Data processing

The processing procedures used in the current study were largely adapted from Moher and Song (2013). Three-dimensional resultant speed scalars were created for each trial using a differentiation procedure in MATLAB. These scalars were then submitted to a second-order, low-pass Butterworth filter with a cutoff of 10 Hz. Movement onset was calculated as the first point on each trial after stimulus onset at which hand movement speed exceeded 10 cm/s. Each individual trial was visually inspected as in previous work (e.g., Song & Nakayama, 2007); for trials in which the default threshold clearly missed part of the movement or included movement back to the starting point, thresholds were adjusted manually. The proportion of trials requiring manual adjustments for each age group was as follows: 5-year-olds, M = .24, SD = .16; 9-year-olds, M = .20, SD = .18; 13- and 14-year-olds, M = .37, SD = .34; and adults, M = .23, SD = .25.

Initiation time (IT) was calculated as the time elapsed between stimulus onset and movement onset, whereas movement time (MT) was calculated as the time elapsed between movement onset and response completion. Trajectories for calculating curvature (CURV) were measured in two-dimensional *xy* space by calculating a line from the start point to the end point of the movement and measuring the orthogonal deviation of the actual movement from that line at each sample. CURV was defined as the maximum point of deviation in centimeters divided by the length of the line from the start point to the end point of the movement in centimeters (following Desmurget, Jordan, Prablanc, & Jeannerod, 1997, and Moher & Song, 2013).

Results

There were three primary variables of interest in the current analysis: age group (5 years, 9 years, 13–14 years, or adult), distractor (present or absent), and target location (repeated or switched). Error rates were near floor (<0.5% overall) and consequently were not analyzed further. For our primary analysis, we conducted a mixed analysis of variance (ANOVA) with a between-participants factor of age group and within-participant factors of distractor and target location on three different dependent measures: IT, MT, and CURV. In these analyses, we excluded the first trial of each block, all error trials, and all trials preceded by an error. Main effects and interactions that are not explicitly reported failed to reach significance ($ps > .05$). To minimize the effect of age-related differences in processing speed, all analyses revealing a main effect of age group or a significant interaction with age group were also conducted using log-transformed data.[3] All condition means for the untransformed data are reported in Table 1. The data and analysis files associated with this study are available through the Open Science Framework (https://osf.io/rw5b7/?view_only=3e353146b32540738d96dec8843d0f22).

Age group

As expected, there were main effects of age group across all three measures ($ps < .001$). IT and MT were longer in younger age groups, and CURV was higher (see Table 1). Simple main effects analyses revealed that 5-year-olds had longer IT and MT and higher CURV relative to all other age groups ($ps < .05$). The 9-year-olds had longer IT and higher CURV relative to the older age groups as well ($ps < .05$). No other comparisons were significant. These effects remained significant when log-transformed data were analyzed.

Distractor presence

There was no main effect of distractor presence on IT, $F(1, 92) = 0.23$, $p = .63$, $\eta_p^2 = .003$. MT was longer when distractors were present (549 ms) than when they were absent (533 ms),

[3] As noted by Cepeda, Blackwell, & Munakata (2013), attempts to control for differences in processing speed are complicated by the observation that measures of processing speed often correlate with measures of executive control. Consequently, attempts to control for differences in processing speed may remove variance associated with differences in controlled processing.

Table 1
Three-way analysis with factors of age, distractor presence, and target location.

Dependent Variable	Age Group	Target Location	Distractor		Main Effects		Interactions	
			Present	Absent	Distractor	Location	Distractor × age	Location × age
Initiation Time						***		***
	5	Repeat	508 ± 23 ms	531 ± 25 ms				
		Switch	563 ± 28 ms	556 ± 27 ms				
	9	Repeat	375 ± 16 ms	365 ± 15 ms				
		Switch	382 ± 17 ms	379 ± 16 ms				
	13/14	Repeat	282 ± 7 ms	287 ± 8 ms				
		Switch	286 ± 8 ms	285 ± 8 ms				
	Adult	Repeat	271 ± 6 ms	273 ± 6 ms				
		Switch	273 ± 6 ms	273 ± 5 ms				
Movement Time					***	***	***	***
	5	Repeat	631 ± 21 ms	598 ± 21 ms				
		Switch	689 ± 24 ms	642 ± 23 ms				
	9	Repeat	520 ± 15 ms	503 ± 16 ms				
		Switch	536 ± 16 ms	518 ± 17 ms				
	13/14	Repeat	504 ± 16 ms	501 ± 16 ms				
		Switch	507 ± 17 ms	499 ± 16 ms				
	Adult	Repeat	502 ± 15 ms	503 ± 14 ms				
		Switch	502 ± 13 ms	501 ± 13 ms				
Movement Curvature					***	***		***
	5	Repeat	0.128 ± 0.008	0.104 ± 0.005				
		Switch	0.173 ± 0.012	0.148 ± 0.009				
	9	Repeat	0.099 ± 0.005	0.082 ± 0.004				
		Switch	0.129 ± 0.006	0.099 ± 0.004				
	13/14	Repeat	0.082 ± 0.005	0.066 ± 0.003				
		Switch	0.087 ± 0.005	0.075 ± 0.003				
	Adult	Repeat	0.084 ± 0.007	0.069 ± 0.007				
		Switch	0.083 ± 0.007	0.076 ± 0.006				

Note: Error terms reflect standard error of the mean. * = $p < .05$, ** = $p < .01$, *** = $p < .001$. Columns omitted for interaction analyses where nothing was statistically significant.

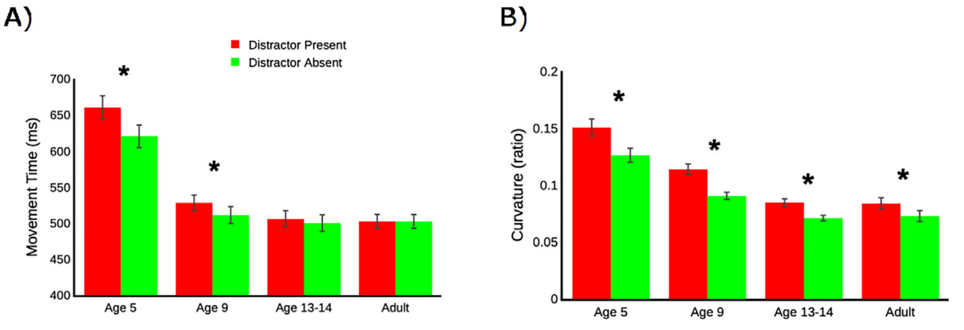


Fig. 2. (A) Movement times were longer in the presence of a salient distractor in the younger age groups. Error bars reflect standard error of the mean. Asterisks indicate statistical significance in simple main effects analyses. (B) Curvature was longer in the presence of a salient distractor across all age groups. Error bars reflect standard error of the mean. Asterisks indicate statistical significance in simple main effects analyses.

$F(1, 92) = 19.02$, $p < .001$, $\eta_p^2 = .17$. CURV was also higher on distractor-present trials (.108) than on distractor-absent trials (.090), $F(1, 92) = 72.11$, $p < .001$, $\eta_p^2 = .44$.

There were no interactions between age group and distractor presence for IT, $F(3, 92) = 1.68$, $p = .18$, $\eta_p^2 = .05$. However, there was an interaction between age group and distractor presence for MT, $F(3, 92) = 6.06$, $p < .01$, $\eta_p^2 = .17$ (Fig. 2A). Simple main effects analyses revealed a significant distractor cost—that is, the increase in MT when a distractor was present compared with absent—in 5-year-olds (40 ms) and 9-year-olds (17 ms), *ps* < .05, but no significant cost was observed in the older age groups (*ps* > .05). These effects remained significant when log-transformed data were analyzed (*ps* < .05). The interaction between age group and distractor presence did not reach significance for CURV, $F(3, 92) = 2.47$, $p = .067$, $\eta_p^2 = .08$ (Fig. 2B). When this effect was evaluated using log-transformed data (to account for age-related differences in processing speed), the interaction no longer approached significance, $F(3, 92) = 0.19$, $p = .91$, $\eta_p^2 = .01$. These findings indicate that, in contrast to MTs, reach CURVs revealed a robust effect of distractor presence across all age groups. Sample trajectories are shown in Fig. 3, illustrating these effects in 5-year-olds and adults.

Location repetition

Although IT was unaffected by distractors, IT was affected by target location repetition, with shorter IT when the target location was repeated (361 ms) compared with when it was switched (374 ms), $F(1, 92) = 38.98$, $p < .001$, $\eta_p^2 = .30$. MT was also shorter when the target location was repeated (533 ms vs. 549 ms), $F(1, 92) = 46.05$, $p < .001$, $\eta_p^2 = .33$. Finally, CURV was smaller when the target location was repeated (.089 vs. .109), $F(1, 92) = 71.54$, $p < .001$, $\eta_p^2 = .44$.

Location repetition also interacted with age group for IT, MT, and CURV (Fig. 4) (*ps* < .001). These effects remained when the log-transformed data were analyzed (*ps* < .001). For all three dependent variables, simple main effects analyses on the log-transformed data revealed that these interactions followed the same pattern; the 5-year-olds showed a large repetition effect, with longer IT and MT and more curved responses when the target location was switched as opposed to when it was repeated (*ps* < .01). There was a significant repetition effect for both MT and CURV in 9-year-olds as well (*ps* < .01), but not for IT, $F(1, 23) = 2.20$, $p = .15$. There was a location repetition benefit for CURV in 13- and 14-year-olds, $F(1, 23) = 6.62$, $p = .017$, $\eta_p^2 = .22$, but not for MT or IT (*ps* > .05). Target location repetitions did not significantly benefit performance of adults across any of the measures (*ps* > .05). In sum, much like the effect of distractor presence observed in MT, location repetitions had an effect largely in the younger but not older age groups. However, unlike distractors, repetitions of the target location affected the timing of the initiation of the movement in the younger age groups. There were no interactions between location repetition and distractor presence (*ps* > .05). Together, these results

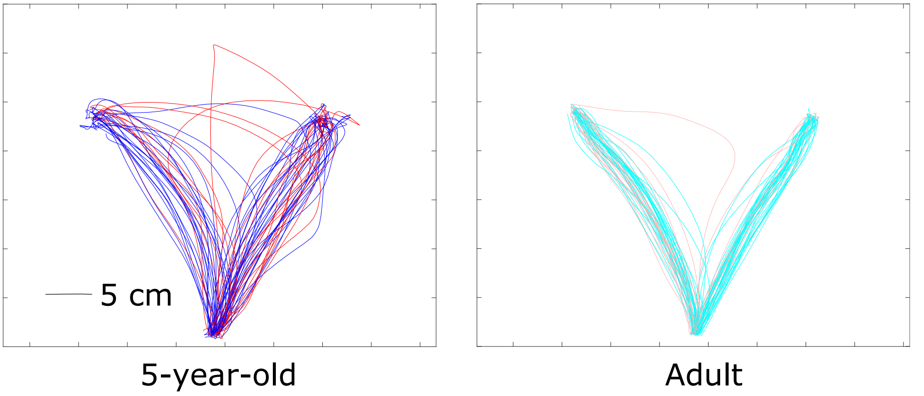


Fig. 3. Sample trajectories from a single 5-year-old participant (left) and a single adult participant (right). Blue represents trajectories on distractor-absent trials to targets on the left or right, and red represents trajectories for trials in which a distractor was present on the opposite side of the display. Both groups show greater curvature when distractors are present. In addition, 5-year-olds show greater overall curvature relative to older age groups regardless of whether distractors are present or not. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

suggest that task-irrelevant properties such as salient distractors and repetitions of the target location can have a strong influence on goal-directed actions in younger children.

Exploratory analyses

Movement time deconstructed

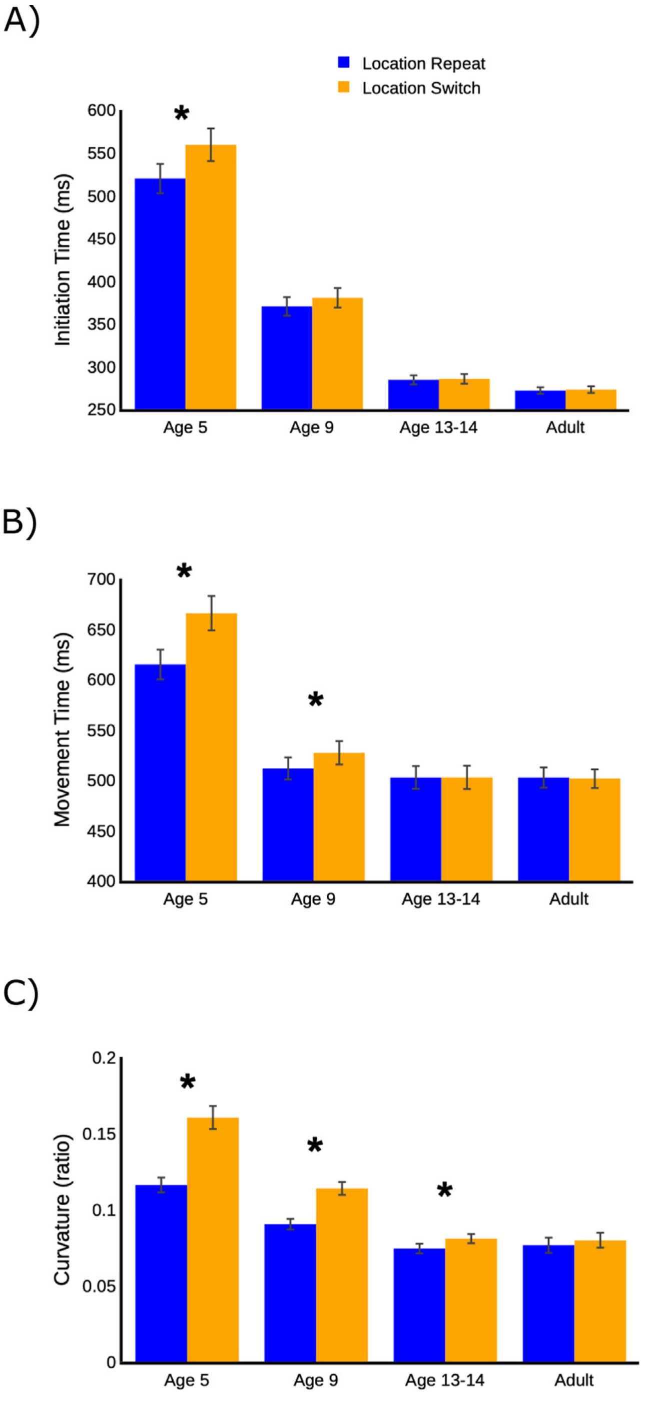
Because our primary focus was on the impact of salient distractors, and because MT was the measure that demonstrated developmental change in the impact of salient distractors, we focused our next set of analyses on further breaking down MT.

Based on experimenter observations of participant performance during the task, we evaluated the data for instances of mid-movement stopping across all age groups. We defined mid-movement stopping by examining hand movements along the *z* axis only during the middle 80% of the movement. In other words, by distance, we eliminated the first 10% and final 10% of the movement along the *z* axis. We then looked for any trial where the velocity went below 10 cm/s during this portion of the movement.[4] Our stopping measure was binary; therefore, any trial on which movement below this threshold occurred was considered a stopping trial, and all other trials were considered non-stopping trials. Using this definition, we conducted a 4 $\times$ 2 ANOVA with age group and distractor presence as factors and total number of stopping trials as the dependent variable.[5]

We found that stopping occurred more frequently in the presence of distractors (stops per participant: 0.9%) compared with when no distractor was present (0.5%), $F(1, 92) = 5.10$, $p = .026$, $\eta_p^2 = .05$.

[4] Note that this is the same as the threshold used to define the end of a movement in our initial analysis but that we examined trajectories by hand to ensure that the entire movement was captured, so in cases where this threshold was reached in the middle of the movement, we corrected to capture the entire movement. For the current stopping analysis, we defined the beginning of the movement as the start of the trial and defined the end of a movement using the same parameters that were used to determine accuracy online during the task. Thus, this analysis ignored any of the by-hand corrections that were used for other primary analyses to capture instances of mid-movement stopping.

[5] Because this was a binary measure on each trial, we did not do a log-transformed version of the variable in this particular analysis. However, we are not concerned that the interaction is an artifact of higher overall stopping frequency among the 5-year-old age group because simple main effects analyses showed no effect of distractor presence on stopping frequency among all the other age groups.


A)
Location Repeat
Location Switch
Initiation Time (ms)
600
550
500
450
400
350
300
250
*
Age 5
Age 9
Age 13-14
Adult
B)
Movement Time (ms)
700
650
600
550
500
450
400
*
*
Age 5
Age 9
Age 13-14
Adult
C)
Curvature (ratio)
0.2
0.15
0.1
0.05
0
*
*
*
Age 5
Age 9
Age 13-14
Adult

Stopping also occurred more frequently when the target location was switched (0.9%) compared with when it was repeated (0.6%), $F(1, 92) = 17.83$, $p < .001$, $\eta^2_p = .16$. There was also a main effect of age, $F(3, 92) = 7.69$, $p < .001$, $\eta^2_p = .20$, with far more frequent stops among 5-year-olds (2.4%) than any among other age group (all < 0.4%). Subsequent pairwise comparisons revealed that 5-year-olds stopped more frequently than all other groups (all *p*s < .01), whereas the other three age groups did not differ from each other in their stopping frequency (all *p*s > .05).

Finally, there were interactions between distractor presence and age group, $F(3, 92) = 3.55$, $p = .017$, $\eta^2_p = .10$, and between location and age group, $F(3, 92) = 10.80$, $p < .001$, $\eta^2_p = .26$. For distractor presence, there was a marginal effect for 5-year-olds (present: 3.2%; absent: 1.6%), $p = .051$, $\eta^2_p = .16$, whereas no other age group showed any distractor effects (*p*s > .05). A similar pattern was observed for location repetition effects, with a large effect for 5-year-olds (repeated: 1.9%; switched: 2.9%) and no effect for any other age group (*p*s > .05). There was no interaction between location and distractor, and there was not a three-way interaction (*p*s > .05).

Note that the measure of stopping used in the above analyses was conservative considering that the measure examined only the middle 80% of the movement and thus did not consider full stops that occurred near the very beginning or end of the movement. Still, we found evidence that 5-year-olds stop their movements more frequently and that these stops are more likely to be brought on by the presence of a salient distractor or the repetition of the target location. This behavior is largely distinct to this particular age group; none of the other age groups tested were susceptible to mid-movement pauses elicited by salient distractors.

Color repetition

The primary focus of this project was on distractor and location repetition effects. We presumed that location repetition effects would be fairly robust based on previous research (e.g., Maljkovic & Nakayama, 1996). However, because color was not a target-defining feature in the current task, it was less clear how robust color repetition effects would be, although some prior research found effects of color repetition in similar tasks (e.g., Graves & Egeth, 2016). Furthermore, additional contingencies, such as whether there was a distractor present or not on the previous trial, may interact with color repetitions, but accounting for these contingencies would leave the analysis underpowered due to a very small number of trials per condition. Consequently, we were not able to include them in the analysis. Still, as an exploratory analysis, we conducted a mixed ANOVA with a between-participants factor of age group and within-participant factors of distractor and target color on three same three dependent measures (IT, MT, and CURV) as our primary analysis. The full dataset is available at our Open Science Framework site. Here, we provide a brief summary of the results that are most relevant to the interpretation of the effects reported above.

We found a main effect of color repetition on both IT and CURV, with shorter IT and lower CURV when the color was repeated (IT: 364 ms; CURV: .099) compared with when it was switched (IT: 376 ms; CURV: .105), *p*s < .001. The interaction between target color and age group was also significant, $F(3, 92) = 8.11$, $p < .001$, $\eta^2_p = .21$, although this interaction did not reach significance when looking at log-transformed IT data, $F(3, 92) = 2.28$, $p = .085$, $\eta^2_p = .07$. The general pattern of effects matched those observed for location repetition, with repetition effects decreasing as age increased (repetition benefit for 5-year-olds: 34 ms; 9-year-olds: 7 ms; 13- and 14-year-olds: 6 ms; adults: 1 ms). These results should be interpreted with caution, however, given the exploratory nature of this analysis

Fig. 4. (A) Initiation times were shorter when the target location was repeated compared with when the target location was switched for 5-year-olds. Error bars reflect standard error of the mean. Asterisks indicate statistical significance in simple main effects analyses. (B) Movement times were shorter when the target location was repeated compared with when the target location was switched for younger age groups. Error bars reflect standard error of the mean. Asterisks indicate statistical significance in simple main effects analyses. (C) Curvature was smaller when the target location was repeated compared with when the target location was switched for all groups except adults. Error bars reflect standard error of the mean. Asterisks indicate statistical significance in simple main effects analyses.

and the fact that the log-transformed data only approached significance. Critically, the three-way interaction did not approach significance for log-transformed data for any of the measures (all *ps* > .39).[6] In other words, the interactions discussed in earlier sections between distractor and age group were independent of color repetitions.

Participant-level correlations

In some of the above analyses, we observed different patterns of results for MT and CURV. Although MT and CURV can generally be expected to correlate, these measures can present different patterns of results. For instance, Erb and Marcovitch (2019) found that age-related differences in the Simon task were more pronounced in MTs than in CURVs when evaluating the congruency sequence effect. To further consider the relations among our primary dependent measures of IT, MT, and CURV, we conducted exploratory analyses to examine the participant-level correlations among each pair of measures. To do this, we took every accurate trial that was included in the earlier analyses for each participant and calculated a Pearson's *r* value for the correlation between each pair of measures: IT and MT, IT and CURV, and MT and CURV. We then calculated one-sample *t* tests at the group level for participant-level correlations to determine whether, on average, each correlation differed from 0 and calculated one-way ANOVAs with age group as a between-participants factor to determine whether the correlations differed among age groups.

Each correlation differed significantly from 0 (IT + MT: −.09; IT + CURV: −.11; MT + CURV: .36), *ps* < .001. There was a significant effect of age on the correlations for IT + MT, $F(3, 92) = 3.30$, $p = .02$, $\eta_p^2 = .10$, in which correlations were stronger for younger age groups (5 years: −.12; 9 years: −.13) compared with older age groups (13–14 years: −.01; adults: −.08). There was also a significant effect of age on correlations for MT + CURV, $F(3, 92) = 12.85$, $p < .001$, $\eta_p^2 = .30$. Again, correlations were stronger for younger age groups (5 years: .48; 9 years: .44) compared with older age groups (13–14 years: .31; adults: .20). There was no effect of age on the participant-level correlations between IT and CURV, $F(3, 92) = .18$, $p = .91$.

The correlation between MT and CURV was by far the most robust and, interestingly, participant-level correlations were in general stronger for younger participants compared with older participants. This developmental difference could reflect (a) age-related increases in velocity following a movement redirection, (b) more pronounced or frequent decreases in velocity on trials featuring a movement redirection in children relative to adolescents and adults (as suggested by our exploratory analysis of MT), or (c) a combination of the two. Notably, a great deal of variance was unexplained by the relationship between MT and CURV, indicating that the measures were sufficiently independent to provide differing unique insights into behavior reflected by differing patterns of distractor interference across development.

Discussion

The current study sought to address three central questions:

1. To what extent are age-related differences in attentional capture observed when the target and distractor are presented simultaneously?
2. Does attentional capture automatically bias response activations in children and adolescents as in adults?
3. How do the cross-trial dynamics of attentional capture change across development?

We address each of these questions in turn in the following sections.

[6] The three-way interaction was significant for raw data for the CURV measure, $F(3, 92) = 2.83$, $p = .04$, $\eta_p{}^2 = .08$. However, with log-transformed CURV data, the three-way interaction did not approach significance, $F(3, 92) = 0.31$, $p = .82$, $\eta_p{}^2 = .01$.

Are age-related differences in attentional capture observed?

Reach CURVs revealed a significant distractor effect in each age group. The size of this effect did not differ as a function of age, indicating that children, adolescents, and adults were equally susceptible to attentional capture by a distractor that appeared at the same time as the target. In contrast to reach CURVs, MTs revealed significant distractor effects in 5-year-olds and 9-year-olds but not in adolescents and adults. These findings indicate that although each age group did experience attentional capture (as observed in reach CURVs), adolescents and adults appear to have recovered more effectively from capture (as observed in MTs). Indeed, exploratory analyses evaluating MTs in greater detail revealed that 5-year-olds were significantly more likely to pause during their movements when a distractor was present, suggesting that young children in particular struggle to recover from attentional capture.

The increased rate of pausing in 5-year-olds' movements can be interpreted in a number of ways. For instance, the pausing may have reflected a "brake" process that has been suggested to suppress motor output temporarily when signals of conflict are detected (Frank, 2006). Previous research by Erb and colleagues (Erb & Marcovitch, 2018; Erb et al., 2017) suggests that this process is developing between early and late childhood, with conflict resulting in briefer periods of motoric stopping in older children than in younger children. The effect may have also stemmed from age-related differences in working memory capacity. For instance, 5-year-olds may have struggled to maintain robust representations of the task's rules such that, upon detecting the conflict between the response cued by shape and the response cued by color on distractor-present trials, these children needed to reflect to a greater degree (Blackwell, Cepeda, & Munakata, 2009; Marcovitch, Boseovski, Knapp, & Kane, 2010). The ability to maintain task-relevant information in a more robust manner may have enabled older children, adolescents, and adults to alter the trajectory of their movements in a more flexible manner.

Another possibility is that CURV effects reflect an earlier part of processing relative to MTs. Song and Nakayama (2008) examined curved trajectories in which the final selected target appeared to differ from the initially selected target based on analyses of movement trajectories. Based on time course analyses, they concluded that the second, corrective target is selected before the movement begins; however, because that selection process takes time to be translated into a motor movement, the correction is only evident starting mid-flight. Similarly, Heath, Hodges, Chua, and Elliott (1998) found that when target size was changed at the start of movement initiation, hand velocity could be adjusted to account for the change in size only during the deceleration phase of the movement (after peak velocity had already been achieved). In the current data, it could be that curved trajectories reflect an initial capture of attention that triggers a goal-directed movement but that MTs can be adjusted later in time, and thus differences in MTs across age groups may reflect later processes such as recovery from capture. Furthermore, the timing and nature of these processes, including when and how an initial movement is overridden, may differ across development. Further research would be needed to test these possibilities.

Finally, it is possible that the distractor effect observed in hand trajectories reflected the parallel activation of competing responses rather than the sequential activation of the distractor and target locations. A growing body of research indicates that multiple responses can be prepared simultaneously and that this parallel activation of responses allows for enhanced flexibility (Cisek & Kalaska, 2010; Coallier, Michelet, & Kalaska, 2015; Gallivan et al., 2015; Gallivan, Chapman, Wolpert, & Flanagan, 2018; Klaes, Westendorff, Chakrabarti, & Gail, 2011). In light of these findings, researchers have emphasized the importance of developing theoretical frameworks and computational models that link decision making and sensorimotor control (Cisek & Kalaska, 2010; Gallivan et al., 2015, 2018; Wispinski, Gallivan, & Chapman, 2018). On this view, the CURV effects observed in the current study reflect the continuous activation dynamics of competing responses, including online corrections that can be implemented after a movement is initiated. In comparison with adolescents and adults, children in the current study were less capable of implementing online corrections, resulting in significant distractor effects in their MTs. From the perspective of evidence accumulation frameworks, this developmental difference could be understood to reflect the continued accrual of evidence following movement initiation (Resulaj et al., 2009; Wispinski et al., 2018). Adolescents and adults were able to update their movements in a flexible online fashion as more evidence accumulated in favor of the response cued by the target on distractor-present trials. However, this continued accumulation of evidence on distractor-present trials may have caused children to slow their movements, as noted above, due to the effects of conflict detection (Erb & Marcovitch, 2018; Erb et al., 2017) or difficulties in maintaining robust representations of task-relevant information in working memory (Blackwell et al., 2009; Marcovitch et al., 2010).

In sum, our results indicate that age-related reductions in attentional capture costs partly reflect an improved ability to recover from capture. This finding is particularly notable because it highlights the possibility that the developmental differences in attentional capture observed in pre-cueing tasks and attributed to age-related changes in susceptibility in previous studies (e.g., Gaspelin, Margett-Jordan, et al., 2015) may have been driven, at least in part, by age-related changes in recovery.

Although the current study revealed evidence of capture in reach CURVs at each age group, multiple studies with adults indicate that attentional capture can be reduced or avoided by adult participants under certain conditions. These conditions include when observers are able to adopt efficient search strategies through experience or when distractors occur with high probability and thus can be suppressed (e.g., Bacon & Egeth, 1994; Gaspelin, Leonard, & Luck, 2015; Leber & Egeth, 2006; Moher, Abrams, Egeth, Yantis, & Stuphorn, 2011; Müller, Geyer, Zehetleitner, & Krummenacher, 2009; Vatterott & Vecera, 2012). This is relevant for the current study because participants were likely to use a strategy referred to as *singleton detection mode* given the parameters of our task (Bacon & Egeth, 1994). This strategy involves simply searching for the item in the display that pops out because of its physical salience. On distractor-absent trials, this is an efficient strategy to find the target; however, when a distractor is present, this strategy produces attention capture effects. Thus, results in the current study might not reflect automatic stimulus-driven capture but rather might reflect capture resulting from the use of this particular search strategy. An important direction for future research to explore therefore concerns the extent to which children and adolescents are also capable of avoiding capture of action altogether using alternative search strategies such as feature search mode (e.g., Bacon & Egeth, 1994) and other top-down strategies.

Is action captured during childhood and adolescence?

As noted above, we observed a significant distractor effect in reach CURVs at each age group. Thus, our findings indicate that the link between attention and action previously observed in adults (e.g., Kerzel & Schönhammer, 2013; Moher, Anderson, et al., 2015; Welsh, 2011) is present as early as the preschool years. The results support action-centered models of attention (Tipper et al., 1992; Welsh, 2011) and underscore the importance of incorporating continuous behavioral measures into developmental research on perception and action (see also Marcovitch & Zelazo, 2009; Thelen, Schöner, Scheier, & Smith, 2001). Indeed, the conclusions of the current study would have been entirely different if the spatial characteristics of participants' movements were not measured given that no evidence of attentional capture was observed in adolescent or adult ITs or MTs.

Developmental psychology has a rich history of emphasizing the links among perception, cognition, and action (Gauthier, Vercher, Ivaldi, & Marchetti, 1988; Kontra, Goldin-Meadow, & Beilock, 2012; Piaget, 1952; Smith & Gasser, 2005). However, relatively little developmental work has engaged directly with action-centered models of attention (e.g., Daum & Gredebäck, 2011; Diamond & Lee, 2000; Thelen et al., 2001). Given the important links among perception, cognition, and action highlighted by developmental studies investigating topics ranging from the perception of goal-oriented actions (e.g., Sommerville, Woodward, & Needham, 2005) to the role of gesture in mathematics (e.g., Gunderson, Spaepen, Gibson, Goldin-Meadow, & Levine, 2015; Novack, Congdon, Hemani-Lopez, & Goldin-Meadow, 2014), we believe that future work should seek to integrate action-centered models of attention more fully into developmental research and theory. More generally, we believe that developmental research would be well served by increased involvement in ongoing efforts within computational and cognitive neuroscience to develop and test theoretical frameworks and computational models that link decision making and sensorimotor control (Cisek & Kalaska, 2010; Gallivan et al., 2015, 2018; Wispinski et al., 2018).[7]

How do the cross-trial dynamics of attentional capture change across development?

In addition to the distractor effects observed in reach CURVs and MTs, children's performance was significantly affected by an additional task-irrelevant factor—response repetition type. The 5-year-olds' ITs and MTs were slower, and their reach CURVs were larger, when they were required to reach to a different location than in the previous trial. Similarly, the 9-year-olds' MTs and reach CURVs (but not their ITs) exhibited a significant effect of response repetition type, whereas only a CURV effect was observed in the 13- and 14-year-olds and no such effects were observed in the adults. In an exploratory analysis, hints of similar age-related color repetitions were observed, with numerically greater color repetitions for 5-year-olds relative to the other age groups. These findings indicate that children and adolescents are influenced by a broader range of task-irrelevant properties than adults and highlight the importance of considering trial sequence effects when evaluating developmental dynamics (Erb & Marcovitch, 2018, 2019). Interestingly, these cross-trial dynamics were largely independent of attentional capture, suggesting that task-irrelevant properties can additively influence behavior and that they demonstrate developmental change.

What might underlie children's susceptibility to response repetition effects? One possibility is that children were more prepared to attend to or move toward the location that was most recently the target of visually guided action. That is, adolescents and adults may be better able to "wipe the slate clean" after each trial to minimize the influence of task-irrelevant factors. Alternatively, children may have been more likely to form active expectations regarding the location of the target on each trial. Anecdotally, while performing the task, children did occasionally remark that they had anticipated where the target would appear. In addition, the exploratory analyses showed that 5-year-olds (but not the other age groups) were more likely to stop mid-movement when the target location was switched. Thus, it is also possible that adolescents and adults were more likely to expect the target's location to be randomized and, consequently, were less likely to form active expectations regarding the target's location.

Conclusion

The current study used reach tracking to investigate the dynamics of attentional capture and control across childhood, adolescence, and adulthood. In contrast to traditional button-press methods, this approach provided a more detailed view of how attention and action are linked across development. The results indicate that (a) age-related reductions in attentional capture costs are driven in part by an improved ability to recover from capture; (b) action is captured along with attention by as early as 5 years of age, consistent with action-centered models of attention (Tipper et al., 1992; Welsh, 2011); and (c) children are more susceptible to interference from a wider range of task-irrelevant factors than adolescents and adults, at least in the context of the current task. In addition to shedding new light on the dynamics of attention and distraction across development, these findings contribute to a growing body of research highlighting the benefits of incorporating continuous behavioral measures into developmental research (Erb, 2018).

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[7] The distinction between attentional capture and action capture explored in the current study is questionable from the perspective of these frameworks because it is predicated on the notion that attention and action are easily separated. For a discussion regarding why attention and action are not easily separated, see Hommel et al. (2019).

Data availability

The data and analysis files associated with this study are available through the Open Science Framework (https://osf.io/rw5b7/?view_only=3e353146b32540738d96dec8843d0f22).

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