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Responses to Navon tasks differ across development and between tasks with differing attentional demands

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ABSTRACT

Navon hierarchical stimuli are designed to measure responses to the global level (grouped local elements, e.g. a forest) and the local level (individuated local elements, e.g. trees) of a visual scene. Cross-sectional evidence suggests that there are developmental changes in global and local processing. We examined global and local processing in 135 typically developing children in Year 1 (aged 5–6 year), Year 3 (aged 7–8 years), and Year 5 (aged 9–10 years). Participants completed a range of Navon tasks, each with different attentional demands. The design of the Navon stimuli remained constant across the tasks, ensuring that any task-related differences were not due to stimulus characteristics. Sixty children from Years 1 and 3 repeated the testing session two years later. Linear mixed model analyses combined longitudinal and cross-sectional data to assess developmental changes and the influence of attentional task demands on responses. The results revealed differing patterns of global and local processing responses according to Year group and attentional task demands. We found some evidence of developmental change in responses from a relatively more local advantage to a relatively more global advantage, which is consistent with the literature. However, the age at which this transition occurred varied across the tasks. We conclude that responses to hierarchical Navon stimuli are modulated by attentional task characteristics which mask any underlying global or local processing advantage.

1. Introduction

Most visual environments are hierarchical in nature, which means individual elements may be considered as being at a more global or local level than other elements (Farran, Jarrold, & Gathercole, 2003; Harrison & Stiles, 2009; Poirel, Pineau, & Mellet, 2006). For example, a whole forest can be the global level and individual trees the local level, or a tree can be the global level and individual leaves the local level. An important role of the visual system is to identify which elements of a visual stimulus belong together to form a whole object (global processing) and which are details or textural features (local processing) (e.g. Kimchi, 2015; Navon, 1977; Wang, Mottron, Peng, Berthiaume, & Dawson, 2007). Studies typically measure global and local processing using hierarchical stimuli (Navon, 1977), for example where a large H (global stimulus) is composed of small S's (local stimuli). Both levels are equally recognisable, and the content at each level is independent and cannot be predicted from one another (Kimchi, 1992; Navon, 1977). Navon tasks, therefore, can measure both global and local processing independently (Kinchla & Wolfe, 1979).

One focus of research has been to establish how, and indeed whether, people can be categorised as being more inclined towards global or local processing. Navon's original research with neurotypical adults demonstrated a global advantage as measured by a faster response time (RT) or higher accuracy to global than local level information (Navon, 1981). However, subsequent research has indicated that this finding is not universal. In the adult population, the presence of a global advantage varies across different neurodevelopmental disorders (Bölte, Holtmann, Poustka, Scheurich, & Schmidt, 2007; D'Souza, Booth, Connolly, Happé, & Karmiloff-Smith, 2016; Gerlach, Klargaard, Petersen & Starrfelt, 2017; Plaisted, Swettenham, & Rees, 1999), special-interest groups such as artists and musicians (Chamberlain, Van der Hallen, Huygelier, Van de Cruys, & Wagemans, 2017; Stoesz, Jakobson, Kilgour, & Lewycky, 2007), and cultures (Davidoff, Fonteneau, & Fagot, 2008; Lao, Vizioli, & Caldara, 2013; Oishi et al., 2014). It also varies depending on a participant's emotional state (Fredrickson & Branigan, 2005; Srinivasan & Hanif, 2010), and can be manipulated through priming (Huttermann,

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Bock, & Memmert, 2014; Poirel et al., 2014). This suggests that an individual's observed visual processing advantage towards either the global or local level is malleable rather than static.

Responses can be influenced by stimulus and task characteristics. A global advantage can be reduced by modulating the visual characteristics of the stimuli to include a larger visual angle (Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; Wang, Mottron, Peng, Berthiaume, & Dawson, 2007), a lower density of local elements (Dukette & Stiles, 1996; Harrison & Stiles, 2009; Kimchi, 2015; Kimchi, Hadad, Behrmann, & Palmer, 2005), and a closed form of local elements (Han & Humphreys, 2002, 1999; Kimchi, 1994). These effects can be attributed to Gestalt processes, the preattentive grouping and integration of elements into distinct objects whereby objects similar to each other or close to each other will be automatically grouped together (Brooks, 2015; De-Wit & Wagemans, 2015; Han & Humphreys, 1999; Wagemans et al., 2012). In Navon stimuli, if local elements are in a sparser configuration or are composed of different colours, the automatic grouping is interrupted and the global advantage will be reduced (Dukette & Stiles, 1996; Harrison & Stiles, 2009; Kimchi, 2015; Kimchi et al., 2005).

Additionally, responses can be modulated by attentional task demands, and differ according to the age of the participant (e.g., Harrison & Stiles, 2009; Kimchi, 2015). The aim of the present study was to investigate the development of global and local processing in childhood using Navon tasks, and to assess the impact of varying attentional task demands on response patterns whilst keeping visual characteristics constant.

1.1. Attentional differences in Navon task demands

Visual perception can be modulated by both bottom-up and top-down attentional processes (Kimchi, Yeshurun, Spehar, & Pirkner, 2016). This is important to note when studying behavioural responses to visual perceptual tasks. It may be unclear the extent to which responses are derived from an individual's global or local processing advantage, or their ability to appropriately direct attention to meet the task goals. When completing a Navon task, participants can be asked to select which of two presented choices is most similar to a target stimulus (a free choice task) (Dukette & Stiles, 1996; Harrison & Stiles, 2009); to name the stimuli at a pre-specified level (a selective attention task) (Wang et al., 2007); or to identify whether a particular shape or letter is present or where a target is located (a divided attention task) (Katagiri, Kasai, Kamio, & Murohashi, 2013; Plaisted et al., 1999). These tasks require participants to attend to a single level (selective attention Navon tasks) or to switch their attention between two levels (divided attention Navon tasks) (Katagiri et al., 2013). As such, the degree to which an individual demonstrates a global or local advantage is not solely due to processes associated with object perception, but can also depend on the attentional demands of the task (Caparos, Linnell, Bremner, de Fockert, & Davidoff, 2013; Dale & Arnell, 2013).

There may also be differing attentional demands within a single task. Global advantage can be modulated by the familiarity of the stimuli; it is reduced if a novel object is presented at the global level and a more familiar object is positioned at the local level (Poirel et al., 2006; Poirel, Pineau, & Mellet, 2008). This is likely to be driven by attentional differences between the automatic processing of meaningful stimuli and greater resources required for recognising and categorising novel objects (Harrison & Stiles, 2009; Poirel et al., 2006). In selective attention Navon tasks, congruency effects can modulate responses. Faster response time (RT) and higher accuracy are observed when the stimuli at global and local levels are identical (congruent trials) than when the levels include inconsistent information (incongruent or neutral trials). Interference is greater when irrelevant information is presented at an individual's more dominant level, than at their less dominant level (Farran et al., 2003). In divided attention Navon tasks, studies with adults have identified an accuracy or RT cost on switch trials compared with stay trials while attentional resources are shifted from one level to the other (Katagiri et al., 2013; Wilkinson, Halligan, Marshall, Büchel, & Dolan, 2001). Although this has not been investigated in children, a divided attention study with a different proportion of global responses in each block, creating a response bias, found no effect of bias on 6-year-olds but there was an effect in the older age groups (Kovshoff, Iarocci, Shore, & Burack, 2015). This is suggestive of a lack of priming effect in younger children.

1.2. Developmental changes in global and local responses

There is general agreement in the literature that a local-to-global processing change occurs with development. This shift is thought to result from later maturation of processes associated with grouping elements relative to the processes involved with segmenting elements from a whole, particularly when the task parameters (e.g., duration) and stimulus design (e.g., density of local elements) leads to more effortful grouping and easier segmenting (Kimchi et al., 2005; Scherf, Luna, Kimchi, Minshew, & Behrmann, 2008). Although the visual system undergoes extensive changes in the first year of life and adult-level visual acuity is generally reached by about 7-years of age, the development of perceptual processing continues until adolescence, partly due to the development of processes associated with visual attention which occur at a slower rate (Leat, Yadav, & Irving, 2009; Mondloch, Geldart, Maurer, & de Schonen, 2003).

There is a lack of consensus on the timescale of this local to global developmental change. This is partly due to difficulties in making robust comparisons between studies with contrasting stimuli designs and task demands. Also, there is a high volume of cross-sectional studies, and a lack of longitudinal studies which are more effective to study development (Thomas et al., 2009).

Cross-sectional studies using free choice tasks have revealed an increasingly global advantage with age. Using the same task design, this change has been revealed between 4 and 6 years (Dukette & Stiles, 1996) and between 9 and 10 years (Harrison & Stiles, 2009). Both studies presented the target and choice stimuli together, however only Harrison and Stiles (2009) included a maximum RT, which may have led to the later developmental shift observed in this study. In both studies, some stimuli were designed to encourage a response towards a particular level, and participants of all ages then responded more globally or locally according to that bias. This suggests that grouping and segmenting process were available to children and adults in certain conditions. Other studies revealed a higher proportion of global matches in 5-year-olds (Vinter, Puspitawati, & Witt, 2010), 7-year-olds (Poirel et al., 2011), and 7- to 12-year-olds (Kramer, Ellenberg, Leonard, & Share, 1996) compared with younger children. Booth (2006) also identified a local-to-global pattern of development but with a transition in adolescence rather than childhood; this may have been driven by the fact each target stimulus was only visible for 250 ms, increasing the difficulty of the task. In summary, these results suggest that as the task demands of free choice paradigms increases, through using sparser stimuli, shortening the presentation time, or increasing memory load, the age at which responses became more global increases. Despite this, the studies generally indicated that changes in global and local responses to free choice tasks occurred between the ages of 5- and 7-years-old.

A similar shift in responses from a local to a global advantage has also been observed in children aged approximately 5 to 7 years using other task designs. On a task where participants had to identify whether two stimuli were the same or different, 4- to 5-year-olds made fewer errors on the local level than the global level, while 9-year-olds made fewer errors on the global level (Poirel, Mellet, Houdé, & Pineau, 2008). Using a drawing task where children had to recreate a given Navon stimulus, the local level dominated children's drawings until the age of 5 years, at which point levels began to be more integrated (Vinter et al., 2010). However, there are also studies revealing different patterns of development. In a small-scale selective attention Navon study comparing responses of children (8- to 13-year-olds), adolescents (14- to 17-year-olds), and adults (aged 18 years and above), a local advantage in accuracy was identified in both children and adolescents and a global advantage in RT in adults (Scherf, Behrmann, & Luna, 2009). This later transition may be due to the stimuli having relatively sparse local elements.

Some studies have revealed later local than global processing development. A study comparing responses in a selective and divided attention task revealed earlier development of adult-level global responses (by 8-years-old) followed by later development of adult-level local responses (Kovshoff et al., 2015). Mondloch et al. (2003) also observed later local development in a task where participants had to identify whether pairs of stimuli were the same or different. Adult-like global responses were observed in 10-year-olds, but adult-like local responses were not observed until 14 years. This may be explained by the very short presentation time of only 50 ms, such that participants accessed only the early perceptual processes of basic shape perception (Hebart & Hesselmann, 2012; Zachariou, Klatzky, & Behrmann, 2014). Further, in a divided attention study with three hierarchical levels where participants had to identify whether a square was present or absent in trials with zero to five distractor stimuli, 5- and 6-year-olds responded more accurately to the global and intermediate levels, whereas 9-year olds and adults responded equally accurately to all levels. All age groups responded more slowly to the local level (Krakowski et al., 2016). In both these examples, the widening of the attentional field to perceive multiple stimuli may have increased the saliency of the global level relative to the local level. Therefore, this more global advantage in the younger age groups may reflect poorer attention control when faced with more complex stimuli, resulting in an inability to disengage from the more salient (global) level.

There are several suggestions as to why a developmental shift may be observed in children aged 5–10 years. A study using a Navon matching task with 6-year-olds identified reduced grey matter volume in the right hemisphere in the group responding with a global advantage compared with the local advantage group. This may reflect differences in maturation and specialisation in these regions, commensurate with a perceptual and attentional shift towards global processing (Poirel et al., 2011). Developmental changes in domain-general abilities may also explain these childhood changes in global and local processing. A transition around this age has been observed in behavioural studies examining the development of inhibitory control and attention. Improved response inhibition (Cragg & Nation, 2008), selective attention (Cragg, 2016), and sustained attention (Betts, Mckay, Maruff, & Anderson, 2006) may allow children to better selectively attend to relevant global or local information and inhibit a response towards a non-target level.

1.3. Current study

Responses on Navon tasks vary as a function of age over childhood and adolescence and can be modulated by perceptual features of the stimulus and attentional task demands. The interaction of these factors is yet to be examined systematically with longitudinal data across a number of Navon tasks. This study investigated the impact of participant age and task-related attentional demands on the responses to Navon tasks in children aged 5 to 10 years. This spans the age when, in the majority of studies, a change in global and local processing responses has been reported to occur. In order to track changes in individuals' responses, the study included both longitudinal and cross-sectional data. We predicted that children's responses would reflect a change from a local to a global advantage, however the age at which this occurred would likely to vary across tasks. In the free choice task, as no restriction on presentation time was used, we predicted that we would observe a local to global shift within the age span of this study (Dukette & Stiles, 1996; Harrison & Stiles, 2009; Kramer, Ellenberg, Leonard, & Share, 1996; Poirel et al., 2011; Vinter, Puspitawati, & Witt, 2010). In the selective and divided attention tasks, as the stimuli included two hierarchical levels and no distractor, we predicted that we would be able to observe a local advantage in the younger children, in contrast to studies that use more complex stimuli (Krakowski et al., 2016; Mondloch et al., 2003). We also predicted that incongruent trials would elicit slower and less accurate responses than congruent trials in the selective attention task (Gerlach & Poirel, 2018), and that priming and the cost of switching between local and global stimuli might only be observed in the older children in the divided attention task (Kovshoff, Iarocci, Shore, & Burack, 2015).

2. Method

2.1. Participants

Participants were recruited from a single community primary school and were tested at two time-points. Parents or carers were given the opportunity to opt-out at the first time-point (T1) and to opt-in the second time-point (T2) two years later. All children provided informed verbal consent to take part in the study at each time-point. There were marginal differences in gender by Year at T1, $\chi^2(1) = 5.75$, $p = .056$, and significant differences in gender by Year at T2, $\chi^2(1) = 4.29$, $p = .038$ (Table 1). This reflected the gender distribution in the school itself.

The inclusion criterion was that participants did not have a statement of Special Educational Needs and Disabilities (SEND). Sixty-two percent of Year 1 children undertook the longitudinal follow-up when they were in Year 3, and 71% of Year 3 children undertook the longitudinal follow-up when they were in Year 5 (Table 1). Non-verbal and verbal abilities were measured using standardised tests. Non-verbal IQ was measured using Raven's Coloured Progressive Matrices (Raven, Raven and Court, 2003) and receptive vocabulary was measured using the British Picture Vocabulary Scale III (Dunn, Dunn, Styles and Sewell, 2009). Both were administered following the standard guidelines, and raw scores were recorded for each. The sub-sets of children who took part in the longitudinal follow-up at T2 did not differ from the complete sample of T1 children in terms of mean cognitive abilities [1]. The studies were approved by the University College London Institute of Education ethics committee.

2.2. Navon tasks

Three types of Navon task were included in the test battery, each with differing attentional demands: A free choice task, a selective attention task, and two divided attention tasks. All tasks used the same

Table 1
Participant demographics.

	Year 1	Year 3	Year 3	Year 5	Year 5
	T1	T2	T1	T2	T1
Number of participants	45[a]	28[a]	45[b]	32[b]	45
Males:females	16:29	10:18	27:18	20:12	24:21
Mean age in months (SD)	68.6 (3.3)	92.2 (3.6)	91.8 (3.5)	114.2 (3.6)	115.4 (3.6)
Mean age in years; months	5;8	7;6	7;6	9;6	9;7

[a] Longitudinal cohort in Year 1 at T1 and Year 3 at T2.
[b] Longitudinal cohort in Year 3 at T1 and Year 5 at T2.

[1] Independent t-tests were carried out to check whether the sub-sets of children who took part in longitudinal testing differed in verbal or non-verbal IQ scores from the T1 children. No significant differences were observed. Year 1: verbal IQ, $t(71) = -0.181$, $p = .857$; non-verbal IQ, $t(71) = 0.468$, $p = .641$; Year 3: verbal IQ, $t(75) = -0.251$, $p = .802$; non-verbal IQ, $t(75) = -0.284$, $p = .777$.

simple geometric shapes (squares, circles, triangles, and trapeziums) rather than letters or digits, which minimised the effect of differential familiarity with the alphabet or numbers across individuals and across Years (Dukette & Stiles, 1996). Each global and local stimulus occupied a square-shaped area. The global stimulus was 30 mm wide, which subtended a visual angle of 3.44°, based on an unrestrained viewing distance of 50 cm. The local stimulus size was 5 mm wide which subtended a visual angle of 0.57°. These sizes were in line with other research which have used Navon stimuli (Hayward et al., 2012; Katagiri et al., 2013; Mondloch et al., 2003; Scherf et al., 2009, 2008; Volberg & Hübner, 2007; Wang et al., 2007) and have been shown to elicit faster global responses in typically developing adults (Hayward et al., 2012; Wang et al., 2007). As the three Navon tests used the same density, form, and size of stimulus, the primary difference between the tasks related to their differing attentional demands.

The Navon stimuli were presented via MATLAB (R2010b), using the Cogent toolbox (http://www.vislab.ucl.ac.uk/cogent_2000.php), on a 12-inch Dell laptop. Responses were made using laptop keys which were identified using stickers. Participants responded with a key press using their left hand to press the left key and their right hand to press the right

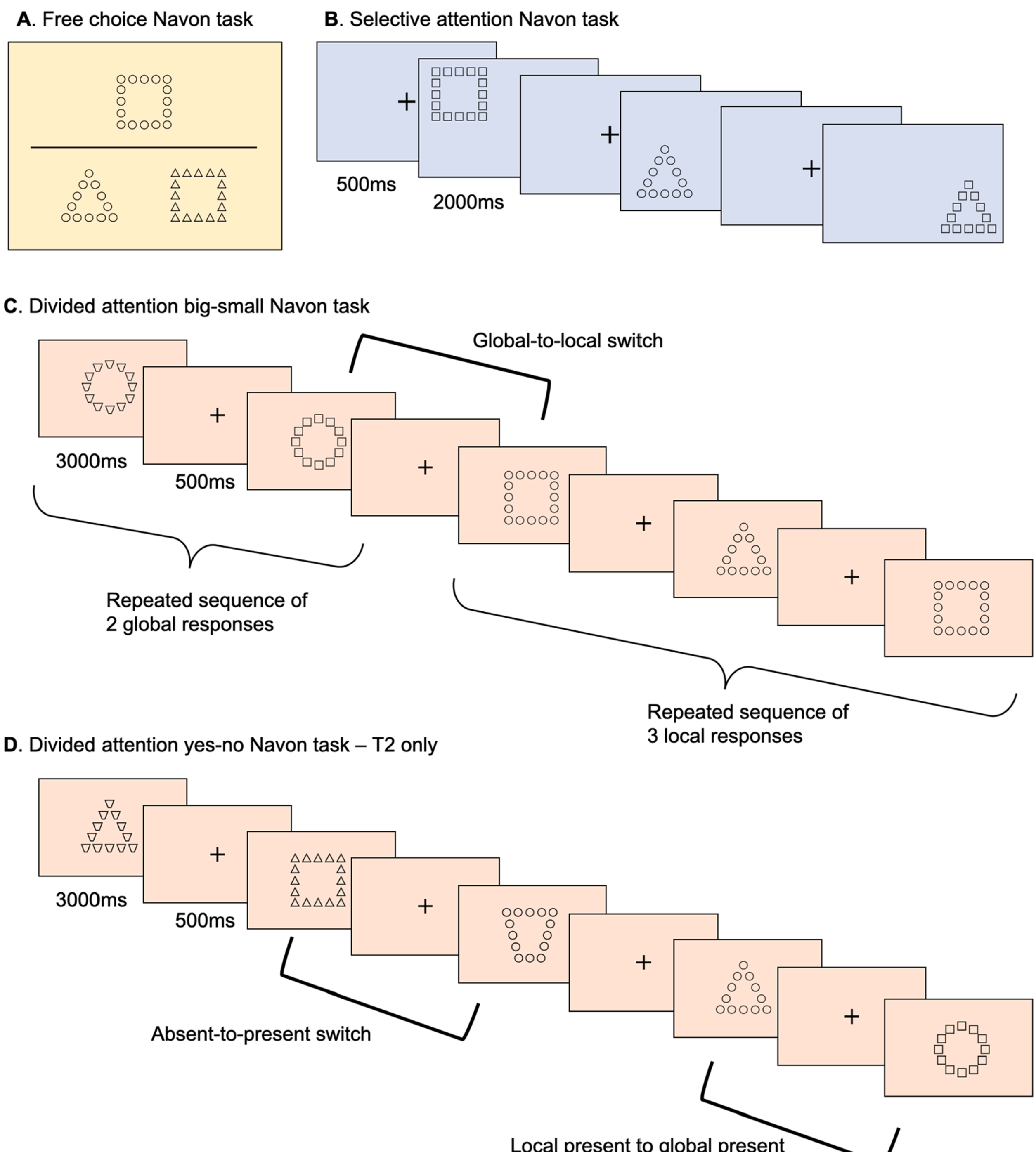

Fig. 1. Example trials from each of the Navon tasks. **A.** The Navon free choice task. The choice on the left is the local match, and the choice on the right is the global match. **B.** The global block of the selective attention task, where the responses would be square (congruent stimulus), triangle (neutral stimulus), triangle (incongruent stimulus). **C.** Divided attention big-small Navon task. **D.** Divided attention yes–no Navon task, time 2 (T2) only.

key. The responses associated with each key were counterbalanced across participants within each age group. To distinguish the separate Navon tasks, different pale background colours were used. Although some studies have found that background colour affects performance on Navon tasks (Michimata, Okubo, & Mugishima, 1999), others have found no significant effects on performance (Dore, Dumani, Wyatt, & Shepherd, 2018). The background colours used in the current study are lighter and paler than the region of the visible light spectrum suggested to influence responses (Dore et al., 2018). The interstimulus interval was 500 ms in all tasks. The order of the whole battery was counterbalanced within each age group, with children completing the activities in one of two sequences. The free choice task was always the first test performed to eliminate priming effects from other tasks, and the global and local selective attention blocks were separated in the test battery to avoid confusion. For the selective and divided attention Navon tasks, the order of blocks was counterbalanced across participants within each age group. There were no order effects in any task at either time-point, p's > .065.

Free choice Navon task. An incongruent target stimulus was presented above a line. Underneath the line were two further incongruent stimuli; one of which matched the target at the local level while the other matched the target at the global level (Fig. 1A). Children were asked to select the figure that was most similar to the target shape, forcing them to choose a response consistent with a focus either on the global or local similarities. There was no time limit. In order to minimise the effect of priming response choices, there were only four trials (Koldewyn, Jiang, Weigelt, & Kanwisher, 2013). The position of the local and global stimuli was counterbalanced across the four trials, with the same order of trials for all participants. The number of matches at the global level were recorded.

Selective attention Navon task. Participants were directed to attend to either the global or local level for one block of 36 trials each. There were six different stimuli, each presented six times in each block. Participants had to indicate whether the shape at the attended level was a triangle or a square. The maximum RT was 2000 ms, which is longer than some studies due to the younger sample tested here. Each block had an equal number of congruent stimuli (where there was no interference), incongruent stimuli (where a triangle was presented at one level and a square at the other), and neutral stimuli (where a triangle or square was presented at one level, and a circle at the other) (Fig. 1B). The circle shape in the neutral trials was not associated with a key press whereas the non-attended level in the incongruent stimuli was associated with the key press options. This enabled a comparison of the impact of attentional demands when the distractor was task-related and when it was not related to the task. The stimuli within each block were presented in a fixed pseudo-random sequence, with no repeats of the same response more than three times in succession. The pseudo-random sequence provided control over the order of stimuli whilst ensuring responses were not predictable.

As participants were focussing on one hierarchical level at a time, it is possible that the attentional field would narrow or widen according to the task demands, and only the relevant level would be actively perceived (Gerlach & Krumborg, 2014; Navon, 2003; Wilkinson et al., 2001). To minimise this, the stimuli moved around the screen in a pre-set random order, such that an equal number of stimuli appeared in each of four locations (Fig. 1B). The offset was 140 pixels on both the y and x axes, equivalent to a distance from the central cross of 6°. RT and accuracy data were recorded.

Divided attention Navon tasks. In the task presented at T1 and T2, participants had to identify whether a circle was featured at the global or local level, with a maximum RT of 3000 ms. The instruction was simplified for the children by asking whether the circle was the big or small shape (big-small divided attention task). This meant that both the global and local levels could be examined, and therefore attention was divided between the hierarchical levels. There were two blocks of 37 trials separated by a short break. To assess the impact of possible priming effects and switching costs, responses where the target appeared at the same level were presented in groups of two, three, or four consecutive stimuli (Fig. 1C). Within each block, there were four groups of each set of repeated responses presented in a pseudo-random order, i.e., a total of four groups of 2 repeat trials, four groups of 3 repeat trials, and four groups of 4 repeat trials. At the end of each sequence of repeat trials, there was a switch trial where the response switched from global-to-local, or local-to-global. Within each block, there were six global-to-local and six local-to-global switches. The trials were presented in a pre-set order in each block, which allowed control over the sequence of stay and switch trials whilst appearing to be randomly ordered. RT and accuracy data were recorded.

At T2, an additional divided attention task was included. Although the big-small divided attention task was designed to measure responses when children's attention was split across both levels, it is possible that children were inferring the presence or absence of a circle while attending to a single level. The additional task at T2 sought to examine this possibility. Participants were asked to identify whether a circle was present or absent, increasing the need for both the global and local level to be examined before responding (Fig. 1D). The instruction was simplified for the children by asking whether there was a circle, with buttons indicating 'yes' or 'no' (yes–no divided attention task). There were two blocks of 36 trials separated by a short break. In half of the trials the target was absent; in the other half the target was present either at the local or global level with equal frequency of both trial types. Participants had up to 3000 ms to respond and the trials were presented in a pre-set order in each block. RT and accuracy data were recorded. The two divided attention tasks were separated in the battery at T2 to reduce confusion arising from the different task instructions.

2.3. Procedure

At both time-points, testing took place at the participants' primary school in quiet, well-lit rooms during lesson times. The data collected were part of a larger test battery which included field independence tasks and maths and science misconception questions, plus additionally at T1, maths and science tasks, and parent questionnaires about systemizing and empathizing traits (Morris, Farran, & Dumontheil, 2019). Children completed these tasks within several sessions lasting 30 min each.

Each task was explained to the participants immediately prior to them attempting the activity. Participants started with six practice trials for the selective and divided attention Navon tasks, to ensure that they understood the instructions. If they scored less than four on the practice trials, they repeated the practice up to a maximum of five times. Five participants on the selective attention task and three participants on the big-small divided attention task repeated the practice trials more than twice. With the exception of one participant in the divided attention task, all participants passed the practice trials. Participants did not have practice trials for the free choice Navon task, as there were no correct or incorrect responses.

2.4. Statistical analyses

Accuracy and RT data were analysed using a series of linear mixed models (LMMs) combining cross-sectional and longitudinal data. LMMs allow for differing numbers of repeated measures and time points between participants, such as instances where participants were tested at T1 but not at T2 (Molenberghs & Verbeke, 2001). It also allows for the fact that observations by the same individual at different time points are not independent (Shek & Ma, 2011; West, 2009). LMMs have been shown to be robust when data violate the normal distribution assumptions (Schielzeth et al., 2020). This was important here where a Kolmogorov-Smirnov test revealed some data were negatively skewed; for example, selective Navon task global accuracy, $D(135) = 0.171$, $p < .001$, and local accuracy, $D(135) = 0.214$, $p < .001$, as well as the divided Navon task global accuracy, $D(134) = 0.226$, $p < .001$, and local accuracy, $D(134) = 0.235$, $p < .001$. A compound symmetry covariance structure was used, which assumes constant variance and correlations between the time points, as the gap between each Year group was two years and the gap between each time point was also two years. All main effects and interactions between all factors were modelled as fixed effects. Mean RTs included data from correct responses only. Estimated means and standard error (*SE*) were reported in all analyses. All follow-up paired comparisons used Bonferroni-corrected alphas.

Outliers were identified as datapoints ± 3.29 standard deviations (*SD*) from the mean (Field, 2013). The analyses were run with and without the outliers. Analyses without outliers are only reported if there were any changes to main effects or interactions reported. In the free choice Navon task, high scores represent a global preference and low scores a local preference, therefore this data-set contained no outliers.

The data for each task were analysed separately and distinct response patterns relating to Year group were analysed to explore developmental changes. The effect of congruency was examined in the selective attention task, and the cost of switching from one level to the other was examined in the divided attention task to understand between-trial differences where attentional demands varied within a task.

3. Results

All children attempted all tasks, however, one Year 1 male participant failed the practice session of the divided attention Navon task at T1 and was not included in the analysis of this task.

Accuracy and RT data were analysed using LMMs combining cross-sectional and longitudinal data. Separate plots of the cross-sectional and longitudinal data are provided in Supplementary Fig. S1.

3.1. Free choice Navon task

An LMM was carried out with the proportion of global responses as the dependent variable (DV) and Year as the between-subject factor. There was a significant main effect of Year, $F(2,129.5) = 16.18$, $p < .001$, with higher proportions of global matches in Years 3 and 5 than in Year 1 (p's $< .001$), but no difference between Years 3 and 5 ($p = .198$) (Fig. 2).

One-sample t-tests were computed to determine whether global choices in each Year and at each time-point were significantly different from 50%. This revealed that Year 1 children at T1 did not demonstrate either a global or local advantage, $t(44) = 0.875$, $p = .386$. All other Years made significantly more global than local choices, Year 3 T1: $t(44) = 9.183$, $p < .001$; Year 5 T1: $t(44) = 3.872$, $p < .001$; Year 3 T2: $t(27) = 9.033$, $p < .001$; Year 5 T2: $t(31) = 10.072$, $p < .001$. Overall, this indicates a developmental change from no global or local advantage to an increase in matching at the global level between the ages of 6 and 7 years.

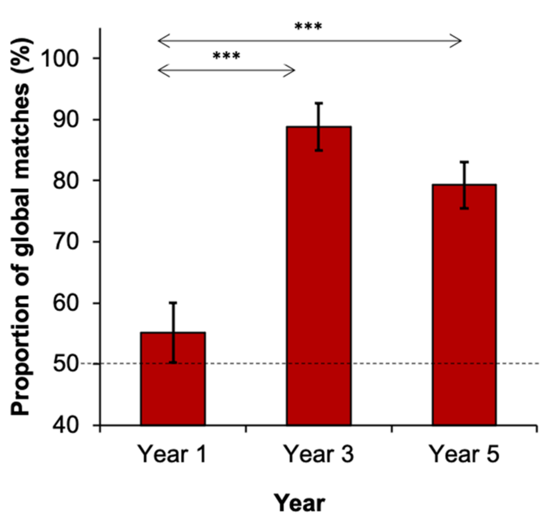

Fig. 2. Proportion of global-level matches from the cross-sectional and longitudinal data as a function of Year (estimated mean ± SE). Dashed line at 50% represents no bias towards global or local choices. * $p < .05$, ** $p < .01$, *** $p < .001$.

3.2. Selective attention Navon task

LMMs were carried out with accuracy or RT as the DV, with level (global, local) and congruency (congruent, neutral, incongruent) as within-subjects factors, and Year as the between-subjects factor.

All main effects are reported in Table 2. To summarise, there was a main effect of congruency such that participants were faster and more accurate in congruent and neutral trials than in incongruent trials (p's $< .001$), while performance did not differ between congruent and neutral trials (p's $> .220$). Participants were also faster and more accurate with each increasing Year (p's $< .001$). For the main effects of level, participants were faster but less accurate in global trials than in local trials.

The main effects in the accuracy data were modulated by two-way interactions between congruency and Year, $F(4,1015.7) = 7.11$, $p < .001$, between congruency and level, $F(2,1015.7) = 5.22$, $p = .006$, and between level and Year, $F(2,1015.7) = 19.15$, $p < .001$. These interactions were further modulated by a three-way interaction between congruency, level, and Year, $F(4,1015.7) = 5.24$, $p < .001$. The three-way interaction was followed up by running separate LMMs in each Year, revealing a significant interaction between congruency and level in Year 1 only, $F(2,220.0) = 7.10$, $p = .001$ (Years 3 and 5: F's < 1) (Fig. 3A). Further follow-up LMMs were run for each type of congruency in Year 1 which indicated that accuracy was higher in local than global trials when stimuli were incongruent ($p < .001$) and neutral ($p = .003$), but there was no effect of level in congruent trials ($p = .430$). The 3-way interaction was therefore driven by the fact that Year 1 children, but not older children, showed relatively poorer performance in global than local incongruent and neutral trials. This indicates that interference from the local level modulated responses to the global level regardless of whether the non-target stimulus was task-relevant in Year 1 only, but there was no asymmetric interference in Years 3 and 5 (Fig. 3A). This interaction also drove the significant two-way interactions.

There was an interaction between level and Year in the RT data, $F(2,1013.3) = 8.48$, $p < .001$. LMMs run for each Year revealed no effect of level in Year 1 ($p = .857$), but significantly quicker responses to the global level than the local level in Years 3 and 5 (p's $< .001$) (Fig. 3B).

Table 2
Linear mixed model main effect results for accuracy and response time (RT) in the selective attention task. Estimated marginal means and standard error (SE) are reported. Significant effects in bold.

Main effect	Measure	Statistics	Estimated means (SE)
Level	Accuracy	**$F(1,1015.7) = 28.90$, $p < .001$**	Global: 87.3% (0.7) Local: 91.1% (0.7)
	RT	**$F(1,1013.3) = 29.09$, $p < .001$**	Global: 1052 ms (15) Local: 1111 ms (15)
Congruency	Accuracy	**$F(2,1015.7) = 82.55$, $p < .001$**	Congruent: 93.2% (0.8) Incongruent: 82.8% (0.8) Neutral: 91.6% (0.8)
	RT	**$F(2,1013.3) = 13.92$, $p < .001$**	Congruent: 1057 ms (16) Incongruent: 1123 ms (16) Neutral: 1066 ms (16)
Year	Accuracy	**$F(2,667.05) = 46.24$, $p < .001$**	Year 1: 82.7% (1.1) Year 3: 90.2% (0.8) Year 5: 94.6% (0.8)
	RT	**$F(2,943.5) = 77.23$, $p < .001$**	Year 1: 1223 ms (20) Year 3: 1077 ms (16) Year 5: 946 ms (17)

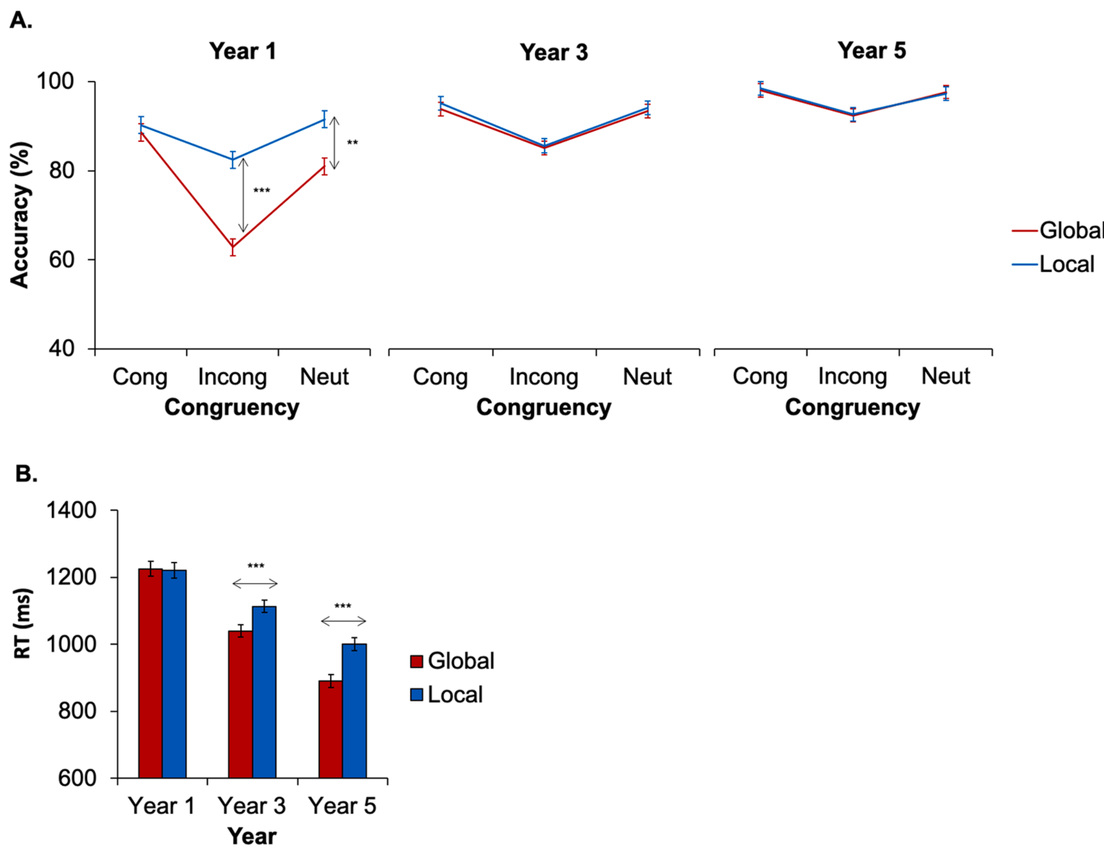

Fig. 3. Plots of selective attention Navon task performance, combining cross-sectional and longitudinal data (estimated mean ± standard error). **A.** Accuracy as a function of Year, congruency (Cong: congruent, Incong: incongruent, Neut: neutral) and level. **B.** Response time (RT) as a function of Year and level. *$p < .05$; **$p < .01$; ***$p < .001$.

In summary, for the selective attention Navon task, participants were overall less accurate and slower in incongruent than congruent and neutral trials, and more accurate but slower at the local than the global level. While this suggests a speed-accuracy trade-off between global and local levels, interaction effects indicated otherwise. The lower accuracy in the global than local level was only observed in Year 1 children, in the absence of difference in RT and driven by the incongruent and neutral trials. In contrast, no difference in accuracy but quicker responses to global than local trials were evident in Years 3 and 5. Overall, the data indicate a developmental change from a local advantage in Year 1 (as determined by accuracy) to a global advantage in Years 3 and 5 (as determined by RT) in the selective attention task.

3.3. *Divided attention Navon tasks*

3.3.1. *Big-small Navon task*

An initial LMM was carried out to assess whether there was a difference between stay and switch trials in the present study. Level (global, local) and trial type (switch, stay) were entered as within-subject variables, and Year as the between-subjects factor. There were no main effects of or interactions with trial type in either the accuracy data (p's > .155), or the RT data (p's > .105). Switch/stay trial type was therefore removed from the LMM analysis and planned analyses examining the effect of the number of stay trials before a switch trial were not undertaken. Main effects of the subsequent LMM analysis are presented in Table 3.

Participants were quicker and more accurate when responding to local trials than global trials, and both accuracy and RT improved with ascending Year group (p's < .006). The main effects in accuracy were modulated by a two-way interaction between Year and level, $F(2,626.9) = 8.40$, $p < .001$. Follow-up LMMs run in each Year indicated higher accuracy in local than global trials in Years 1 and 3 (p's < .010), but no effect of level in Year 5 ($p = .323$) (Fig. 4A). There was no interaction in the RT data (Fig. 4B).

Table 3
Linear mixed model main effect results for accuracy and response time (RT) in the big-small divided attention task. Estimated marginal means and standard error (SE) are reported. Significant effects in bold.

Main effect	Measure	Statistics	Estimated means (SE)
Level	Accuracy	$\boldsymbol{F(1,626.9) = 15.47, p < .001}$	Global: 85.7% (1.0) Local: 89.0% (1.0)
	RT	$\boldsymbol{F(1,638.3) = 8.22, p = .004}$	Global: 1032 ms (15) Local: 996 ms (15)
Year	Accuracy	$\boldsymbol{F(2,666.5) = 60.40, p < .001}$	Year 1: 77.4% (1.4) Year 3: 90.4% (1.1) Year 5: 94.2% (1.2)
	RT	$\boldsymbol{F(2,657.8) = 83.19, p < .001}$	Year 1: 1178 ms (21) Year 3: 1001 ms (17) Year 5: 864 ms (17)

In summary, for the big-small divided attention task, participants became faster and more accurate with age. There was an overall local advantage in the accuracy data which was driven by Years 1 and 3. There was no between-level difference in accuracy in Year 5. Overall, this indicated a change from a local advantage to no processing advantage between Years 3 and 5.

3.3.2. *Yes-No divided attention Navon task at time 2 only*

The responses on the yes–no task were generally slower and less accurate than on the big-small task (Fig. 4). Note, statistical comparisons were not carried out as the tasks were too distinct.

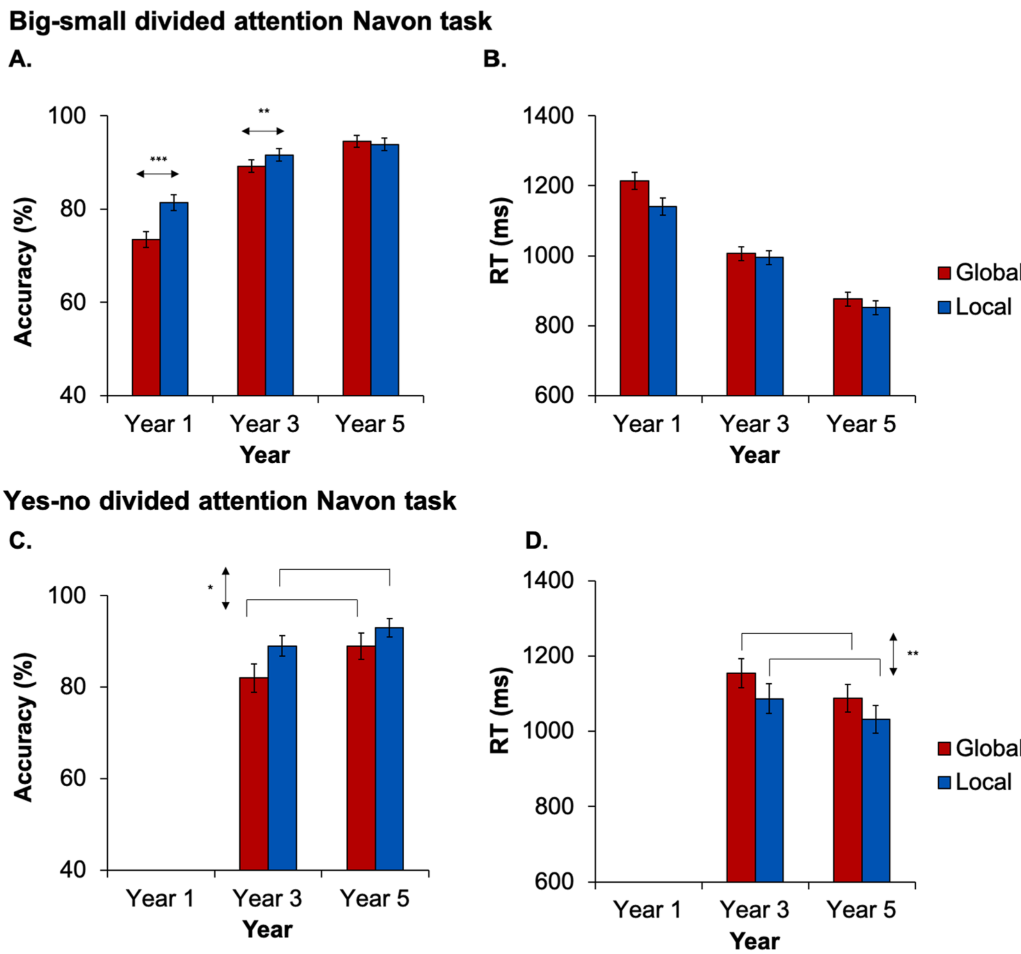

Fig. 4. Plots of divided attention Navon tasks performance, combining cross-sectional and longitudinal data (estimated mean ± SE). **A.** Big-small divided attention task accuracy as a function of Year and level. **B.** Big-small divided attention task RT as a function of Year and level. **C.** Time 2 accuracy on the yes–no divided attention task. **D.** Time 2 RT on the yes–no divided attention task. **p* < .05; ***p* < .01; ****p* < .001.

Two repeated measures ANOVAs were carried out to compare responses to the global and local level when the target was present. Accuracy and RT data were the DVs, with level (global, local) as the within-subjects factor and Year (3, 5) as the between-subjects factor (Table 4). Responses were quicker and more accurate when the target appeared at the local compared with the global level, and fewer errors were made by the older Year group (Fig. 4C and D). This indicates a local processing advantage across Years 3 and 5, which was only observed to be significant in Years 1 and 3 in the big-small divided attention task.

With the removal of outliers, the main effect of Year on accuracy of the global and local trials became non-significant ($p = .200$), suggesting that the two outlier data-points were lowering the Year 3 accuracy in the original analysis. There were no further differences in the main effects or interactions for the accuracy or RT data. Overall, this revealed a local advantage in both Years 3 and 5.

3.4. *Summary of the Navon task responses*

A summary of the developmental changes in each Navon task can be viewed in Fig. 5.

4. Discussion

The purpose of this study was to examine developmental changes in global and local responses to Navon shape stimuli in 5- to 10-year-old children, and to assess the influence of differing attentional demands

Table 4
Main effect for accuracy and response time (RT) for target-present (yes) trials in the yes–no divided attention task at Time 2. Estimated marginal means and standard error (SE) are reported. Significant effects in bold.

Main effect	Measure	Statistics	Estimated means (SE)
Level	Accuracy	**$F(1,58) = 4.49$, $p = .038$, $\eta^2_p = .072$**	Global: 85.3% (2.1) Local: 90.8% (1.5)
	RT [(a)]	**$F(1,57) = 10.97$, $p = .002$, $\eta^2_p = .161$**	Global: 1122 ms (26) Local: 1064 ms (27)
Year	Accuracy	**$F(1,58) = 4.15$, $p = .046$, $\eta^2_p = .067$**	Year 3: 85.4% (1.9) Year 5: 90.7% (1.8)
	RT	$p = .199$	

[(a)] One Year 3 participant did not respond correctly to any global level trials in the yes–no divided attention task.

		Tasks			
		Free choice	Selective attention	Big-small divided attention	Yes-no divided attention (T2)
Year and age	Year 1 (5-6 years)	=	Local advantage	Local advantage	N/A
	Year 3 (7-8 years)	Global advantage	Global advantage	Local advantage	Local advantage
	Year 5 (9-10 years)	Global advantage	Global advantage	=	Local advantage

Fig. 5. Summary of the global or local advantage, or no advantage (=), in each task as a function of Year. The yes–no divided attention task was only presented at time 2 (T2).

on responses. This was achieved through assessing children's responses on three Navon tasks using a combination of cross-sectional and longitudinal data, plus an additional Navon task with T2 children only. This is the first study to longitudinally examine global and local processing in typically developing children.

The main finding was that overall responses changed with development from a relatively more local advantage to a relatively more global advantage, which is consistent with our predictions. However, the specific change and the age at which this change took place varied by task. This indicates that the attentional demands of the tasks modulated the global and local responses, with a shift from no preference to a global preference in the free choice paradigm, from a local advantage to a global advantage in the selective attention task, from a local advantage to no effect of level in the big-small divided attention task, and a constant local advantage in the yes–no divided attention task. This supports prior observations that Navon tasks are not only measuring variation in global and local processing, but also attention, conflict resolution, and maintenance of task goals (De-Wit & Wagemans, 2015).

4.1. Developmental changes in global and local processing

In the Free Choice task, Year 1 children (aged 5–6 years) had no preference in their matching choice, but those in Years 3 and 5 (aged 7–10 years) were more likely to select the global match. This largely reflects previous studies which found that typically developing children make more global than local matches on free choice Navon tasks (Deruelle, Rondan, Gepner, & Fagot, 2006; Koldewyn et al., 2013; Wang et al., 2007), and supports studies where children from age 6- to 7-years-old begin to match the global level more consistently than the local level (Dukette & Stiles, 1996; Harrison & Stiles, 2009).

In the selective attention Navon task, there was also a change in response pattern between Years 1 and 3. Year 1 children responded equally quickly to both levels, but were more accurate on local than global trials, while children in Years 3 and 5 were equally accurate across level but responded more quickly to global than local trials. Overall, this demonstrates a developmental change from a local advantage to a global advantage between Years 1 (aged 5–6 years) and 3 (aged 7–8 years) on the selective attention Navon task. This somewhat supports results from a selective attention study of 5- to 12-year-olds by Koldewyn et al. (2013), where no significant difference was found between global and local accuracy responses, and there were marginally quicker responses to the global than local level. However, there was no analysis of developmental change, so it is unclear whether there were age-specific patterns similar to those observed in the present study. In contrast, Scherf et al. (2009) identified higher accuracy and quicker responses in local trials than global trials during a selective attention task in children (aged 8–13 years) and adolescents (aged 14–17 years). This more persistent local advantage may have resulted from smaller global stimuli with fewer local stimuli, making the local level comparatively salient.

In the big-small divided attention Navon task, children had higher accuracy on local than global trials in Years 1 and 3, and revealed no difference in accuracy between levels in Year 5. Overall, RT was quicker in local than global trials. This demonstrates a change from a local advantage in Years 1 and 3 (aged 5–8 years) to no advantage in Year 5 (aged 9–10 years). In the yes–no divided attention task, completed at T2 only, responses revealed a local advantage across Years 3 and 5 (aged 7–10 years). Although both tasks required participants to divide attention between the levels, the task demands were distinct. Therefore, even when tasks are designed to employ similar attentional demands, there may be observable differences if the tasks themselves differ from each other. The results on both of these tasks are in contrast with previous divided attention studies, where participants had to identify whether a target was present or absent (similar to the yes–no task here). Children aged 6 to 14 years were slower and less accurate when a letter was presented at the local level than the global level (Plaisted et al., 1999), and local responses were slower and less accurate than intermediate and global responses in 5- and 6-year-olds (Krakowski et al., 2016). This greater global advantage may be due to contrasting saliency balances between the levels, whereby the global stimuli were larger and the local stimuli were smaller and more numerous (Krakowski et al., 2016; Plaisted et al., 1999) than in the present study. In a further study, Farran et al. (2003) found no significant difference in accuracy or RT between target stimuli presented at the global or local level in 6- to 7-year-olds. This may be due to the use of letters rather than shapes (Farran et al., 2003) which has been shown to induce a larger global advantage in children and adults (Dukette & Stiles, 1996; Pletzer, Scheuringer, & Scherndl, 2017).

In summary, although the specific patterns of global and local responses differed across the tasks, this study identified a general developmental change from a more local advantage to a more global advantage. This occurred between Years 1 (aged 5–6 years) and 3 (aged 7–8 years) in the free choice Navon task and the selective attention Navon task, where older children responded with a global advantage; and between Years 3 (aged 7–8 years) and 5 (aged 9–10 years) in the big-small divided attention Navon task, with a change from a local advantage to no advantage. The yes–no divided attention task revealed a local response for children in Years 3 and 5 (aged 7–10 years). This differing pattern of responses when the design of the stimuli remained constant in terms of size, density, and shape, helps to explain why there is a high degree of variability in the literature about global and local development. The differing task demands clearly have an impact on responses, therefore studies with inconsistent task designs should not be expected to reach the same conclusions about the type and age of developmental changes in global and local processing.

4.2. Attentional demands in global and local processing

This study examined changes in responses based on differing task demands, but also analysed within-task differences in attentional demands. In the selective attention Navon task, congruency effects revealed slower and less accurate responses in incongruent trials than in congruent and neutral trials, which supports previous findings (Bouvet, Rousset, Valdois, & Donnadieu, 2011; Weinbach & Henik, 2014). This suggests that only distractors which were task-relevant interfered with responses and that the longer RTs were likely due to inhibitory control or conflict resolution processes involved in suppressing the irrelevant stimulus and response. In Years 3 and 5, there was no difference in interference whether the non-target level was global or local. However, in Year 1, accuracy on global trials was significantly lower than accuracy on local trials when information was inconsistent between levels. This means that for children aged 5–6 years, information at the non-target local level interfered with global responses, but information at the non-target global level did not interfere with local responses. This interference was evident regardless of whether the non-target information was relevant to the task. There was no commensurate congruency by level effect in the RT data. This suggests that younger children are less able to appropriately direct their attention to the task-relevant target when there is distracting information. This asymmetric pattern of interference indicates that the local level is more salient than the global level. This contrasts with adult studies which have identified not only faster responses to the global than local level, but also global-to-local interference (Gerlach & Poirel, 2018; Gerlach and Poirel, 2019).

This local advantage in younger children may result from the fact that the local level stimuli are solid shapes, whereas the global representation is only perceived by grouping individual elements. It is possible that younger children are more familiar with solid forms of the shapes and this contributes to the apparent later development of grouping processes compared with segmenting processes. This suggestion is supported by studies incorporating unfamiliar shapes in Navon stimuli, which have found that the automatic identification of a familiar object attracts attentional resources and influences responses (Poirel et al., 2006). If the global level is less similar to younger children's pre-existing representation of that shape, it may be less salient than the local level. As children develop, their wider experiences of shape may result in a more varied internal representation and, therefore, quicker shape identification. This requires further investigation.

Studies of divided attention Navon tasks with adults have identified an accuracy or RT cost on switch trials compared with stay trials while attentional resources are shifted from one level to the other (Hübner & Volberg, 2005; Wilkinson et al., 2001). Surprisingly, this effect was not evident here in the big-small divided attention Navon task. This suggests that, in children, there are no lingering effects of the target level beyond an individual trial. There are two possible explanations for this lack of effect. First, children might examine both levels before making a decision, which leads to an accuracy and RT cost regardless of whether the trial is a stay or switch trial. This could reflect a poorer control of their attentional resources meaning children are less able to select appropriate strategies for the task. Second, children might attend to only one level and respond according to whether the circle is present or absent. This would also lead to no advantage of a stay trial over a switch trial. This latter possibility led to the introduction of the yes–no divided attention Navon task at T2, where the strategy could not be employed to successfully complete the task as attention needed to be directed to both levels. Children were slower and less accurate on the yes–no divided attention task than the big-small divided attention task (although this has not been compared using statistical analyses). The slower RT in the yes–no task could be due to the need to direct attention to both levels to check if the target was present before responding. This could indicate that both levels were not always attended to in the big-small divided attention task, resulting in the relatively quicker RT. A tentative suggestion therefore is that the lack of switching effect in the big-small divided attention task was not due to children attending to both levels before responding. However, this requires further investigation.

4.3. Implications and future development

This study has determined that developmental changes and attentional processes are both contributing factors to observed global and local processing in children. However, it is not clear from this study whether the changing responses with development in each task reflect attentional development or perceptual development, or a combination. A local-to-global transition with development may be explained by later maturation of grouping processes in the perceptual system compared with segmentation processes (Kimchi et al., 2005; Scherf et al., 2008). However, the different patterns of responses both within and across the tasks here, indicate that a more nuanced explanation is needed involving developmental changes in domain-general abilities. For example, the lower global accuracy in incongruent and neutral selective attention trials in Year 1, and the lower global accuracy in the divided attention task in Years 1 and 3, is suggestive of poorer grouping processes in younger children, but only when there is task-irrelevant information that needs to be overcome. Future studies could explore this further by controlling for individual differences in attention such as sustained attention and inhibitory control. Studies could also examine why attentional task demands modulate the age at which children change from responding with a more local to a more global processing advantage. This could have wider implications for activities such as reading which rely on visuo-attentional processes (Franceschini, Bertoni, Gianesini, Gori, & Facoetti, 2017; Peters, De Losa, Bavin, & Crewther, 2019). In addition, individual differences in global precedence (quicker responses to the global than local level) and global-to-local interference have been found to relate to visual object recognition in adults (Gerlach & Poirel, 2018). Although this has not been examined in childhood, the developmental shift towards a global advantage observed in the present study may indicate a commensurate change in object recognition.

There is some evidence in the literature of a greater global advantage in males than females, however this is not a consistent finding in childhood, even across similar tasks or similar age ranges (Dukette & Stiles, 2001; Harrison & Stiles, 2009; Kramer, Ellenberg, Leonard, & Share, 1996; Tzuriel & Egozi, 2010; Vinter, Puspitawati, & Witt, 2010) and it has been argued that gender differences may depend on the task used (Kimchi, Amishav, & Sulitzeanu-Kenan, 2009). Nonetheless, one limitation of this study is that the gender distribution differed between Years at T2, with a higher proportion of females than males in Year 3 and a higher proportion of males than females in Year 5. In order to limit any effect of gender, future research would ideally have an equal balance of males and females, and could also specifically examine gender effects across development on global and local processing tasks with differing attentional demands.

The selective attention task included an additional element of location uncertainty compared with the other tasks. This ensured that attention was not widened or narrowed to only include the features of interest. However, it would be useful to include a comparison task where the stimuli were presented centrally so comparisons with other centrally-presented tasks can be made.

The free choice task included only four trials presented at the start of the test battery in order to gain an initial impression of the participants' dominant level and ensure there were minimal priming effects. However, the mixed responses from the youngest children could simply reflect the fact they had not understood the task when presented with novel stimuli. Therefore, it would be useful to include a longer free choice task in future studies with practice trials to obtain a more robust response pattern.

5. Conclusion

This is the first study to longitudinally examine global and local processing in typically developing children. By keeping the stimulus design consistent in each Navon task, this study has examined the effects of different attentional task demands on global and local responses. The age at which a local-to-global change was observed in children aged 5 to 10 years varied across tasks. This supports the notion that attentional demands of the task have an influence on responses, and that this masks any underlying global or local processing advantage. Although task-related differences in global and local processing development were observed in this age group, the results overall support the predicted diminishing local advantage with age.

CRediT authorship contribution statement

Su Morris: Conceptualization, Methodology, Software, Investigation, Formal analysis, Writing - original draft. **Iroise Dumontheil:** Conceptualization, Methodology, Software, Writing - review & editing, Supervision, Funding acquisition. **Emily K. Farran:** Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.visres.2021.03.008.

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