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Endogenous control is insufficient for preventing attentional capture in children and adults

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ABSTRACT

Adults are known to have developed the ability to selectively focus their attention in a goal-driven (endogenous) manner but it is less clear at what stage in development (5–6 & 9–11 years) children can endogenously control their attention and whether they behave similarly to adults when managing distractions. In this study we administered a child-adapted cued visual search task to three age-groups: five- to six-year-olds (N = 45), nine- to eleven-year-olds (N = 42) and adults (N = 42). Participants were provided with a cue which either guided their attention towards or away from an upcoming target. On some trials, a singleton distracter was presented which participants needed to ignore. Participants completed three conditions where the cues were: 1) usually helpful (High Predictive), 2) usually unhelpful (Low Predictive) and 3) never helpful (Baseline) in guiding attention towards the target. We found that endogenous cue-utilisation develops with increasing age. Overall, nine- to eleven-year-olds and adults, but not five- to six-year-olds, utilised the endogenous cues in the High Predictive condition. However, all age-groups were unable to ignore the singleton distracter even when using endogenous control. Moreover, we found better cue-maintenance ability was related to poorer distracter-inhibition ability in early-childhood, but these skills were no longer related further on in development. We conclude that overall endogenous control is still developing in early-childhood, but an adult-like form of this skill has been acquired by mid-childhood. Furthermore, endogenous cue-utilisation was shown as insufficient for preventing attentional capture in both children and adults.

1. Introduction

The attentional system is a dynamic and complex structure. To focus our attention on a particular object in our environment is a highly effortful skill. We often embark on our everyday activities with plans and goals in mind. Whether that is when we are commuting, buying groceries or studying for an upcoming exam, we regularly find ourselves planning ahead. This ability is also referred to as *top-down, proactive* or *endogenous control*; a higher-order process which enables us to direct our attention towards goal-relevant objects and away from goal-irrelevant objects (Desimone & Duncan, 1995; Soto et al., 2008). At the same time, our attention can be distracted away from our tasks by irrelevant and salient features in our environment (Theeuwes, 2010). This is a common occurrence in classroom environments which can impact school readiness and academic attainment (Fisher et al., 2014; Godwin & Fisher, 2011; Steele et al., 2012). It is argued that children are more susceptible to distractions than adults (Gaspelin, Margett-Jordan & Ruthruff, 2015; Iarocci et al., 2009; Johnson et al., 2020; Rodrigues and Pandeirada, 2018). Children are said to undergo development for utilising endogenous (goal-driven) cues in their environment (Leclercq & Siéroff, 2013; Shimi et al., 2014; Wainwright & Bryson, 2005). Yet little research has investigated whether children can use this attentional control mechanism to ignore salient distractions, how their performance compares to adults and whether this ability is related to distracter-inhibition abilities.

1.1. Endogenous control in development

Endogenous control is argued to gradually develop throughout childhood and adolescence before reaching "peak" levels in young adulthood (Goldberg et al., 2001; Jakobsen et al., 2013; Schul et al., 2003). In the early school years, children are theorised to undergo a key transition between ages five and six from using mainly exogenous control to using mainly endogenous control when it is possible (Munakata et al., 2012). Research suggests that endogenous control becomes comparable to adults by mid-childhood (nine to 11 years old; Goldberg

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et al., 2001; Leclercq & Siéroff, 2013; Pearson & Lane, 1990; Schul et al., 2003; Wainwright & Bryson, 2005). However, others suggest that it is not until age 12 and over that endogenous control reaches maturity (Merrill & Conners, 2013; Wong-Kee-You et al., 2019).

There is mixed evidence for whether endogenous control is evident in early-childhood. Studies using a Posner task (Posner, 1980) and manual reaction time task have shown that five- to six-year-olds were faster when a spatial cue guided attention towards (valid cue) relative to away from (invalid cue) the upcoming target location (Jakobsen et al., 2013; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005). Moreover, orienting attention in response to arrows, pointing hands and gaze cues appears to stabilise from a young age and shows no developmental change between early- to mid-childhood (Hermens, 2018; Landry et al., 2019). These findings indicate that the ability to encode a goal-relevant cue to anticipate an upcoming event has developed and stabilised between ages five to six.

Importantly however, five- to six-year-olds tend to produce large orienting effects in a block of trials where the cue is usually invalid as well as in a block of trials where the cue is usually valid (Brodeur & Boden, 2000; Brodeur & Enns, 1997; Iarocci et al., 2009). In contrast, seven-year-olds tend to only orient to cues which are usually valid (Shimi et al., 2014). This suggests that five- to six-year-olds orient towards the cued location regardless of its target predictiveness. They may be utilising exogenous control to orient their attention as it is the mere presence of this cue which produces a reflexive rather than a goal-directed response (Chun, 2000; Theeuwes et al., 2006).

Despite the uncertainty in early-childhood, endogenous control continues to develop throughout childhood (Schul et al., 2003; for neurodevelopmental accounts see Amso & Scerif, 2015; Corbetta et al., 2008), although it remains unclear at what stage this skill is used in a similar way to adults. At age seven, children voluntarily utilise endogenous cues that are usually valid, allowing them to benefit from them in guiding attention towards the target, and this ability continues to develop in children aged 11 (Brodeur & Boden, 2000; Brodeur & Enns, 1997; Goldberg et al., 2001; Lookadoo et al., 2017; Pearson & Lane, 1990; Shimi et al., 2014; Shimi et al., 2015). However, only ten-year-olds, and not eight-year-olds, behaved similarly to adults by showing negative orienting (faster on invalid vs valid trials) in a block of trials where the cue was usually invalid (i.e. cue presented on the left informs target will be on the right; Leclercq & Siéroff, 2013; Van Gerven et al., 2016). These findings suggest that by mid-childhood endogenous control has matured as children show similar patterns to adults in their orienting response and are able to strategically modulate their attention. This is heavily debated however, as others suggest that attentional abilities do not mature until late-childhood and adolescence (Luna et al., 2004; Schul et al., 2003; Wong-Kee-You et al., 2019).

There is, therefore, mixed evidence concerning at what point endogenous control is acquired and whether this skill is comparable to adults during mid-childhood.

1.2. Attentional capture

Distraction or *attentional capture* is a rapid process whereby a stimulus captures attention within approximately 100 ms of it appearing in our visual field (Müller & Findlay, 1988). Stimulus-driven theories define attentional capture as an automatic process which occurs outside of our own volition (Theeuwes, 2010). It is postulated that the physical characteristics of an object, or its *salience*, driven by the visual system, guides our attention (Theeuwes, 2004; Tsvetanov et al., 2013; Van der Stigchel et al., 2009). For instance, a red distracter item amongst a homogenous display of green items has been shown to evoke slower response times compared to when this red singleton distracter was absent from the search-display (Gaspelin, Leonard & Luck, 2015; Hickey et al., 2006). In contrast, goal-driven theories suggest that attentional capture is contingent on our task-goals as capture effects are produced when an irrelevant distracter matches a target-defining feature (Eimer & Kiss, 2008; Folk et al., 1992). Based on our understanding of attentional capture, it is vital to comprehend whether endogenous control can help children and adults to reduce capture effects on attention.

The signal suppression hypothesis proposes that goal-directed attention can enable us to suppress a singleton distracter (Sawaki & Luck, 2010). This framework theorised that a singleton distracter will produce an early "attend to me" signal which is fed back to the attentional control system. By maintaining a task-goal at an early point in processing, this allows weights to be assigned to task-relevant features in the environment (Found & Müller, 1996; Wolfe, 2020; Wolfe et al., 1989). This would enable us to actively suppress the bottom-up response before our attention is deployed towards the singleton distracter (Gaspelin et al., 2017; Gaspelin, Margett-Jordan & Ruthruff, 2015; Mevorach et al., 2010; Sawaki & Luck, 2010, 2013). Event Related Potential (ERP) evidence has shown that task-goal maintenance enables adults to produce a distracter-positivity (Pd) response (an electrophysiological marker of attentional suppression; Hickey et al., 2009) to a singleton distracter, before deploying attention towards the target (indicated by the N2pc ERP component; Gaspar et al., 2016; Gaspar & McDonald, 2014; Sawaki & Luck, 2010). Maintenance of a task-goal allows us to selectively engage attention and inhibit information which conflict with our goal; without this goal, attention is susceptible to distraction (Riddoch et al., 2010; Sawaki & Luck, 2013).

There is little research on the dynamic between endogenous control and the prevention of attentional capture in children. Research has shown that young children are unable to modulate their exogenous response towards a distraction (Iarocci et al., 2009). Furthermore, four- to five-year-olds are more vulnerable to distraction relative to adults in the capture contingency paradigm where participants were presented with a cue which was either compatible (matched target colour) or incompatible (mismatched target colour) with a target-defining feature (Gaspelin, Leonard & Luck, 2015). Gaspelin, Leonard & Luck (2015) showed that adults, but not four- to five-year-olds, produced a compatibility effect (slower on compatible vs incompatible trials; see also Iarocci et al., 2009). This suggests that by early-childhood, children have not yet acquired the ability to inhibit a prepotent response towards a salient distraction, despite being provided with early information about the upcoming target.

By mid-childhood, it remains unclear whether the ability to suppress distracters has matured. In a cued visual search task, eight- to eleven-year-olds were unable to suppress distracters which were surrounding a spatially cued target, and a similar level of suppression to adults was only attained for children aged 12 and above (Wong-Kee-You et al., 2019). Moreover, nine-year-olds behaved similarly to six-year-olds, rather than adults, when they were required to search for the less salient grey target and ignore the black singleton distracter (Merrill & Conners, 2013). On the other hand, some evidence has shown comparative performance to adults by mid-childhood for overcoming attentional capture effects under certain conditions (Iarocci et al., 2009; Michael et al., 2013). It is uncertain therefore whether the ability to endogenously inhibit an "attend to me" signal of a distraction using visual cues is reserved for adolescents and adults or whether this ability is acquired by mid-childhood.

1.3. Comparing cue-maintenance and distracter-inhibition in development

Cue-maintenance and distracter-inhibition abilities are said to be key components in orienting behaviour (Brodeur & Boden, 2000; Brodeur & Enns, 1997). Cue-maintenance in the cued visual search task is defined by the ability to utilise a cue to make an anticipatory response to the target. Distracter-inhibition in this task is defined by the ability to suppress a distracter or invalidly cued location in order to reorient attention (Soto et al., 2008; Wainwright & Bryson, 2005). From this point forward, we will refer to cue-maintenance and distracter-inhibition skills in the context of their use in the cued visual search task as defined above.

It is possible that cue-maintenance and distracter-inhibition abilities are independent but related processes, and that one may benefit the other, i.e. that better cue-maintenance leads to better distracter-inhibition. In adults, endogenous control has been shown to reduce or prevent attentional capture in visual search (for a review, see Chelazzi et al., 2019). The majority of cueing studies compared how endogenous cues reduced distraction on valid trials relative to neutral trials however. This means that the level of exogenous cueing was not accounted for as performance was not compared to a mostly invalid block condition (Theeuwes & van der Burg, 2008). If attentional capture is reduced in a mostly valid block relative to a neutral block *and* mostly invalid block, this provides stronger evidence for the involvement of endogenous control, as opposed to purely exogenous processes. Thus, it remains uncertain whether cue-maintenance of endogenous cues can improve distracter-inhibition in adults.

In children, the developmental profiles of cue-maintenance and distracter-inhibition are argued to change with age (Brodeur & Boden, 2000). When a cue has guided attention towards a non-target location, participants must inhibit this location to disengage and reorient their attention in search for the target (Wainwright & Bryson, 2005). Young children struggle to do this (Brodeur & Boden, 2000; Brodeur & Enns, 1997; Iarocci et al., 2009; Wainwright & Bryson, 2005). In contrast, older children appear to have better control over suppressing distracting information (Iarocci et al., 2009; Michael et al., 2013). As cue-maintenance and distracter-inhibition are said to be components of endogenous orienting (Brodeur & Boden, 2000), it is of interest to examine this area further to understand the relationship between these abilities and how they change in development.

1.4. Current study

We used a cued visual search task to assess developmental differences in endogenous control and attentional capture. Participants were asked to search for and discriminate the direction (left or right) of a white tilted-line target presented in one of three coloured circles. Immediately prior to the search-display, participants were presented with a coloured circle cue. Valid cues guided attention towards the target to assist search (e.g. blue cue – target presented in the blue circle; Kiyonaga et al., 2012; Laarni, 2001). Invalid cues guided attention away from the target to hinder search (e.g. blue cue – target was not presented in blue).

As it has been difficult to disentangle endogenous and exogenous processes in previous research (Pearson & Lane, 1990; Theeuwes & van der Burg, 2008; Wainwright & Bryson, 2005) we included conditions where the cues are mostly helpful (High Predictive block; 66.67% valid cues: 33.33% invalid cues; aimed to encourage endogenous cue-use) and conditions where the cues are mostly unhelpful (Low Predictive block; 33.33% valid cues: 66.67% invalid cues; aimed to discourage cue-use).

We also included a neutral cue block (Baseline block: 100% neutral cues). In this condition the cued colour was absent from the search-display and so could not guide attention (see also Soto et al., 2007; Soto & Humphreys, 2007). This type of neutral cue has the advantage that trials will have a similar structure and timing to the other types of cued trials and thus create a similar level of expectation in the trial sequence (i.e. cue followed by search-display). It also allows us to match our search-display as closely as possible between our three types of trial block (see Materials & methods).

Finally, in each block condition, 41.67% of trials included a salient singleton distracter (a black diamond) in the search-display to assess attentional capture effects.

This study was pre-registered on the Open Science Framework (osf.io/cvj8p) and had three aims. First, we aimed to understand the stage in development (early-childhood: 5–6 years, mid-childhood: 9–11 years, adulthood) at which endogenous cues can guide attention in a goal-driven manner. Endogenous control would be shown by large differences between valid and invalid response times and accuracy indicating high cue-utilisation. If endogenous control has developed, we would expect to find greater cue-utilisation in the High Predictive block than the other block conditions. We predicted that nine- to eleven-year-olds and adults would show this pattern of results, with adults having significantly greater cue-utilisation than nine- to eleven-year-olds. It is uncertain however whether five- to six-year-olds will show greater cue-use in the High Predictive block compared to Baseline (Gaspelin, Leonard & Luck, 2015; Johnson et al., 2020).

The second aim was to investigate whether children and adults can utilise endogenous control to reduce attentional capture. To do this we compared performance when there was a singleton distracter present in the search-display, to when it was absent. If endogenous control reduces attentional capture, we expected to find a smaller difference between singleton-present and singleton-absent trials in the High Predictive block compared to the other block conditions. It remains unknown whether children and adults are able to utilise endogenous cues to reduce attentional capture (Theeuwes & van der Burg, 2008).

The third aim was to assess whether cue-maintenance and distracter-inhibition abilities in cued visual search are related more generally. Our measure for cue-maintenance was cueing ratios (invalid/valid response times) on singleton-absent trials in the High Predictive block. Our measure for distracter-inhibition was distraction ratios (singleton-present/singleton-absent response times) in the Baseline block. If cue-maintenance and distracter-inhibition abilities are related, we expect to find a negative relationship; as the ability to maintain a cue increases, distraction caused by the singleton distracter decreases. However, age-group may moderate this relationship as research suggests that young children are still developing the ability to maintain and inhibit information (Brodeur & Boden, 2000; Brodeur & Enns, 1997; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005).

2. Materials and methods

2.1. Participants

One hundred and twenty-nine participants from three age-groups (5–6, 9–11 & 18–25 years) took part in this study (see Table 1) after exclusion (5–6 years: attrition = 5, failure to follow instructions = 3; 9–11 years: failure to follow instructions = 3; adults: failure to follow instructions = 3; experimenter error = 3, reported to have had a diagnosis of a mental health condition and/or developmental disorder = 3).[1] Children were recruited from two primary schools and one infant school

[1] We conducted a power analysis using the method described by D'Amico et al. (2001) and Osborne (2006) (see osf.io/cvj8p). This method used pilot data to simulate our effect size to understand the number of participants needed for the required power. This found that 40 participants were required per age-group to attain a power of 0.8 at an alpha criterion of 0.05 for a simulated effect size of $\eta_p^2 = 0.051$. However, due to experimenter error in inputting the pilot data this power analysis was inaccurate. Correcting this error resulted in a simulated effect size of $\eta_p^2 = 0.076$ and required sample size of 30 participants per age-group for the analysis of cue-utilisation in a Block × Age-Group interaction. Therefore we attained more than adequate power for this study.

Table 1
Participant demographic information.

	5- to 6-year-olds	9- to 11-year-olds	Adults
N	45	42	42
M age (SD) (years)	5.98 (0.32)	10.43 (0.56)	20.47 (1.79)
Age range (years)	5.50–6.67	9.50–11.50	18.00–25.50
Gender Identity (m: f)	40%: 60%	42.86%: 57.14%	23.81%: 76.19%
Ethnicity	80% White, 8.89% Asian, 2.22% Black, 8.89% Mixed Ethnic Groups	92% White, 4.76% Asian, 2.38% Mixed Ethnic Groups	61.90% White, 28.57% Asian, 4.76% Black, 4.76% Mixed Ethnic Groups
Bilingual	13.33%	2.38%	30.95%

Note: M – mean; SD – standard deviation; m – male; f - female.

in the Derbyshire region between January and May 2018. The schools ranged from a 3rd to 10th multiple deprivation decile in the 2015 English Indices of Multiple Deprivation which measures relative deprivation ranking from the most deprived areas (smaller ranks) to the least deprived areas (larger ranks). Adults were undergraduate and postgraduate students from the University of Nottingham. This study was granted ethical approval by the University of Nottingham School of Psychology Ethics Committee. Parents and adults provided informed consent and verbal assent was gained from children. Adults were compensated for their time in the form of a course credit or an inconvenience allowance and children were compensated in the form of a certificate, stickers and a novelty pencil.

2.2. Design

We used a mixed design which included three within-subject variables (Cue Validity, Block Predictiveness & Singleton Presence) and one between-subject variable (Age-Group). Cue Validity was manipulated to guide participants' attention towards (valid cue) or away (invalid cue) from the target as well as not guide attention (neutral cue). Block Predictiveness manipulated cue validity over three block conditions in the High Predictive block (66.67% valid: 33.33% invalid cues), Low Predictive block (33.33% valid: 66.67% invalid cues) and Baseline block (100% neutral cues; *for trial proportions see* Table 2 *Results*). Singleton Presence (present, absent) assessed attentional capture as a singleton distracter was present on 41.67% of trials in each block.

2.3. Stimuli

In each block condition, participants were first presented with a fixation cross (0.41° width × 0.41° height) presented in black on a white background, followed by a coloured circular cue (4.90° width × 4.90° height) in the centre of the screen (*see* Fig. 1). The cue was created using GIMP software (The GIMP Development Team, 2018) which had a raised cosine mask applied to form a blurred circular outline (0.59° fringe width). Four colours were equally presented as a cue in each block condition (pink [X = 67.96, Y = 54.41, Z = 60.99], yellow [X = 80.49, Y = 78.77, Z = 34.52], blue [X = 58.15, Y = 65.95, Z = 87.82] and green [X = 57.87, Y = 83.53, Z = 50.62 cd/m^2]; CIE XYZ 1931 Colour Space).

The cue was presented for 300 ms before the presentation of the search-display which consisted of a fixation cross and three coloured circles with the same size properties as the cue. Each circle was presented in one of four quadrants of the screen, leaving one quadrant blank on each trial. On each trial, each circle was presented in one of four randomly selected locations within each quadrant (ranging between 4.09° to 4.90° away from fixation on *x* and *y* axis respectively). This ensured the locations of the circles varied across trials. On each trial, two coloured circles contained a white vertical line (0.08° width × 0.41° height) in their centre and the remaining circle contained the white tilted-line target which was presented with equal probability either 45° clockwise or anticlockwise from vertical for all colours and quadrants in each block condition. The singleton distracter was a black diamond (1.55° width × 1.55° height; black [X = 4.29, Y = 4.38, Z = 4.52 cd/m^2]) which was presented on 41.67% of trials in each block condition. The singleton distracter was presented in one of four randomly selected locations within each quadrant (locations ranging between 0.82° and 2.45° away from fixation on *x* and *y* axis respectively). There was no overlap between the circles and the singleton distracter in the search-display. To strengthen the comparisons between block conditions, we ensured that the physical characteristics of search-displays (i.e. positions of the singleton distracter, coloured circles, target line and its orientation) on trials in each block condition were closely matched to one another. This would allow us to have more control over sensory confounds in the search-displays (Hillyard et al., 1973; Hillyard & Munte, 1984; Sawaki & Luck, 2014) whilst the cue-displays (a manipulated variable of interest) differed from one another in each block condition.

In a pilot study with adults, we manipulated the presence of our singleton distracter in a visual search task without a cue. We found that the singleton distracter slowed performance by 41 ms when it was present in the search-display relative to when it was absent. A comparison with previous research suggests that this singleton distracter yields a medium attentional capture effect (Gaspar et al., 2016 – 21 ms; Forster & Lavie, 2008 – Exp 1: 37 ms – 52 ms, Theeuwes, 2004 – Exp 1: 65 ms; Liesefeld et al., 2017 – 225 ms).

The experiment was run using PsychoPy2 version 1.84 (Peirce, 2009), which was also used to create the line and singleton distracter stimuli. The stimuli were presented on a LCD iiyama ProLite B2206WS monitor (34.05° width × 23.06° height) which had been calibrated such that the relationship between voltage increments and luminance increments was linear. Stimuli were mirrored from an Apple MacBook Pro 2 laptop via DVI-D to Thunderbolt Apple Adapter connection. An American National Standards Institute (ANSI) Apple keyboard with a US English layout was connected to the Apple MacBook Pro 2 via USB, to record participants' responses. This experimental set-up allowed testing conditions to be portable across classroom and lab settings.

2.4. Procedure

Data collection was either carried out in a quiet classroom (child participants) or a university lab (adult participants) in darkened to minimal lighting conditions. To help the children to understand the instructions and to reduce fatigue, the experiment was designed as a game. Participants were asked to play the "Let's Find Dory Game" by completing three different games on the computer. In the games they were told that Dory was lost but she would provide them with clues (cues) to help them follow her trail (tilted-line target). Both children and adult participants were provided with the same instructions. No cartoon images or sound effects were presented within the experimental paradigm, only during the instruction and break screens.

2.4.1. Practice phases

Participants completed two phases of practice. Response practice (9 trials), was to familiarise participants with the stimuli and key-responses. They were presented with the fixation cross, followed by the search-display (no cue). They were instructed to press the 'z' key if the tilted-line was pointing towards the left and the '/' if it was pointing towards the right. Stickers were placed on the keys to help participants to locate them.

The cue practice (9 trials), consisted of a fixation cross for 500 ms, followed by the cue-display for 300 ms. The search-display remained on

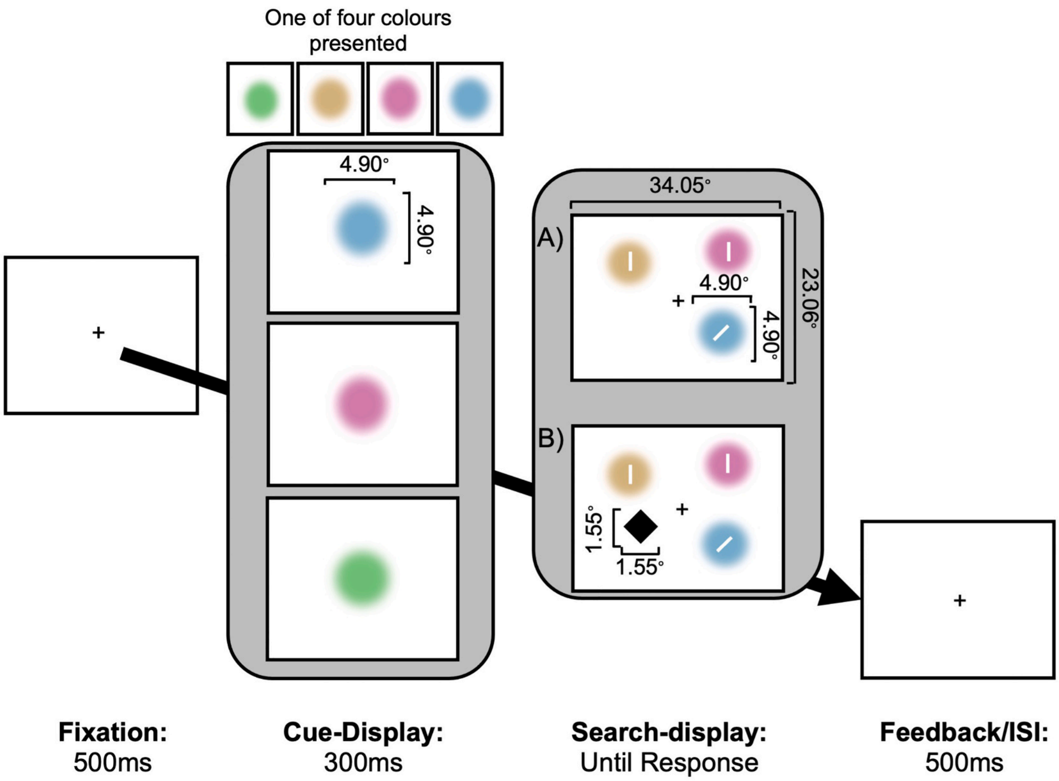

Fig. 1. Schematic representation (not to scale) of the sequential order of the cued visual search task with time durations. Following fixation, only one of the four colours was presented in the Cue-Display. The Search-Display depicts a singleton-absent (A) and singleton-present (B) trial. In this trial, if the cue was valid, a blue cue would guide participants' attention towards the white tilted-line target in the blue circle. If the cue was invalid, a pink or a yellow cue would guide attention away from the target. If the cue was neutral, a green cue was expected to not guide attention towards or away from the target as this colour is not present in the search-display. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the screen until a response was made. An inter-stimulus-interval of 500 ms was applied for all trials.[2] Visual feedback appeared as "Oops, wrong way!" in red Arial font for 500 ms following inaccurate responses in all practice and experimental trials. In each block condition, the experimenter narrated whether the cue was helpful or not on the first two trials of the cue practice phase. We did not inform participants about the proportion of cue types in each block condition but rather they were encouraged to consider and learn about this themselves. Following cue practice, both children and adults were asked: "Do you think Dory's clues helped you find her trail/the tilted-line?" If participants responded with an incorrect response ("I'm not sure", Low Predictive and Baseline blocks: "I think they were helpful"; High Predictive block: "I don't think they were helpful"), participants were asked to repeat the cue practice phase and were asked the same question again.

If three or more trial responses were incorrect in any of the practice phases, participants were asked to repeat the practice phase (once: 5–6 years: 20%; 9–11 years: 16.67%; adults: 9.52%; twice: 5–6 years: 2.22%; 9–11 years: 4.76%; adults: 0%, across all block conditions). Both practice phases could be repeated up to three times each. If participants failed the practice by continuing to make three or more errors during these phases, they were thanked for taking part and compensated for their time.

2.4.2. Experimental phase

The experimental trials had the same stimulus presentation as the cue practice phase. Children completed a block condition (144 experimental trials per condition) in three 20 minute sessions on different days within a one to two week period. Adults completed three block conditions (288 experimental trials per condition) in a one hour session. Three break periods were provided within each block condition. The order of the block conditions was counterbalanced.[3]

3. Results

3.1. Pre-analysis

We compared performance in the High and Low Predictive blocks to the Baseline block. For this purpose, we assigned valid and invalid labels to trials in the Baseline block. The aim was to control for as many sensory confounds as possible to strengthen comparisons between conditions (Hillyard et al., 1973; Hillyard & Munte, 1984; Sawaki & Luck, 2014). We assigned valid and invalid labels to neutral trials in the Baseline block that matched the same search-displays in the High Predictive block (as this was our main condition of interest). Thus, when we compared performance between blocks, the search-displays were the same and only the colour (and validity) of the cue differed between blocks (see Fig. 1 and Table 2).[4]

[2] We intended fixation and the inter-trial stimulus to be set at 500 ms, but analysis from subsequent experiments has shown that this varied between 500 ms to 800 ms.

[3] There were six possible orders for the three block conditions. The order of the three block conditions was counterbalanced for nine- to 11-year-olds and adults. The counterbalancing of order was not achieved for the five- to six-year-old age-group. For this group, 8.89% of five- to six-year-olds repeated an order but no order was repeated more than one, or in one case, two additional times.

[4] Our procedure for variable assignment differed from our pre-registered procedure. This is because random variation between trials needed to be controlled for. We ensured variable assignment of all trials in the Baseline block matched the High Predictive block.

Table 2
The proportion (%) (and number of trials) of cued (valid vs invalid) and singleton (absent vs present) trials in the High and Low Predictive blocks, as well as the Baseline block following variable assignment. There were 144 trials per block for child age-groups and 288 trials per block for adults.

Block	Overall valid	Overall invalid	Valid		Invalid	
			Absent	Present	Absent	Present
High Predictive	66.67% (96)	33.33% (48)	68.75% (66)	31.25% (30)	37.50% (18)	62.50% (30)
Low Predictive	33.33% (48)	66.67% (96)	37.50% (18)	62.50% (30)	68.75% (66)	31.25% (30)
Baseline	66.67% (96)	33.33% (48)	68.75% (66)	31.25% (30)	37.50% (18)	62.50% (30)

Note: Absent – singleton-absent trial; Present – singleton-present trial.

For the analysis, the first trial of each block and the first trial following a break period were removed from the data (2.78% data exclusion). Trials where the singleton distracter shared a quadrant with the target were removed (8.33% data exclusion). Presentation of these trials ensured that the participants could not predict (and thus avoid) the singleton distracter. On these trials, however, the singleton distracter could also have created an additional cue to attention (towards the target). Consistent with this, our pilot study found adults were significantly more accurate on these trials relative to other trials. Finally, all inaccurate trials were filtered from our analysis of response times.

Outliers were assessed by removing trials which were +/− 4SD from a participant's median response time in a block condition. This led to 2.45% total data exclusion (5–6-years: 1.22%; 9–11-years: 0.63%; adults: 0.60%). Multivariate outliers for each age-group were assessed by calculating Mahalanobis Distance for all participants within each age-group across all response time and accuracy variables. No multivariate outliers were found.

For all analyses conducted, Greenhouse Geisser Correction was used when Mauchly's Test of Sphericity was violated ($p < .05$). All simple main effects analysis had Bonferroni Correction applied. An alpha criterion of 0.05 was used as our significance level. Average median RTs and mean accuracy for each condition in the three age-groups can be found in Tables 3 and 4 respectively.

3.2. Endogenous control

3.2.1. Response times

We calculated cueing ratios by dividing participants' average median RT on invalid trials by their average median RT on valid trials when the singleton distracter was absent from the display. A cueing ratio greater than 1 suggests the participant utilised the cue to guide their attention. A 3 (Age-Group: 5–6-, 9–11-year-olds, adults) × 3 (Block Predictiveness: High Predictive, Low Predictive, Baseline) mixed Analysis of Variance (ANOVA) was conducted on average cueing ratios for when the singleton distracter was absent to assess the development of cue-utilisation across age and block conditions.

A significant main effect of Block Predictiveness was found ($F(1.76, 222.16) = 62.07$, $p < .001$, $\eta_p^2 = 0.33$). Simple main effects showed average cueing ratios in the High Predictive block (M = 1.18, SE = 0.02 [95% CI 1.15, 1.22]) were significantly larger than the Baseline block (M = 0.99, SE = 0.01 [95% CI 0.97, 1.01]; $p < .001$) and the Low Predictive block (M = 1.08, SE = 0.01 [95% CI 1.06, 1.10]; $p < .001$). Cueing ratios were significantly larger in the Low Predictive block

Table 3
Average median response times (s) and 95% confidence intervals from the mean across block, cue validity and singleton-presence variables.

Block	Cue	Singleton	5- to 6-year-olds		9- to 11-year-olds		Adults	
			M	95% CI	M	95% CI	M	95% CI
Baseline	Valid	Absent	1.63	1.53, 1.73	0.92	0.82, 1.03	0.63	0.52, 0.74
		Present	1.67	1.57, 1.77	1.00	0.90, 1.11	0.65	0.55, 0.75
	Invalid	Absent	1.63	1.51, 1.75	0.92	0.80, 1.05	0.61	0.49, 0.74
		Present	1.72	1.62, 1.83	1.01	0.90, 1.12	0.66	0.54, 0.77
Low Predictive	Valid	Absent	1.57	1.47, 1.66	0.92	0.83, 1.02	0.59	0.50, 0.69
		Present	1.70	1.60, 1.81	0.98	0.87, 1.09	0.63	0.52, 0.73
	Invalid	Absent	1.57	1.48, 1.66	0.99	0.89, 1.08	0.67	0.58, 0.77
		Present	1.73	1.63, 1.84	1.08	0.97, 1.18	0.71	0.60, 0.81
High Predictive	Valid	Absent	1.54	1.46, 1.63	0.87	0.78, 0.96	0.58	0.49, 0.67
		Present	1.66	1.55, 1.76	0.92	0.82, 1.02	0.60	0.49, 0.70
	Invalid	Absent	1.63	1.52, 1.73	1.04	0.93, 1.15	0.74	0.63, 0.85
		Present	1.71	1.60, 1.82	1.11	1.00, 1.22	0.78	0.66, 0.89

Note: M – mean; CI – 95% confidence intervals from the mean (lower bound, upper bound).

Table 4
Mean accuracy and 95% confidence intervals from the mean across block, cue validity and singleton-presence variables.

Block	Cue	Singleton	5- to 6-year-olds		9- to 11-year-olds		Adults	
			M	95% CI	M	95% CI	M	95% CI
Baseline	Valid	Absent	0.96	0.95, 0.97	0.96	0.95, 0.97	0.97	0.96, 0.98
		Present	0.96	0.95, 0.97	0.96	0.95, 0.98	0.97	0.96, 0.98
	Invalid	Absent	0.96	0.95, 0.98	0.98	0.97, 0.99	0.97	0.96, 0.99
		Present	0.97	0.96, 0.98	0.96	0.95, 0.97	0.97	0.96, 0.98
Low Predictive	Valid	Absent	0.97	0.96, 0.98	0.97	0.95, 0.98	0.98	0.96, 0.99
		Present	0.96	0.95, 0.97	0.97	0.95, 0.98	0.97	0.95, 0.98
	Invalid	Absent	0.97	0.96, 0.98	0.97	0.95, 0.98	0.97	0.96, 0.98
		Present	0.96	0.95, 0.98	0.96	0.95, 0.97	0.97	0.96, 0.98
High Predictive	Valid	Absent	0.96	0.95, 0.97	0.96	0.95, 0.98	0.98	0.96, 0.99
		Present	0.96	0.94, 0.97	0.96	0.95, 0.97	0.97	0.96, 0.99
	Invalid	Absent	0.95	0.92, 0.97	0.93	0.91, 0.95	0.95	0.93, 0.97
		Present	0.95	0.93, 0.97	0.94	0.92, 0.96	0.96	0.94, 0.98

Note: M – mean; CI – 95% confidence intervals from the mean (lower bound, upper bound).

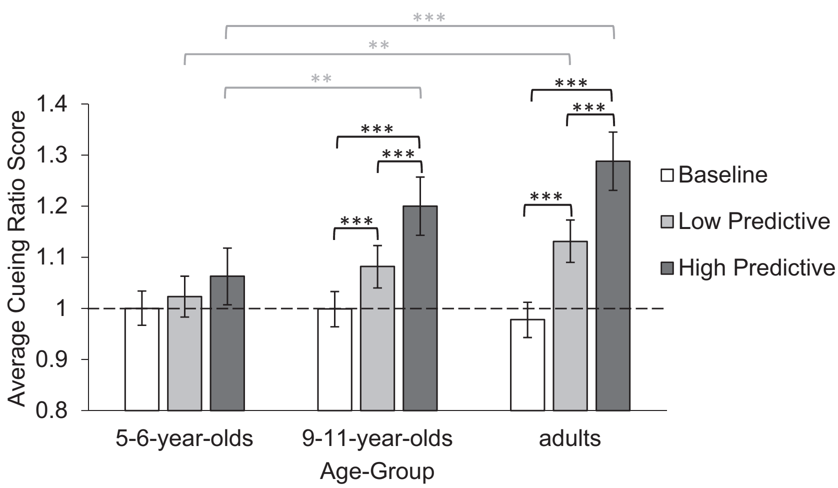

Fig. 2. Average Cueing Ratio Scores on singleton-absent trials for the Baseline block (white bars), Low Predictive block (light grey bars) and High Predictive block (dark grey bars) across three age-groups. Average cueing ratios above 1 suggest cue-use for guiding attention. Error bars represent 95% confidence intervals from the mean. Note: * $p < .05$; ** $p < .01$; *** $p < .001$.

relative to the Baseline block ($p < .001$). A significant main effect of Age-Group was also found ($F(2, 126) = 12.80$, $p < .001$, $\eta_p^2 = 0.17$) and simple main effects showed cueing ratios were significantly smaller for five- to six-year-olds (M = 1.03, SE = 0.01 [95% CI 1.00, 1.06]) than nine- to eleven-year-olds (M = 1.09, SE = 0.02 [95% CI 1.06, 1.12]; $p =$ .007) and adults (M = 1.13, SE = 0.02 [95% CI 1.10, 1.16]; $p < .001$). Cueing ratios did not significantly differ between nine- to eleven-year-olds and adults ($p = .203$).

A significant Age-Group × Block Predictiveness interaction was found ($F(3.53, 222.16) = 8.88$, $p < .001$, $\eta_p^2 = 0.12$; see Fig. 2). In five- to six-year-olds, simple main effects found cueing ratios in all block conditions did not significantly differ from one another (all *ps* > .200). In nine- to eleven-year-olds and adults, cueing ratios were significantly larger in the High Predictive block relative to the Baseline block and the Low Predictive block (all *ps* < .001). In both of these age-groups, cueing ratios in the Low Predictive block were also significantly larger than the Baseline block (9–11 years: $p = .005$; adults: $p < .001$). Comparisons between age-groups show that in the Low Predictive block, cueing ratios for five- to six-year-olds did not significantly differ from nine- to eleven-year-olds ($p = .140$), but they were significantly smaller than adults ($p =$ .001). Cueing ratios for nine- to eleven-year-olds in the Low Predictive block did not significantly differ from adults ($p = .287$). In the High Predictive block, cueing ratios were smaller for five- to six-year-olds relative to nine- to eleven-year-olds ($p = .002$) and adults ($p < .001$). Cueing ratios did not significantly differ between nine- to eleven-year-olds and adults in the High Predictive block ($p = .100$). All cueing ratios in the Baseline block did not significantly differ between age-groups (all *ps* = 1.00).

3.2.2. Accuracy

Cueing ratios were calculated for each participant by dividing their average accuracy on valid trials by their average accuracy on invalid trials for when the singleton distracter was absent from the display. A cueing ratio greater than 1 suggests cue-utilisation for guiding attention. A 3 (Age-Group) × 3 (Block Predictiveness) mixed ANOVA was conducted on average cueing ratios for accuracy on singleton-absent trials. A main effect of Block Predictiveness was found ($F(1.50, 189.31) = 9.79$, $p < .001$, $\eta_p^2 = 0.07$). Simple main effects showed that cueing ratios in the High Predictive block (M = 1.03, SE = 0.01 [95% CI 1.01, 1.05]) were significantly larger than in the Low Predictive block (M = 1.01, SE = 0.004 [95% CI 1.00, 1.01]; $p = .034$) and Baseline block (M = 0.99, SE = 0.01 [95% CI 0.98, 1.00]; $p = .001$). Cueing ratios in the Low Predictive block did not significantly differ from the Baseline block ($p =$ .098). The main effect of Age-Group was not significant ($F(2, 126) =$ 0.26, $p = .77$, $\eta_p^2 = 0.004$) and the Age-Group × Block Predictiveness interaction was also not significant ($F(3.01, 189.31) = 1.22$, $p = .304$, $\eta_p^2 = 0.02$; *see* Table 5).

Table 5
Average cueing ratio and 95% confidence intervals from the mean for accuracy data on singleton-absent trials for all block conditions and age-groups.

Block	5–6-year-olds		9–11-year-olds		Adults	
	M	95% CI	M	95% CI	M	95% CI
Baseline	1.00	0.98, 1.01	0.98	0.97, 1.00	1.00	0.98, 1.01
Low Predictive	1.00	0.99, 1.02	1.00	0.99, 1.02	1.01	1.00, 1.02
High Predictive	1.02	0.99, 1.05	1.05	1.02, 1.09	1.03	1.00, 1.06

Note: M - mean; 95% CI - 95% confidence intervals from the mean (lower bound, upper bound).

3.3. Attentional capture

3.3.1. Response times

We calculated distraction ratios by dividing participants' average median RT on singleton-present trials by their average median RT on singleton-absent trials. Distraction ratios which are greater than 1 suggest high levels of distraction by the singleton distracter. This simplifies the measure of distraction and its interpretation compared to our pre-registration and thus must be considered exploratory. We also conducted an analysis exactly as per the pre-registration and report this in Appendix A Supplementary data. It should be noted that the findings from both statistical tests were consistent with one another.

We explored whether the singleton distracter caused attentional capture in general by conducting Bonferroni corrected one-sample *t*-tests for each age-group on average distraction ratios. This was conducted only for the Baseline block as this condition isolates the effect of the singleton distracter with little influence from the cue. We found that the distraction ratios in the Baseline block for all three age-groups were significantly greater than 1 (5–6-year-olds: $t(44) = 3.54$, $p = .001$, two-tailed, M = 1.06, SE = 0.02 [95% CI 1.02, 1.09]; 9–11-year-olds: $t(41) =$ 7.37, $p < .001$, two-tailed, M = 1.09, SE = 0.01 [95% CI 1.07, 1.11]; adults: $t(41) = 6.70$, $p < .001$, two-tailed, M = 1.05, SE = 0.01 [95% CI 1.03, 1.06]).

To assess whether cue-utilisation influences distraction across cue validity and block conditions, a 3 (Age-Group) × 2 (Cue Validity: valid,

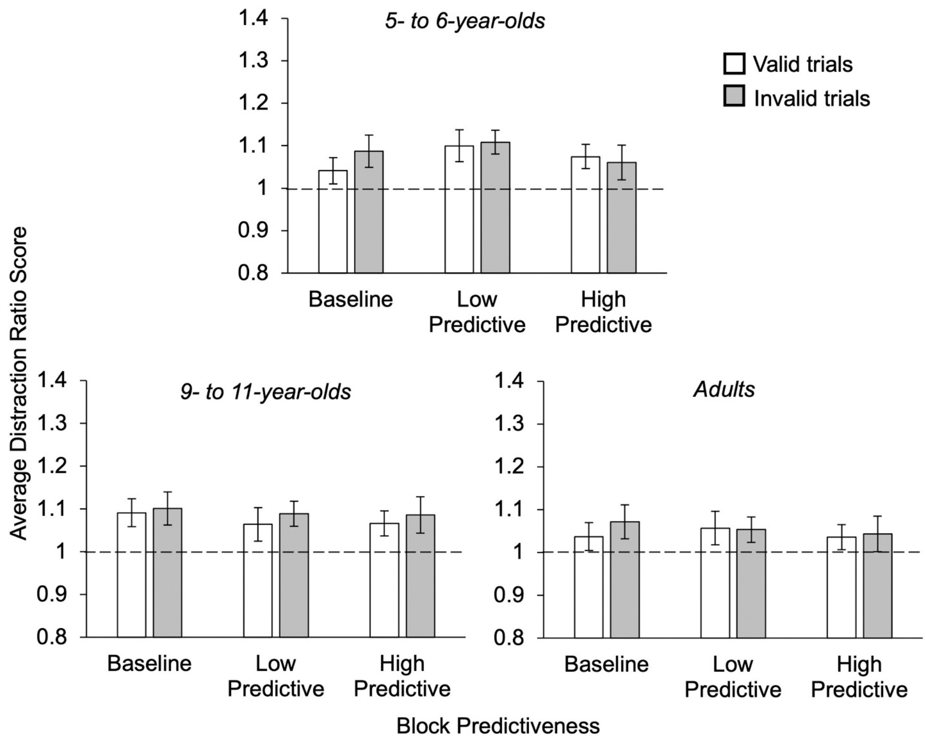

Fig. 3. Average Distraction Ratio Scores for valid (white bars) and invalid (grey bars) trials in the Baseline, Low Predictive and High Predictive blocks across three age-groups. Error bars represent 95% confidence intervals from the mean.

invalid) × 3 (Block Predictiveness: High Predictive, Low Predictive, Baseline) mixed ANOVA was conducted on average distraction ratios. The Age-Group × Cue Validity × Block Predictiveness interaction was not significant ($F(4, 252) = 0.70$, $p = .595$, $\eta_p^2 = 0.01$; *see* Fig. 3). A main effect of Cue Validity was significant ($F(1, 126) = 4.06$, $p = .046$, $\eta_p^2 = 0.03$) and simple main effects showed that distraction ratios were larger on invalid trials (M = 1.08, SE = 0.01 [95% CI 1.07, 1.09]) than valid trials (M = 1.06, SE = 0.01 [95% CI 1.05, 1.07]). A main effect of Age-Group was also found ($F(2, 126) = 4.60$, $p = .012$, $\eta_p^2 = 0.07$). Simple main effects showed distraction ratios for five- to six-year-olds (M = 1.08, SE = 0.01 [95% CI 1.06, 1.09]) did not differ from nine- to eleven-year-olds (M = 1.08, SE = 0.01 [95% CI 1.07, 1.10]; $p = 1.00$), but they were larger than adults (M = 1.05, SE = 0.01 [95% CI 1.03, 1.07]; $p = .047$). Nine- to eleven-year-olds also had significantly larger distraction ratios than adults ($p = .019$). All other main effects and interactions were non-significant.

3.3.2. Accuracy

Distraction ratios were calculated for accuracy data (singleton-absent/singleton-present average accuracy; *see also Appendix A Supplementary data*). A 3 (Age-Group) × 2 (Cue Validity) × 3 (Block Predictiveness) mixed ANOVA was conducted on distraction ratios for accuracy data. The Age-Group × Cue Validity × Block Predictiveness interaction was non-significant ($F(4, 252) = 0.58$, $p = .675$, $\eta_p^2 = 0.01$; *see* Table 6). All other main effects and interactions were non-significant (all $ps > .05$).

Table 6
Average distraction ratio and 95% confidence intervals from the mean for accuracy data across block and cue validity for three age-groups.

Block	Cue	5–6-year-olds		9–11-year-olds		Adults	
		M	95% CI	M	95% CI	M	95% CI
Baseline	Valid	1.00	0.99, 1.01	0.99	0.98, 1.01	1.00	0.99, 1.01
	Invalid	1.00	0.98, 1.01	1.02	1.00, 1.04	1.00	0.99, 1.02
Low Predictive	Valid	1.01	1.00, 1.03	1.00	0.98, 1.02	1.01	0.99, 1.03
	Invalid	1.01	0.99, 1.02	1.01	1.00, 1.02	1.00	0.99, 1.01
High Predictive	Valid	1.01	0.99, 1.02	1.01	0.99, 1.02	1.01	0.99, 1.02
	Invalid	1.00	0.98, 1.02	0.99	0.97, 1.02	0.99	0.97, 1.01

Note: M - mean; 95% CI - 95% confidence intervals from the mean (lower bound, upper bound).

3.4. Comparing cue-maintenance and distracter-inhibition in development

We aimed to understand if the ability to maintain information for guiding attention and the ability to inhibit irrelevant information were related. We predicted a negative relationship, with distraction caused by the singleton distracter decreasing as the ability to maintain a cue increases.

As specified in our pre-registration, we first calculated Pearsons' Correlation Coefficients between cueing and distraction ratios within

Table 7
Regression model for predictors of distraction ratios in the Baseline block.

Predictor	Model 1 $R^2 = 0.058$	Model 2 $R^2 = 0.146$** $\Delta R^2 = 0.088$**
	β	β
Cueing	0.086	0.237*
Young vs Older Children	−0.042	−0.257*
Older Children vs Adults	0.210	0.100
Cueing × Young vs Older Children		0.531**
Cueing × Older Children vs Adults		0.345*

Note: * $p < .05$; ** $p < .01$; *** $p < .001$.

each block condition for each age-group (*see Appendix A Supplementary data*). However, this analysis does not directly compare the age-groups and does not control for the influence of cue validity and singleton presence on our measures, respectively.

We therefore conducted a hierarchical multiple regression (all assumptions were met) to assess the relationship between cue-maintenance ability on trials where no distracter was present and distracter-inhibition ability where no cue was present, and whether age-group moderates this relationship. For our measure of cue-maintenance, we used response time cueing ratios in the High Predictive block (on trials when the singleton distracter was absent from the search-display). We used response time distraction ratio scores from the Baseline block as a measure of distracter-inhibition of the singleton distracter. Distraction ratios for each age-group in the Baseline block ranged from: 0.78–1.26 (5–6 years), 0.98–1.30 (9–11 years) and 0.95–1.16 (adults), with distraction ratios above 1 indicating greater distraction.

To determine if the relationship between the amount of cue-use on the amount of distraction experienced is different in early- vs mid-childhood as well as mid-childhood vs adults we created dummy variables by assigning weights (0, 1 & −1) to compare: 1) five- to six-year-olds and nine- to eleven-year-olds and, 2) nine- eleven-year-olds and adults. We then created interaction terms by multiplying each participant's cueing ratio score by the assigned weight in our dummy variables. This resulted in two interaction terms: Cueing × Young vs Older Children and Cueing × Older Children vs Adults.

Distraction ratio in the Baseline block was our outcome variable and our predictor variables were included in two models. Model 1 consisted of: cueing ratio in the High Predictive block, Young vs Older Children Dummy Variable, Older Children vs Adults Dummy Variable. Model 2 consisted of the two additional interaction variables: Cueing × Young vs Older Children and Cueing × Older Children vs Adults.

Our analysis showed that Model 1 explained 5.8% (Adjusted $R^2 =$ 3.5%) of the variance in distraction ratios but this was not significant ($F(3, 125) = 2.55$, $p = .059$; *see* Table 7). The addition of our interaction terms showed Model 2 to significantly explain 14.6% (Adjusted $R^2 =$ 11.1%) of the variance in distraction ratios ($F(5, 123) = 4.21$, $p = .001$). Model 2 produced a significant change in explaining an additional 8.8% of the variance in distraction ratios, relative to Model 1 ($F(2, 123) =$ 6.37, $p = .002$).

Further assessment shows that the dummy variable Young vs Older Children ($t(123) = -2.07$, $p = .040$) and Cueing ($t(123) = 2.31$, $p =$ .023) met significance. The interaction term Cueing × Young vs Older Children also explained a significant proportion of the variance in Model 2 ($t(123) = 3.55$, $p = .001$), as well as Cueing × Older Children vs Adults ($t(123) = 2.02$, $p = .046$). All other predictor variables in Model 2 were

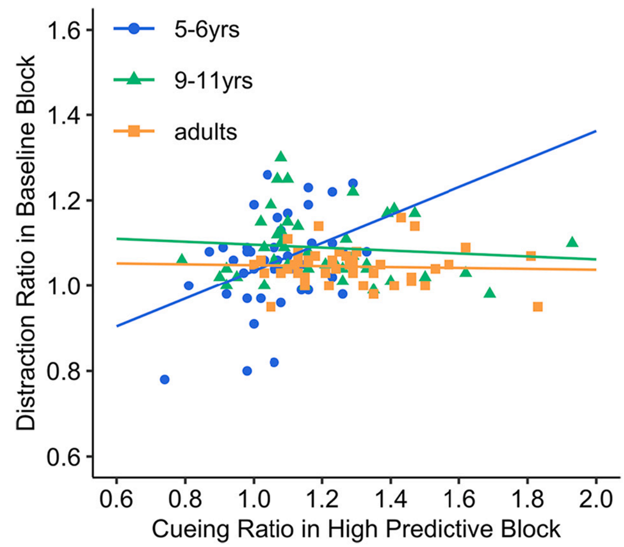

Fig. 4. The relationship between cueing ratios (singleton-absent trials in High Predictive block) and distraction ratios (Baseline block) for three age-groups: 5–6 years (blue; $r = 0.40$), 9–11 years (green; $r = -0.09$) and adults (orange; $r = -0.07$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

non-significant (all *ps* > .05). The interaction terms, Cueing × Young vs Older Children and Cueing × Older Children vs Adults, suggest that the positive relationship of cueing ratio on the amount of distraction experienced is significantly different between age-groups. To understand the direction of these findings, we used Pearsons' Correlation Coefficients to further explore the relationship between cueing ratios (on singleton-absent trials in the High Predictive block) and distraction ratios (in the Baseline block) for each age-group. This showed that five- to six-year-olds had a positive correlation between cueing ratios and distraction ratios ($r = 0.40$, $p = .006$; *see* Fig. 4). This suggests that larger cueing ratios on singleton-absent trials in the High Predictive block are related to larger distraction in the Baseline block. In contrast, nine- to eleven-year-olds ($r = -0.09$, $p = .561$) and adults ($r = -0.07$, $p = .678$) both had a negative, but weak, correlation between cueing ratios and distraction ratios.

4. Discussion

We aimed to understand the development of endogenous control using a cued visual search task. We investigated the stage in childhood (early-childhood: 5–6 years; mid-childhood: 9–11 years) at which endogenous control is acquired and whether this skill can reduce attentional capture. We found that endogenous cue-utilisation is acquired by mid-childhood as cue-use in nine- to eleven-year-olds was similar to that of adults. In contrast, five- to six-year-olds did not use the cue effectively, even when it was usually predictive of the target.

Contrary to expectation, all age-groups, including adults, were unable to reduce attentional capture by a singleton distracter using endogenous cues. We also investigated the predictive relationship between the ability to maintain a cue and the ability to inhibit a singleton distracter, when measured independently. Our findings suggest that these abilities are only related during early-childhood but no trade-off is seen in nine- to eleven-year-olds and adults. We will discuss each of our findings and their application in turn.

4.1. Endogenous control

While previous research has indicated that five- to six-year-olds have acquired endogenous control (Hermens, 2018; Jakobsen et al., 2013; Landry et al., 2019; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005), others have opposed this (Gaspelin, Leonard & Luck, 2015; Johnson et al., 2020). This mixed evidence warranted further investigation. In this study, if participants had developed endogenous control we expected them to show greater cue-utilisation in the High Predictive block compared to the Low Predictive and Baseline blocks. Children aged five to six showed no evidence of cue-utilisation as cueing ratios did not significantly differ across all three block conditions. Our findings therefore support existing research which show endogenous control has not yet developed or is still developing in early-childhood (Gaspelin, Leonard & Luck, 2015; Johnson et al., 2020; Munakata et al., 2012).

The inclusion of a Baseline block added understanding by showing that cueing ratios in the High Predictive block did not significantly differ from baseline performance, where the cues could not guide attention to any item in the search-display. Our findings therefore indicate that, overall, five- to six-year-olds were using an exogenous process in all block conditions to serially search each item until they came across the target (Treisman & Gelade, 1980; Treisman & Sato, 1990; Wolfe, 2020). This suggests that five- to six-year-olds were unable to benefit from valid cues in guiding their attention and, at the group level, they were unable to maintain the cue to anticipate the target.

The finding of reduced cue-utilisation in five- to six-year-olds relative to nine- to eleven-year-olds conflicts with some cueing literature which has indicated that younger children have larger orienting responses than older children and adults (Iarocci et al., 2009; Leclercq & Siéroff, 2013). The measure we used in our analysis of cue-utilisation was cueing ratios (invalid/valid response time) which controlled for differences in baseline response times across age-groups, as opposed to untransformed difference scores (invalid – valid response time) used in past research (Iarocci et al., 2009; Wainwright & Bryson, 2005). We also used a discrimination task rather than a detection task for identifying the target which is known to produce longer response times overall (Ridderinkhof & Van der Stelt, 2000).

This study indicates that endogenous control is mature by mid-childhood. Nine- to eleven-year-olds and adults used endogenous control to locate the target in the High Predictive block as their cueing ratios were larger in this block than both the Low Predictive and Baseline blocks. This is consistent with endogenous control being comparable to adults by mid-childhood (Goldberg et al., 2001; Iarocci et al., 2009; Leclercq & Siéroff, 2013; Pearson & Lane, 1990; Shimi et al., 2015).

Our results also showed that cueing ratios for nine- to eleven-year-olds and adults were higher in the Low Predictive block than the Baseline block. The exact processes involved in this block are unclear. Some research suggests that a Low Predictive block encourages a purely exogenous form of control (Theeuwes & van der Burg, 2008; Van der Stigchel et al., 2009). Cues which infrequently guide attention towards the target discourage cue-utilisation and so any cueing behaviour found in this condition is thought to measure reflexive responses towards the stimuli. Others propose that a hybrid of endogenous and exogenous processes is involved in a Low Predictive block (Carlisle & Woodman, 2012; Moher et al., 2014). By using a cue to inform where *not* to search for the target, nine- to eleven-year-olds and adults could have strategically disregarded the cued-colour in the search-displays of this condition (Arita et al., 2012; Beck et al., 2018; Kiyonaga et al., 2012; Laarni, 2001; Moher & Egeth, 2012; Woodman & Luck, 2007). Further evidence would be required to understand whether this is the case.

One puzzling finding in our results was a cueing ratio below 1 for adults in the Baseline block, indicating that performance was faster on assigned-invalid compared to assigned-valid trials in this condition. As this cannot be due to cue validity, which was not manipulated in the Baseline block, it must be due to a feature or configuration of the search-display or trial sequences which facilitated performance on assigned-invalid trials. As the search-displays were identical between the Baseline and High Predictive blocks, this facilitation would also be present on invalid trials in the High Predictive block. The use of dummy coding which matched the search-displays across blocks therefore controlled for this unanticipated noise in the data. Noise in visual search paradigms is not uncommon (Jannati et al., 2013; Liesefeld et al., 2017; for further discussion, see Sawaki & Luck, 2014). One possible source of this artifact could be selection history effects. Research has shown that selection of a previous feature or location of the cue, target or singleton distracter on trial-n-1 can differentially influence performance on trial-n (Carlisle et al., 2011; Luck et al., 2021; Talcott et al., 2022; Wang & Theeuwes, 2018). Selection history in cued visual search is complex due to the multiple stimulus features and locations changing on a trial-by-trial basis. Future research could aim to consider the role of selection history effects on endogenous control and its limits on attentional capture across development.

Overall, our findings demonstrate that both nine- to eleven-year-olds and adults can benefit from valid cues in a highly predictive context which can encourage cue-maintenance to anticipate the upcoming target.

4.2. Attentional capture

One key aim of this study was to understand whether endogenous control could reduce attentional capture. Our singleton distracter did produce attentional capture, since distraction ratios were significantly greater than 1 for all age-groups in the Baseline block. Our findings show that, in general, children and adults were unable to reduce attentional capture in any of the block conditions, evidenced by the fact that we did not find reduced distraction on valid trials in the High Predictive block relative to the Baseline block. We did find that attentional capture effects reduced with increasing age which is consistent with the results from a recent study that showed children (five & nine years), adolescents and adults were unable to reduce attentional capture using endogenous control but the ability to recover from distraction improved with age (Erb et al., 2022). Our results suggest that all age-groups experienced attentional capture but overall they were unable to decrease this response using endogenous cue-utilisation.

This conflicts with past research which suggests that endogenous control can prevent attentional capture when it is used at an early point in processing (Gaspar & McDonald, 2014; Gaspelin et al., 2017; Gaspelin, Margett-Jordan & Ruthruff, 2015; Iarocci et al., 2009; Michael et al., 2013; Sawaki & Luck, 2010). Instead, our findings support the notion that endogenous cues which usually guide attention towards the target, are *not* sufficient to diminish the automatic response towards a singleton distracter (Forster & Lavie, 2008; Theeuwes, 2010; Theeuwes & van der Burg, 2008; Van der Stigchel et al., 2009). We have extended this understanding from a developmental perspective by showing that this lack of control over a distraction is demonstrated in both adults and children despite both having developed a form of endogenous control (Erb et al., 2022; Merrill & Conners, 2013; Theeuwes & van der Burg, 2008; Van der Stigchel et al., 2009; Wong-Kee-You et al., 2019). Therefore, both developing and developed forms of endogenous control encouraged by cue-guidance are unable to decrease attentional capture, at least in this case.

One possible explanation could be that the predictability of the cue in the High Predictive block (66.67% valid) was not high enough. Research has shown that by ensuring the cue is valid on 80% of trials in a block condition, this can reliably encourage cue-utilisation in both children and adults and decrease distraction (Iarocci et al., 2009; Leclercq & Siéroff, 2013; Theeuwes & van der Burg, 2008). Future research would benefit from further considering the influence of block predictability on cue-utilisation and attentional capture, as this manipulation is vital for forming an implicit task-goal (Carlisle & Woodman, 2012; Kiyonaga et al., 2012).

Another potential cause for the lack of endogenous control over attentional capture in this study could be due to the nature of the task. In our task participants searched for a white tilted-line presented amongst two white vertical lines. It may be that our target, which was a singleton, may encourage participants to utilise a singleton detection mode to search for the odd item in the display (Bacon & Egeth, 1994; Lamy et al., 2004; Leber & Egeth, 2006). Some studies have shown that a singleton target led adults to experience attentional capture by a singleton distracter but this was prevented when the target was a non-singleton item (Gaspelin et al., 2017; Gaspelin, Margett-Jordan & Ruthruff, 2015; Sawaki & Luck, 2010, 2013). Here, a singleton detection mode may have made participants vulnerable to distraction by a unique distracter item. In our study, the target and the singleton distracter were not similar and were unlikely to have a shared representation. It may be that the relationship between the effect of a singleton distracter and endogenous control is more subtle than previously thought. Therefore, the relationship between the target and the distracter should be considered in future assessments of attentional capture using this paradigm.

4.3. Comparing cue-maintenance and distracter-inhibition in development

Past research has suggested that cue-maintenance and distracter-inhibition abilities are independent but related processes in attentional orienting (Brodeur & Boden, 2000; Brodeur & Enns, 1997; Wainwright & Bryson, 2005). We found that the relationship between cue-maintenance and distracter-inhibition abilities in the cued visual search task changed between ages six and nine but only marginally changed between nine and adulthood. At an early age both of the skills are related, but they are no longer related during mid-childhood and adulthood which adds to existing research that also found a distinction between these skills in adults (Noonan et al., 2016). We expected to find a negative relationship, such that as the ability to maintain a cue increased, distraction caused by the singleton distracter decreased. In contrast to our predictions, increased ability to maintain cues in five- to six-year-olds was moderately correlated with increased distraction caused by the singleton distracter.

This is not the first study to find better cue-maintenance is linked to poorer distracter-inhibition in five- to six-year-olds. Previous research has suggested that large orienting responses found in five- to six-year-olds is suggestive of an inhibition deficit at invalidly cued locations (Brodeur & Boden, 2000; Wainwright & Bryson, 2005). Despite not finding significant levels of cue-utilisation in five- to six-year-olds at the group level, our moderation analyses allowed us to inspect the independent skills at the individual level within each age-group. We showed that some five- to six-year-olds have better cue-maintenance but this may be at a consequence of poorer distracter-inhibition ability. Therefore, “good maintaining, but poor inhibition” may not apply to all five- to six-year-olds as suggested by others (Brodeur & Boden, 2000; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005). Rather our findings offer support for possible individual differences in cue-maintenance, which coincide with results from different experimental paradigms (AX-Continuous Performance Task: Gonthier et al., 2019; Dimensional Change Card Sort: Marcovitch et al., 2010; Blackwell & Munakata, 2014). Indeed, the period between ages five and six is regarded as a key transition period for the development of maintenance ability and endogenous control (Lucenet & Blaye, 2014; Munakata et al., 2012). Our findings suggest that it is those individuals who have started to develop cue-maintenance within this period who have poorer associated distracter-inhibition in the cued visual search task.

A possible consequence of individual differences in maintenance ability in early-childhood has been shown by Blackwell and Munakata (2014). They asked six-year-olds to perform two different tasks. In the first, children needed to switch between rules in the 3-Dimensional Change Card Sort task. In the second, children needed to maintain and later select an image in the delayed match-to-sample task. The findings showed that some six-year-olds switched between task rules (switchers) but some could not (perseverators). Importantly, the switchers experienced greater distraction from a secondary motor task (finger tapping) during the delay period of the delayed match-to-sample task, relative to perseverators. They concluded that six-year-olds whose maintenance ability has started to improve, are more likely to attempt to maintain early information when they are encouraged. However, when the cognitive load of a task is increased (e.g. maintaining a secondary task-goal), their limited cognitive capacities are insufficient for completing the task which may have caused these individuals to change strategies to an exogenous or *reactive* form of control (Blackwell et al., 2014; Blackwell & Munakata, 2014; Lavie et al., 2004). A similar pattern may have occurred in our study, whereby some five- to six-year-olds may have better cue-maintenance ability than others of the same age but this may have come at a consequence on their limited cognitive capacities; leading these individuals to experience greater distraction from the singleton distracter.

4.4. Proactive & reactive control

Much of the research we have discussed thus far has considered the development of higher-order processes during key periods of childhood. A large body of evidence in the cognitive control literature has also considered similar questions to our study using different behavioural paradigms. Our findings are consistent with a developmental shift from reactive to proactive control. The Dual Mechanisms of Control theory (Braver, 2012) argues that we can control attention in two ways. Proactive control is similar to endogenous control, as it is theorised to encourage maintenance of task-goals in working memory to enable anticipation for an upcoming event at an early point of processing. Reactive control is similar to exogenous control as it stipulates that a task-goal is reactivated in-the-moment that it is required. Much evidence has investigated the development of proactive control and in particular the transition from the main use of reactive to proactive control (Ambrosi et al., 2016; Chatham et al., 2009; Chevalier et al., 2015; Chevalier et al., 2020; Gonthier et al., 2019; Lorsbach & Reimer, 2008, 2011; Lucenet & Blaye, 2014, 2019). Our research contributes towards this literature, as our manipulation of block predictability created a context which aimed to encourage participants to form a task-goal to maintain the largely helpful cues in the High Predictive block; suggestive of encouraging proactive control (Brodeur & Boden, 2000; Kiyonaga et al., 2012). In the Low Predictive and Baseline blocks however, we produced a context which discouraged cue-maintenance as cues were shown as redundant for locating the target and so ignoring of the cue may have allowed participants to serially search for the target; this is suggestive of reactive control.

Our findings suggest that five- to six-year-olds are still mostly dependent on utilising reactive control, whereas nine- to eleven-year-olds and adults benefit from their use of proactive control for attentional orienting (Lorsbach & Reimer, 2011; Lucenet & Blaye, 2014). Further investigation should aim to compare the cued visual search task with another well-known measure of proactive control such as the AX-Continuous Performance Task (AX-CPT), which also manipulates contextual information to assess whether participants can maintain early task-goals (Braver, 2012; Redick, 2014) to directly facilitate comparisons between the two literatures (for further discussion, see Hayre, 2021).

5. Conclusion

In the present study we investigated the development of endogenous control and assessed whether this process benefits children and adults by reducing attentional capture. We found that endogenous control is still developing in early-childhood. This suggests that even when encouraged by cues which are usually predictive of the target's location, five- to six-year-olds as a group tended to mostly utilise an exogenous form of control to search for the target (Gaspelin, Leonard & Luck, 2015; Johnson et al., 2020; Munakata et al., 2012). Nine- to eleven-year-olds behaved similarly to adults as both age-groups utilised an endogenous process in a high predictive context (Goldberg et al., 2001; Leclercq & Siéroff, 2013; Shimi et al., 2014, 2015). However, all age-groups were unable to reduce attentional capture in the High Predictive block, indicating that endogenous cues may not be sufficient to diminish distraction in children and adults (Theeuwes, 2010; Theeuwes & van der Burg, 2008; Van der Stigchel et al., 2009). Our findings also agree with the notion that five to six years is a key transition period for attentional control, as we found evidence of possible individual differences in cue-maintenance which were associated with poorer distracter-inhibition. By mid-childhood however, these abilities grow to become independent. Overall, our assessment of endogenous control enabled us to understand its development and its limits on managing distraction in children and adults.

Data statement

Data files can be accessed on the Open Science Framework at: https://osf.io/qd3re/.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: this research was financially supported by the Economic and Social Research Council and the University of Nottingham as part of a doctorate (PhD) award.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2022.103611.

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