

## Research Article

# Visual Processing Speeds in Children

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The aim of this study was to investigate visual processing speeds in children. A rapid serial visual presentation (RSVP) task with schematic faces as stimuli was given to ninety-nine 6–10-year-old children as well as a short form of the WISC-III. Participants were asked to determine whether a happy face stimulus was embedded in a stream of distracter stimuli. Presentation time was gradually reduced from 500 ms per stimulus to 100 ms per stimulus, in 50 ms steps. The data revealed that (i) RSVP speed increases with age, (ii) children aged 8 years and over can discriminate stimuli presented every 100 ms—the speed typically used with RSVP procedures in adult and adolescent populations, and (iii) RSVP speed is significantly correlated with digit span and object assembly. In consequence, the RSVP paradigm presented here is appropriate for use in further investigations of processes of temporal attention within this cohort.

## 1. Introduction

Human visual attention is limited in respect to both space (how many items can be attended to simultaneously) and time (how rapidly consecutive items can be processed). With regard to the former, it is known that spatial attention can be location based, object based, scene based, and/or a combination of the above (see Tipper and Weaver [1] for a review). Experimental manipulations of attentional selectivity within a visual scene have further demonstrated that attention to a specific location can be narrowed or widened depending upon task constraints; for example, the number of items to be memorised [2]. However, whilst the capacity of visual spatial attention has been extensively researched in both adults and children alike (e.g., Huang-Pollock et al. [3]), research into the ability to process sequentially presented stimuli (i.e., processes of temporal attention) has been conducted primarily with adolescents and adults.

Typically, studies that investigate the time course of visual attention involve the rapid serial visual presentation (RSVP) paradigm in which one or two target items, embedded in a stream of distracter stimuli, must be identified. These investigations have been successful in charting the time-course of visual attention in adults [4, 5] and more recently

in exploring a range of psychopathologies and developmental disorders in both adults and adolescents, such as schizophrenia [6], anxiety [7], and depression [8].

In adolescents displaying high trait impulsivity, it is observed that processes of temporal attention are impaired. That is, when having to identify two targets presented in quick succession (i.e., RSVP), such individuals demonstrate poorer detection of the second target compared to control individuals [9]. Similar findings have also been observed in older children/adolescents with ADHD [10] and dyslexia [11], with such populations displaying more vulnerability than controls to the irrelevant distracter stimuli [11] although Lacroix et al. [12] have found the opposite pattern in a comparison of dyslexic and control adolescents.

However, a limitation of RSVP paradigms is that they typically require participants to identify stimuli such as letters or words. Therefore, the use of RSVP paradigms for investigating typical and atypical development in younger children (e.g., below the age of 11) is problematic, because reading ability, or more specifically the need to learn the configuration of a target, is often a potential confound. This might be one reason why research into the time course of visual attention in preadolescent children has been minimal. To circumvent this problem, we have developed an RSVP

paradigm with schematic faces as target stimuli [13] to investigate visual processing speeds in younger children. Facial configurations are identified early in infancy [14] and as such do not require reading or learning.

There are some recent studies in which nonletter stimuli have been used [10, 15] and some in which younger child participants have been included [10, 15, 16]. However, to our knowledge, no one has systematically investigated the rate of presentation at which children of different ages can identify single targets reliably. If a single target in an RSVP stream cannot be identified reliably, then data from dual-target trials will be difficult to interpret. That is, an incorrect identification of the second target could either be due to the attentional blink (i.e., the second target is masked by the first) or due to an inability to detect stimuli presented at a rapid rate, which may result from difficulties in attentional shift, attentional engagement, and/or attentional disengagement between consecutively presented stimuli (see [17] for review). Although it has been known for 40 years that adults can reliably detect a single target in an RSVP stream at a presentation rate of one item every 100 ms [18], given the large variation in processing speed from childhood to adulthood [19], there is no logical basis for the assumption that children of different ages are *all* capable of processing items at the same speed as adults.

Knowing how rapidly children can process consecutively presented stimuli is not only important for understanding typical and atypical development in younger children, but it is also important for understanding many aspects of cognitive development. For example, attention span at age 4 has been shown to correlate with WISC-R [20] and PIAT [21] scores at age 7 [22]. Visual processing *per se* has further been identified as a key factor in children's reading development [23], and there is evidence that developmental gain in global information-processing speed is correlated with short-term memory capacity [24] and reaction time [25], which in turn are positively correlated with intelligence scores [26, 27]. Thus, it is expected that processes of visual attention, as measured by RSVP, should correlate with performance measures used to investigate aspects of intelligence. Specifically, if visual processing speed is an aspect of global, domain-general, information-processing speed, then one would expect to find correlations between visual processing speed, global processing speed and short-term memory.

This said, it is possible that performance on visual processing tasks is not only a function of global, domain-general, processing speed but also a function of domain-specific processes (see Kail and Miller [28]), particularly if recognisable and interpretable visual stimuli are presented. For example, it has been demonstrated that face recognition is privileged over object recognition due to domain-specific cognitive and neural processes (see McKone et al. [29] for a review), with Morton and Johnson [14] demonstrating that newborn infants display a preferential response to schematic faces over scrambled faces and blank head outlines. In consequence, it is possible that performance on a schematic face identification task may be superior to performance on other (more abstract) measures of processing speed.

Thus, there were two primary aims of the present study. Our first goal was to determine baseline visual processing speeds in primary school children and ascertain whether older children can process visual stimuli at faster speeds than younger children. Our second aim was to investigate whether visual processing speed correlates with further measures of attention, memory, and global processing speed. Specifically, we predicted that participants with higher visual processing speeds would score more highly on these other measures, particularly on measures such as object assembly [30] in which meaningful, as opposed to abstract, stimuli are presented.

## 2. Method

**2.1. Participants.** Participants were recruited from two primary schools in the East Midlands of England, UK. A total of 99 children (46 male) took part in the study, 24 aged 6 ( $M = 77$  months,  $SD = 3.27$ , range = 72–83 months), 17 aged 7 ( $M = 89$  months,  $SD = 3.57$ , range = 84–95 months), 26 aged 8 ( $M = 102$  months,  $SD = 3.89$ , range = 96–107 months), 17 aged 9 ( $M = 114$  months,  $SD = 3.82$ , range = 108–119 months), and 15 aged 10 ( $M = 124$  months,  $SD = 3.41$ , range = 120–131 months). All participants had normal or corrected-to-normal vision. We had not previously asked these children to participate in similar experiments.

**2.2. Procedure.** The experiment consisted of two counterbalanced tasks: the RSVP task and a short-form of the WISC-III [23]. The subtests of the short-form of the WISC-III included (a) block design (measuring visual processing and global processing speed using abstract stimuli), (b) object assembly (measuring visual processing and global processing speed using meaningful stimuli), (c) digit span (measuring working memory and attention span), and (d) symbol search (measuring global processing speed and attention using abstract stimuli) [31].

In the RSVP task, participants had to determine whether a happy face stimulus was embedded in a stream of distracter stimuli. Each trial contained 18 stimuli presented consecutively with no interstimulus interval (ISI). In target trials, 17 distracters were presented along with the happy face stimulus (see Figure 1). The target stimulus was randomly presented at serial position 7, 9, 11, 13, or 15, with equal measure. In nontarget trials, 18 distracters consisting only of scrambled faces were presented. Trials were presented using Inquisit software (<http://www.millisecond.com/>) in blocks of ten. Half contained targets and half did not. We made the decision not to utilize an ISI, as there is no standard interval length, and it is possible that results may vary dependent on the length of such an interval.

To obtain measures of visual processing speed, the task was stepped. The stepwise procedure involved an initial presentation of stimuli at a rate of one stimulus every 500 ms. After each stimulus stream was presented, participants were asked to press one of two buttons to indicate whether they saw a face or not. If participants correctly identified whether a happy face stimulus had or had not been presented with

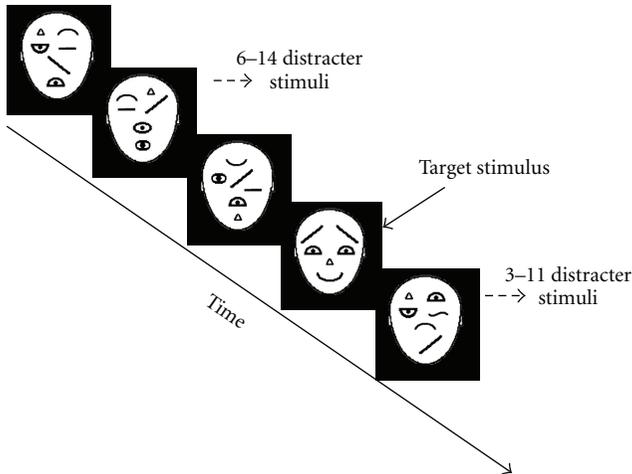


FIGURE 1: Sample stimuli for a target present trial in the RSVP task. On half the trials, the happy face (target) is embedded in a series of distracters at serial positions 7, 9, 11, 13, or 15 (with equal measure). On the other half of the trials, the target stimulus does not appear.

an accuracy of 70% or more across the 10 trials (a criterion used in previous studies, for example, Arnell et al. [32]), RSVP speed was increased by 50 ms. That is, the next block of 10 trials would be presented at a rate of one stimulus every 450 ms. The procedure continued (i.e., 400 ms, 350 ms, 300 ms, etc.) until a speed of 100 ms per stimulus (adult processing speed) was reached. At every level of RSVP speed, up to three blocks of trials could be run. If participants failed to meet the required 70% accuracy level by the end of the third block, the experiment was terminated. The total number of trials prior to termination, accuracy on those trials, response times, and the final RSVP speed achieved were all recorded.

### 3. Results

Data from 23 participants (10 children aged 6, 4 aged 7, 6 aged 8, and 3 aged 9) were excluded, as they dropped out of the RSVP task before reaching the termination criterion. Of the remaining 76 participants, all 10-year olds reached the 100ms level (i.e., adult speed), as did the majority of 8- and 9-year olds (80% and 86%, resp.). The 6- and 7-year olds, however, did not perform as well; only 43% of 6-year olds and 62% of 7-year olds reached 100 ms. A Kruskal-Wallis test on the RSVP level reached by each participant was conducted to examine the developmental trend. The RSVP level was the fastest presentation speed (e.g., 100 ms) at which participants were able to correctly identify the presence or absence of a target stimulus in at least one of three blocks of ten trials with 70% accuracy. There was a significant effect of age,  $H(4) = 14.66$ ,  $P = .005$ . Mann-Whitney tests with a Bonferroni correction were used to follow up this finding ( $\alpha = 0.01$ ). These revealed that 6-year olds performed more poorly than 10-year olds, whilst 7-year olds performed more poorly than 8-, 9-, and 10-year olds. There were, however, no significant differences in performance between the 6- and 7-year olds or between the 8-, 9-, and 10-year olds.

TABLE 1: Target discrimination, mean response times, and mean number of trials for each age group.

Age (years)	Target discrimination ( $d'$ ) (SD)	Mean response times (ms) (SD)	Mean no. of trials per level (SD)
6	2.19 (0.80)	1341 (411)	10.97 (2.43)
7	2.58 (0.73)	1265 (403)	10.31 (3.61)
8	2.91 (0.46)	1085 (319)	8.41 (1.27)
9	2.85 (0.68)	1003 (302)	8.54 (2.62)
10	2.98 (0.77)	948 (293)	8.21 (1.92)
Total	2.72 (0.72)	1121 (367)	9.19 (2.57)

In order to examine whether target discrimination accuracy and speed of target identification increased with age independently of the final RSVP level reached,  $d'$  values were calculated for each participant and mean response times were investigated. Additionally, the mean number of trials each participant completed per level was also explored (see Table 1). That is, as participants were able to attempt up to three blocks of ten trials at each level of presentation speed, it was possible for participants to complete as few as seven, or as many as 30 trials, before progressing to the next level.

A multivariate analysis of variance (MANOVA) with age as the independent variable and discrimination (indexed by  $d'$ ), mean response time and trials per level as the dependent variables were performed. This revealed a significant effect of age on discrimination,  $F(4, 71) = 3.33$ ,  $P = .015$ , with post hoc tests revealing that 6-year olds were less accurate than 8-, 9-, and 10-year olds. However, as all  $d'$  values observed were greater than two, this indicates that even the youngest age group showed no response bias and were, therefore, capable of discriminating both the presence and absence of targets. There was also a significant effect of age on mean response times,  $F(4, 71) = 3.39$ ,  $P = .013$ . Post hoc tests revealed that response times were longer for 6-year olds than for 8-, 9-, and 10-year olds and longer for 7-year olds than for 10-year olds. Finally, there was a main effect of age on mean trials per level,  $F(4, 71) = 4.064$ ,  $P = .005$ . Post hoc tests revealed differences between 6-year olds and 8-, 9-, and 10-year olds ( $P < .01$ ), and differences between 7-year olds and 8- and 10-year olds ( $P < .03$ ). Importantly, the mean number of trials per level for 8-, 9-, and 10-year olds was 8.2–8.5, whilst for the 6- and 7-year olds, it was 10.3 and 11, respectively. This demonstrates that the older children only had to complete one block per level before moving on to the next faster level, whereas, in general, the younger children had to complete two blocks of trials before progressing. Also, of note, for all three dependent measures, the post hoc comparisons revealed no differences between the 6- and 7-year olds or between the 8-, 9-, and 10-year olds.

The second aim of this study was to determine whether visual processing speed was related to other measures of attention, memory, and global processing speed. Table 2 shows the correlations between age, RSVP level, and the WISC-III subtests. As lower RSVP levels suggest that participants were able to process visual stimuli more rapidly,

TABLE 2: Correlations between age, RSVP level, and WISC-III subtests.

	1	2	3	4	5	6	7
(1) Age	—	-.306**	-.065	.055	.021	.060	.024
(2) RSVP level		—	-.165	-.227*	-.190	-.248*	-.301**
(3) Block design			—	.362**	.333**	.326**	.751**
(4) Object assembly				—	.378**	.142	.713**
(5) Symbol search					—	.157	.692**
(6) Digit span						—	.561**
(7) WISC sum of scores							—

\* $P < .05$ , \*\* $P < .01$ .

negative correlations indicate a positive relationship with the other measures in which a higher score denotes superior performance. RSVP level was significantly correlated with age, object assembly, digit span, and the sum of WISC-III subtests but not correlated with block design or symbol search. The latter measures are those in which abstract stimuli are presented.

#### 4. Discussion

The aims of this study were to (i) ascertain whether (and at what age) children aged 6–10 years can reliably process rapidly presented visual stimuli at speeds similar to those found with adults and (ii) determine whether visual processing, as measured by the RSVP task, is correlated with other measures of attention, memory, and global processing speed. Related to this, there were two main findings: first, RSVP level in which stimuli are presented at a rate of one every 100 ms can be used with children aged 8 and above. Second, there is a relationship between visual processing speed and the WISC-III measures of attention, memory, and global processing speed in which meaningful, as opposed to abstract, stimuli were used.

The results show that visual processing speed, as measured by an RSVP task, increases with age. Children aged 8 years and over can typically discriminate visual stimuli presented every 100 ms, which is the speed usually used with RSVP procedures in adult and adolescent populations (e.g., Shapiro et al. [4]). The performance of 6- and 7-year olds was, however, more variable; whilst many of the younger participants were able to discriminate between target and nontarget trials at 100 ms, there were large individual differences. In addition, the children aged 8 years and over were more accurate in the correct identification of the presence or absence of a target stimulus, made responses more quickly, and completed fewer trials for each RSVP level than the younger children. In consequence, the pattern of results suggests that visual processing speed increases significantly between the ages of 6 and 8. It could be argued that this increase is not due to changes in visual processing per se but rather due to changes in response (or reaction) time. However, Arnell et al. [32] have provided evidence that accuracy on an RSVP task is correlated with target identification and response selection rather than “pure” response time measured independently of these further

measures. Thus, our study indicates that it is possible to reliably conduct RSVP-based studies, such as investigations into the attentional blink (i.e., identification of two target stimuli presented in an RSVP stream in quick succession) or repetition blindness (i.e., identification of two *identical* target stimuli presented in an RSVP stream in quick succession), with participants aged 8 years and over using methods employed with adult populations. This is particularly important to know, as with this population, staircase procedures to determine exact processing speeds may be inappropriate given they are likely to considerably lengthen the duration of such experiments and, in consequence, considerably increase noncompletion rates.

The second aim of the study was to determine whether visual processing, as measured by the RSVP task, is correlated with further measures of attention, memory, and global processing speed. If visual processing speed is an aspect of global processing speed, then one would expect to find correlations between visual processing, global processing speed, and short-term memory. The correlations of RSVP level with object assembly, digit span, and WISC-III sum of subtest scores observed do suggest that visual processing speed as measured using RSVP is linked to global mental processing speed, short-term memory, and nonverbal intelligence. However, RSVP level was not correlated with block design or symbol search, both of which also measure global processing speed.

One explanation for this uneven performance is that the block design task is constrained by other factors, such as spatial reasoning skills or visuomotor coordination. However, symbol search involves no spatial reasoning and little in the way of motor skills. An alternative explanation is that whereas both the RSVP and object assembly tasks involve the identification of meaningful stimuli, block design and symbol search feature abstract stimuli such as geometric shapes that do not necessarily have any semantic associations. This said, as 75% of participants reached the 100 ms level on the RSVP task, an analysis of a larger sample of children with slower visual processing speeds would be needed to explore relationships between performance on tasks involving face, object, and abstract stimuli further. Indeed, it may be that stimulus type has an important effect on processing speed. For example, given both the social and evolutionary significance of facial stimuli, it has been suggested that different mechanisms underlie the identification of this stimulus set compared to other stimulus

sets (e.g., cars) or geometric shapes, which allows for their processing to be prioritized [33] (but see Larson et al. [34]). In order to determine this, RSVP tasks with abstract and/or different categories of target stimuli would need to be used.

In sum, we have demonstrated that a pictorial RSVP paradigm with stimuli presented every 100 ms is suitable for use with children aged 8 years and above. As this paradigm does not involve the identification of words or letters, reading ability does not need to be taken into account when using this paradigm. Hence, this task (or variations of it) can now be utilised to (i) further investigate aspects of cognitive development (such as the development of the attentional blink) and (ii) explore developmental processes of temporal attention with atypically developing populations (e.g., primary-aged children displaying behavioural patterns associated with ADHD, impulsivity, and dyslexia). Secondly, we have demonstrated that performance on the RSVP paradigm is linked to short-term memory and, to some extent, domain-general processing speed. However, in order to clarify the relationship between processing speed and RSVP performance, future research is needed to examine whether there are correlations between measures of general processing speed and RSVP performance on a task in which abstract stimuli are used in addition to schematic faces.

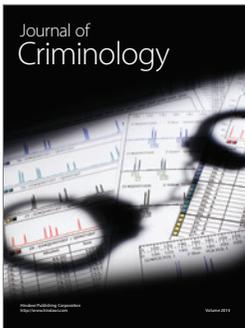
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