**Abstract**

By approximately 6 years of age, children can use time-based visual selection to ignore stationary stimuli, already in the visual field and prioritize the selection of newly arriving stimuli. This ability can be studied using preview search, a version of the visual search paradigm with an added temporal component, in which one set of distractors is presented (previewed) before a second set that contains the target item. Preview search is more efficient than if all items are presented simultaneously, suggesting that temporally 'old' objects can be ignored (the preview benefit). In two experiments, we examined the developmental trajectory for ignoring old moving distractors in a sample of 192 6, 8, and 12-year-old children (49% female, predominantly white), with adults as controls (75% female, predominantly white), in the UK. The results showed an absence of the ability to ignore old moving distractors in 6-year-olds and confirmed its presence from 8 years of age. However, full development of this ability, which includes maintaining inhibition of old items over extended periods, was only present from the age of 12. Individual differences in  EFs, namely inhibition, were associated with preview search efficiency in 6-year-olds and adults. Overall, the results suggest a developmental trajectory in the ability to ignore moving old objects that occurs in two stages and develops later than the ability to ignore stationary objects. The results are discussed in terms of underlying inhibitory mechanisms, in addition to individual differences in the expression of this ability.

*Keywords*: Attention, Inhibition, Executive Functions, Visual search

## Introduction

The ability to attend to moving objects is critical for many aspects of everyday life, such as determining the presence of an object, its direction of travel, its velocity and potential for collision, and safe navigation through the world (e.g., crossing a road). Despite the importance of processing motion, much of the selective attention research in child development has focused on spatial attention with stationary objects. For example, previous visual search studies have shown that the ability to search through spatially distributed stationary objects improves during middle to late childhood (Trick & Enns, 1998; Hommel et al., 2004; Donnelly et al., 2007). However, aside from spatial distribution, animate and inanimate objects (if a force has been applied), also have a temporal distribution. As such, attentional processing of temporal information is essential for safe and efficient interaction with the world.

Time-based selection refers to the ability to use time, in addition to space, to help select objects of relevance. For example, time of appearance can be used to prioritize the selection of newly arriving objects over the selection of 'old' objects already present within a scene (Watson & Humphreys, 1997). Young adults (Watson & Humphreys, 1997), older adults (Watson & Maylor, 2002), and children from the age of six years (Zupan et al., 2018) can all use time-based visual selection effectively when objects are stationary. However, the ability to ignore moving items appears to rely on a different mechanism which requires greater cognitive resources (Watson & Humphreys, 1998; Watson, 2001) and is impaired in older adults (Watson & Maylor, 2002).

Global motion processing, underpinned by the visual dorsal stream, shows both a protracted developmental course (Coch et al, 2005; Hadad et al, 2011) and vulnerability in different developmental disorders (Braddick et al., 2003). Indeed, feature integration and visual selection abilities for moving objects improve with age in 4 to 10-year-old children, particularly for feature integration of color and motion, which involve different neural pathways (Lynn et al., 2019). However, there is no research on how the ability to ignore old moving objects and prioritize the selection of new ones develops, despite this being an important function of the visual attention system. Accordingly, the main goal of the present work was to examine the development of time-based selection for moving objects throughout middle to late childhood.

**Time-based Visual Selection: Accounts and Development**

Time-based visual selection has been investigated using the *preview paradigm* (Watson & Humphreys, 1997). Here, stimuli in a visual search task are separated in time – with one set of distractors presented first (previewed items) and a second set, containing additional distractors and the target added at a later point in time. The *preview benefit* is determined by comparing performance in the preview condition to a full element baseline condition (FEB), where all the stimuli appear simultaneously. If a preview benefit occurs (i.e. people can ignore the previewed items), search will be more efficient in the preview condition than in the FEB condition. In addition, preview performance is sometimes compared to a half-element baseline condition (HEB), comprising the second set of items only. A preview search performance that is indistinguishable from that in a HEB suggests that all the preview items could be ignored given that search was as efficient as when none of them were present (e.g., Watson & Humphreys, 1997).

Several mechanisms are likely to underlie the preview benefit. The original *visual marking* account suggests that with stationary stimuli, the preview benefit occurs through top-down location-based inhibition of old items to prioritize newly arriving, behaviorally relevant information (Watson & Humphreys, 1997). As a top-down process, it is goal-directed (Zupan et al., 2015) and requires cognitive resources (Watson & Humphreys, 1997; Humphreys et al., 2002). Alternative accounts suggest that new items are prioritized using bottom-up processes, via automatic capture (i.e., by abrupt luminance changes associated with newly arriving objects; e.g., Donk & Theeuwes, 2001, 2003), or temporal asynchrony between the presentation of old and new items (Jiang et al., 2002). Lastly, with a small number of old distractors, visual working memory may also play a role (Al-Aidroos et al., 2012). It is likely that both top-down and bottom-up processes have a role in generating the preview benefit (e.g., Watson & Humphreys, 1997; Watson et al., 2003; von Mühlenen et al., 2013).

Recently, the development of time-based visual selection and its relation to executive function (EF), has been examined with stationary objects in children aged 6, 8, and 12 years and young adults (Zupan et al., 2018). On average, children from 6 years upwards were able to ignore old stationary objects and prioritize selection for newly arriving ones. However, at the age of 6, preview benefits occurred only when distractors were presented for short (500ms) and standard (1000ms) durations, but not for extended durations of 1500ms. Past research has suggested that visual marking relies on two stages: i) an inhibitory ‘set up’ stage that requires central, general, resources and, ii) a ‘maintenance’ stage that requires visual resources (Humphreys et al., 2002). The setup stage is responsible for generating a representation of the preview items and coordinating inhibition to those items. The maintenance stage is responsible for maintaining inhibition of the previewed items once established via the setup stage. The inability of 6-year-olds to ignore stationery items over extended durations suggested that the maintenance component may have a protracted developmental trajectory – at least with stationary objects. These findings lend support to top-down accounts (Watson & Humphreys, 1997), since a purely bottom-up explanation predicts that preview search should operate similarly at all durations. Thus, while time-based visual selection for stationary objects is mostly developed at 6 years, its full development is not reached until the age of 8, at least in terms of the length of time that inhibition can be maintained for. This result is consistent with findings that children can use attention volitionally, in a top-down fashion, from 8 years of age (Ristic & Kingstone, 2009). However, no relationships were observed between time-based visual selection for stationary stimuli and EFs in any age group.

As both top-down and bottom-up processes contribute to the preview benefit (Watson & Humphreys, 1997) any development of bottom-up processes could also contribute to preview search age-related changes. The basic bottom-up requirement of segregating objects into old and new by a feature is in place in these age groups as suggested by children's similar performance to adults in single-feature search tasks (e.g., Donnelly et al., 2007; Trick & Enns, 1998; Hommel et al., 2004). However, monitoring multiple feature dimensions (e.g., searching for either color or orientation or size singleton) is not well developed in 6-7-year-olds relative to older children, with a relatively faster search for color than orientation in a single feature task (Donnelly et al., 2007). Segregating objects by features into old and new in preview search may also require monitoring multiple feature dimensions (e.g., color, shape) which accordingly depends on the development of this bottom-up mechanism. Furthermore, any development in bottom-up mechanisms involving perceptual organization over time, such as automatic capture by multiple new onsets (Yantis & Jonides, 1990) might also contribute to age-related changes in the efficiency of preview search. However, to our knowledge, there is no research describing the developmental trends for these mechanisms.

In adults, time-based visual selection can also be applied to moving items, to prioritize the selection of newly arriving objects (Watson & Humphreys, 1998). When objects are in motion, location information is constantly changing, and so old objects cannot be ignored by suppressing their locations (Watson & Humphreys, 1997). Instead, ignoring moving objects requires different processes for encoding and inhibition. Watson and Humphreys (1998) proposed that inhibiting old moving objects occurs by applying inhibition at a whole ‘feature map’ level (e.g., a color map representing green; Treisman & Gelade, 1980). Such feature-based inhibition requires there to be a unique feature difference (e.g., a difference in color) between old and new items. Grouping and inhibiting old items by feature provides the cognitive system with an adaptive advantage (i.e., multiple moving objects do not require individual tracking); individual tracking is more complex, computationally expensive, and resource-demanding (Watson & Humphreys, 1998; but see also Watson, 2001). Given that preview benefits for stationary objects are underpinned by *location-based* inhibition (Watson & Humphreys, 1997), and preview benefits for moving stimuli are underpinned by *feature-based* inhibition (Watson & Humphreys, 1998), different developmental differences may exist for ignoring moving stimuli compared to ignoring stationary stimuli.

## The Present Study

The primary aim of the current study was to examine whether 6 to 12-year-old children can perform time-based selection with moving objects, given that ignoring moving items operates via a different process (i.e., feature-based inhibition; Watson & Humphreys, 1998) to ignoring stationary objects (i.e., location-based inhibition; Watson & Humphreys, 1997). This will inform us as to how dynamic attention develops. That is, when targets and distractors are ‘on the move’, can 6 to 12-year-old children select and process information across time and space as adults do? General search of dynamic displays will be measured by having all the display items constantly moving and calculating the search slopes based on the speed of finding the target relative to the number of objects presented. The temporal selection aspect (i.e. the extent to which old moving items can be ignored) will be determined by presenting a set of distractors before a new set containing the target (i.e., the preview search task) relative to tasks in which all items appear simultaneously (FEB and HEB). We hypothesize that since a preview benefit was observed for stationary, but not moving objects in old age (Watson & Maylor, 2002), similar patterns may occur in development, with younger children (6-year-olds) not being able to ignore old moving objects. This is predicted on the basis that the feature-based processes for ignoring moving items appear to require greater resources than location-based inhibition of stationery items. Thus we would expect a reduced ability to ignore moving items whenever resources are reduced as in childhood or as a result of old age.

The second aim was to determine whether individual differences in the development of time-based visual selection with moving items are associated with developmental changes in EFs. Although previous research has provided little evidence of such associations (Zupan et al., 2018), given the different processes involved in ignoring stationary versus moving items, such a relation is possible. Accordingly, we predict that EFs such as response inhibition and inhibition/switching combined may be especially related to higher individual and/or developmental levels of preview efficiency.

The third aim was to test the completeness of the development of time-based visual selection for objects in motion. As noted earlier, ignoring old items is a two-stage process consisting of a setup stage followed by a maintenance stage (Humphreys et al., 2002). In the current study, we assessed the development of the maintenance component by manipulating the previewed items' duration  (by presenting old items for longer or shorter periods of time before the new items were added; Watson & Humphreys, 1997). We expected younger children, particularly 6-year-olds, to have a reduced ability to maintain inhibition towards old items over longer intervals due to an underdeveloped maintenance process. For example, maintaining inhibition towards old items might be compromised with the reduced resources available to younger children and, younger children might be more easily distracted leading to disruption or resetting of the maintenance process.

## Experiment 1: Time-Based Visual Selection of Moving Objects

Experiment 1 explored the development of time-based selection with moving objects. Potential relationships between the ability to ignore old objects and individual differences in EFs and verbal and spatial working memory were also examined.

### Method

**Participants**. The minimum sample size was determined based on previous experimental findings – in the study of Zupan et al (2018) which used an identical paradigm with stationary stimuli, the effect sizes of the Condition × Age interaction was $\eta_p^2 = .22$ for both Experiments 1 and 2. We used G*Power 3.1.9.7 to calculate the sample size. To detect these effect sizes, with a power level at .8 and alpha .05, the sample size should be between 32 and 48 participants, depending on the nonsphericity correction (0.5-1). The correlational analysis was powered to detect medium effect $r$ =.55 sizes with power level of .8 and alpha .05, resulting in 23 participants. Participants consisted of 24 6-year-olds (12 male, age 5-6, *M* = 5 years, 8 months, *SD* = 4.01 months), 24 8-year-olds (16 male, age 7-8, *M* = 7 years, 8 months, *SD* = 3.38 months)[1], 24 12-year-olds (12 male, age 11-12, *M* = 12 years, 4 months, *SD* = 4.36 months), and

[1] One primary school declined to provide the children's dates of birth. Thus, mean age of 6-year-olds and 8-year-olds reported here is calculated based on the available information of 14 out of 24 6-year-olds, and 13 out of 24 8-year-olds.

24 adults (2 male, age 18-29, *M* = 19 years, 6 months, *SD* = 36.42 months). The sample size was determined according to those used in previous studies using the preview paradigm in these age groups (Zupan et al., 2018), which has shown to be sufficient to determine the presence of preview benefit. Children were recruited via an opt-out procedure (granted with the Head Teacher's agreement) from schools in three UK counties: Warwickshire, Oxfordshire, and West Midlands. Adult participants were recruited from the research participant pool at the University of Warwick. Adults signed informed consent forms and children gave their assent to participate. Both children and adults were debriefed in an age-appropriate way. As rewards for participation, children received stickers, and adults received either course credit or a small payment. Ethical approval was granted from the Psychology Research Ethics Committee at the University of Warwick for the project: "Learning to ignore irrelevant information: The development of top-down time-based visual selection."

**Search tasks**. A custom computer program generated displays and recorded responses on a Samsung 550P5 15-inch LCS (1366 × 768 pixels, 60 Hz) laptop. Participants were seated in front of the laptop and were free to adopt a comfortable viewing distance of approximately 60 cm; however, there was no formal attempt to restrict distance or head movements. The target was a light blue [RGB values = 68, 164, 176] square and distractors were pink [RGB values = 211, 103, 126] squares (8 mm × 8 mm) and light blue [RGB values = 68, 164, 176] circles (10 mm diameter), set against the black monitor screen background. Stimuli were randomly distributed into cells of an invisible 6 × 6 matrix (168mm ×168 mm), with a center-to-center grid spacing of 28 mm. Stimulus locations were also jittered by ±5 mm to remove spatial regularities. There was an equal number of pink and blue distractors to the right and left side of the screen, and targets always fell unambiguously into one of the two most leftward or rightward columns of the invisible matrix. In all conditions, stimuli moved downwards within a virtual window. Once they reached the bottom of the virtual window, they gradually disappeared (1 pixel at a time) by sliding down behind the bottom of a virtual window, and gradually reappeared in a continuous motion at the top of the window, at the same horizontal location. The gradual onset/offset of these items was necessary to ensure rapid luminance changes would not interfere with the preview benefit (Watson & Humphreys,1998). Continuous motion was created by moving stimuli one pixel downwards on every retrace of the screen (60 Hz), thus making motion flicker-free and smooth.

There were three experimental conditions: Half-element baseline (HEB), Full-element baseline (FEB), and Preview search task (see Figure 1). Each trial started with a presentation of a blank screen (500ms), which was followed by a central white [RGB = 180,180,180] fixation dot (2 mm × 2 mm), before adding the stimuli. In the FEB and preview conditions, displays consisted of 4, 8, or 16 items; in the HEB, display size was 2, 4, or 8 items. FEB and preview conditions consisted of blue circles and pink squares, and the blue square target was always present. In the FEB, all items were presented simultaneously, while the preview condition consisted of a two-stage distractor presentation: pink distractors, which comprised half the total number of stimuli, were presented for 1000ms, after which blue distractors and a blue target were added. In the preview condition, the participant's task was to ignore the previewed items that were presented first and to indicate location (left or right) of the target, which always appeared in the second set of stimuli. The HEB comprised only blue items from the FEB, and thus, contained half the number of items in FEB and preview displays. All items (targets and distractors) were always synchronously moving in all conditions. Participants pressed the left or right shoulder button on a gamepad device to indicate the target location, i.e., left or right. Visual feedback was given by presenting the word ‘incorrect’ at the center of the screen when errors were made.

**EF tasks.** EF tasks were the same as in Zupan et al. (2018), based on Miyake and colleagues’ (2000) model which proposes three aspects of EF: shifting, inhibition, and updating (i.e. working memory; WM). We assessed switching and response inhibition using the Shape School task (Espy, 1997), adapted for older children, adolescents, and adults (Ellefson et al., in preparation), and for measures of short-term verbal and visuospatial memory, we used tasks from the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001).

***Shape School.*** The Shape School task is administered in a storybook format, with developmentally appropriate stimuli consisting of cartoon shapes with faces, arms, and legs. The task comprised four conditions (Control, Inhibition, Switching, Both), administered in a fixed order. Each condition consisted of 48 figures arranged across two pages, in eight lines of six stimuli. The participants’ task was to call out figure names according to task instructions given in each condition. Before each condition, participants completed a practice set of six figures. The time to complete each condition was measured using a stopwatch and the number of errors was recorded by the researcher. For each condition, efficiency was calculated by subtracting the number of errors from the correct responses and dividing by total response time for that condition.

In the Control condition, the participants’ task was to name the color (red or blue) of each item, to establish a baseline naming speed. In the Inhibition condition, stimuli were divided into those with happy and sad facial expressions. Here, the participants’ task was to call out the color of figures with happy facial expressions and to inhibit figures with sad facial expressions. In the Switching condition, half the stimuli wore hats; the instruction was to name these figures according to shape (square or circle) and to name the remaining, hatless figures, according to color (red or blue). The ‘Both’ condition combined switching and inhibition, where the stimuli comprised happy and sad, as well as hat-wearing and hatless figures. There were 24 happy figures and 24 sad figures; for each facial expression, half were hat-wearing. The task was to name figures either by color (red or blue) if hatless, and by shape (square or circle) if hat-wearing.

***Working Memory Test-Battery for Children (WMTB-C).*** Two measures from the WMTB-C (Pickering & Gathercole, 2001) were administered: Digit Recall task, also known as digit span, measuring verbal and Block Recall measuring visuospatial short-term memory components of Working Memory. The Digit Recall task consisted of digit sequences constructed from numbers from 1 to 9 in random order. The researcher read the digit sequences aloud to participants at a rate of approximately 1s per digit and the participant’s task was to repeat the digit sequence in the correct order. The practice trial consisted of spans of 1, 2, and 3 digits. In test blocks, there were 6-digit sequences per span, increasing incrementally in length subject to the successful completion of the previous span. If the participant recalled four sequences of the given span correctly, the next digit span was presented. The task was discontinued once the participant failed to recall three sequences of a given span. The final score was the total number of digit sequences recalled. The previously established mean test-retest reliability of the digit recall task for children between 4.5-11 years was .84 (Pickering & Gathercole, 2001).

The Block Recall task consisted of nine cubes distributed across a board. Practice trials with spans from 1 to 3 were administered, with the test trial starting at the length of the correct practice sequence recalled. The researcher tapped a sequence of blocks and the participant’s task was to reproduce the sequence by tapping the same cubes in the same order. If four out of six sequences of a given span were completed correctly, spans increased in length incrementally (the maximum was a span of nine blocks) until the participant failed to reproduce four sequences of a given span in the correct order. The total score was the number of correctly reproduced block sequences. The previously established mean test-retest reliability for the Block Recall task for children between 4.5 and 11.5 years is .83 (Pickering & Gathercole, 2001).

**Design and procedure.** Children were tested individually in a quiet room at their school and adults were tested in a lab space at the Universty of Warwick. Search tasks were administered to children in one session, and the EF tasks in a different session, in a counterbalanced order. Adults completed both the search tasks and the EF tasks in a single session, also in a counterbalanced order. Conditions in the visual search task session were presented in a counterbalanced ABCABC order of the three search conditions There were two blocks of 36 experimental trials per condition (i.e., two blocks of HEB, FEB, and Preview), resulting in a total of six blocks (216 experimental trials), with a self-paced break between the blocks. Before introducing a condition for the first time, 10 practice trials were completed. When the blocks alternated and the condition was presented for the second time, four additional practice trials were administered as a reminder.

This study was not preregistered. All data (Zupan et al., 2022) have been made publicly available at the Open Science Framework and can be accessed at: https://osf.io/m7j4h/?view_only=539f3b636e854d558334a44e36f974b1

## Results

Our results were analyzed using standard frequentist approaches which were supplemented where appropriate with Bayesian analyses. Bayesian analyses provide a Bayes Factor (BF) which gives a numerical estimate of support for the alternative ($BF_{10}$) or null hypothesis ($BF_{01}$). For example, a $BF_{10}$ value of 10 indicates that the alternative hypothesis is ten times more likely than the null hypothesis. By convention, BF values between 1 and 3 provide anecdotal evidence, BF values of 3 to 10 provide substantial evidence, and BF values > 10 provide strong evidence for the alternative (Jeffreys, 1998; Jarosz & Wiley, 2014). For models with interaction terms, the interaction $BF_{incl}$ is reported, which refers to the posterior probability that the inclusion of the interaction, in addition to lower-order terms, produces a model which explains the observed data. BFs for repeated measures ANOVAs, t-tests, and correlations were calculated using JASP version 0.15.0, with a default Cauchy prior width of 0.707. BFs for partial correlations were calculated using RStudio version 4.0.

**Search tasks.** Reaction times (RTs) less than 200ms or greater than 10s were removed as outliers. This resulted in 3.39%, 0.73%, 0.28%, and 0.12% of the data being removed, for 6-year-olds, 8-year-olds, 12-year-olds, and adults, respectively.

***RTs*****:** Mean correct RTs as a function of display size, age, and condition are shown in Figure 2, and search slope statistics in Table 1. The presence of a preview benefit was assessed by comparing search slopes in the preview condition with those from the two baseline conditions, FEB and HEB (Watson & Humphreys, 1997, 1998). Search slopes for the HEB were calculated using twice the true display size, to generate values that would be obtained if all previewed items (i.e., half the display) were ignored in the preview condition (cf. Watson & Humphreys, 1997). Thus, if a preview search slope was the same as an HEB slope, this indicated that old items *could be fully* ignored. In contrast, if preview search slopes matched FEB slopes, this indicated that preview items *could not be* ignored. If the preview slope differed from both the FEB and PRE, this would indicate a partial preview benefit (Blagrove & Watson, 2010).

Search slopes for each condition were calculated and analyzed based on mean RT regressed against display size for each participant. A 3(Condition: FEB, HEB, Preview) × 4 (Age: 6,8,12, adults) mixed ANOVA indicated a main effect of condition, $F(2,184) = 90.85$, $p < .001$, $\eta_p^2 = .50$, and age, $F(3,92) = 21.10$, $p < .001$, $\eta_p^2 = .41$. Pairwise comparisons with Bonferroni adjustment indicated that search performance differed across all age groups (*ps* < .05), except between 12-year-olds and adults ($p = 1$). Bonferroni-corrected comparisons suggested that search was faster in HEB than in preview and FEB conditions, and that search was faster in preview than FEB (*p*s < .001). The Condition × Age interaction was also significant, $F(6,184) = 10.79$, $p < .001$, $\eta_p^2 = .26$[2]. A Bayesian ANOVA found best support for the model including the interaction term, $BF_{10} = 8.997\ e^{+34}$, $BF_{incl} = 2.450\ e^{+8}$. To investigate the interaction, we used further frequentist t-tests or Wilcoxon signed-rank tests, supported by Bayesian analyses, to compare each of the conditions with the FEB for each age group individually.

For 6-year-olds, paired *t*-tests suggested no difference between FEB and preview, $t(23) = 1.12$, $p = .281$, with anecdotal evidence in favour of the null ($BF_{01} = 2.70$), while search in HEB ($M = 6.14$, $SD = 27.02$) was faster than in preview ($M = 70.69$, $SD = 50.97$), $t(23) = 1.11$, $p < .001$, Cohen's $d = 1.53$, with strong evidence in favor of the alternative, $BF_{10} = 28184.43$.
In 8-year-olds, Wilcoxon signed-rank tests suggested that FEB search ($M = 59.25$, $SD = 44.42$) was slower than preview ($M = 38.64$, $SD = 23.67$), $W = 245$, $p < .01$, $r_{rb} = .63$, with substantial

[2] A mixed repeated Condition × Age ANOVA with EF measures, Control, Inhibition, Switching, Both efficiency, and Digit and Block recall as covariates also revealed a Condition × Age interaction, $F(6,166) = 3.80$, $p < .005$, $\eta_p^2 = .121$, and a main effect of age, $F(3,83) = 3.02$, $p < .05$, $\eta_p^2 = .098$. The interaction between Condition × Both efficiency covariate was also significant, $F(2,166) = 4.60$, $p < .05$, $\eta_p^2 = .121$. The main effect of condition was not significant, $F(2,166) = 2.52$, $p = .084$, nor were the other covariates and their interactions, all *F*s < 1.93, *p*s > .15. This indicates that age-related changes in search efficiency of the three conditions are not explained by the development of EFs alone.

support for the alternative, $BF_{10}$ =3.01, and paired *t*-tests indicated that preview search was slower than HEB (*M*=6.93, *SD* =11.46), $t(23) = -5.54$, $p < .001$, Cohen's $d= -1.13$, with strong support for the alternative, $BF_{10}$ = 1774.64. In 12-year-olds, paired *t*-tests indicated that FEB (*M*=34.32, *SD*=12.42) was slower than preview (*M*= 16.68, *SD*= 10.22), $t(23)=8.43$, $p <.001$, Cohen's $d = 1.72$, with strong evidence for the alternative, $BF_{10}$ = 765834.41 and Wilcoxon signed-rank tests suggested that preview search was slower than HEB (*M*=5.78, *SD*= 6.90), *W*=25, $p < .001$, $r_{rb} =-.833$, with strong evidence for the alternative, $BF_{10}$ = 64.78. In adults, paired *t*-tests suggested that search in FEB (*M*= 20.99, *SD*=7.67), was slower than preview (*M*=11.70, *SD* = 6.69), $t(23)= 5.5$, $p < .001$, Cohen's $d =1.12$ with strong evidence for the alternative, $BF_{10}$ =1640.72 and that preview search was slower than HEB (*M* = 3.82, *SD* = 4.57), $t(23)= -7.09$, $p < .001$, Cohen's $d = -1.45$, with strong evidence for the alternative, $BF_{10}$ = 51685.16.

***Error rates:*** Overall error rates (Table 2) were low and decreased across age-groups: 7.81%, 4.24%, 1.74%, 1.00% for 6, 8, 12-year-olds, and adults, respectively. A 3(Condition: FEB, HEB, Preview) × 3 (Display size: 4, 8, or 16 items) × Age (6, 8, 12-year-olds, adults) mixed ANOVA revealed significant main effects of condition, $F(2,184) = 4.26$, $p < .05$, $\eta_p^2 = .04$, and age, $F(3,92) = 13.75$, $p < .001$, $\eta_p^2 = .31$, while the effect of display size was not significant, $F(2,184) = 1.34$, $p = .265$. Bonferroni-corrected pairwise comparisons indicated age-related differences in error rates between 6-year-olds and older age groups (all *ps* < .05), and 8-year-olds and adults ($p <.05$). There was no Condition × Age, $F(6,184) = 1.22$, $p = .299$, $\eta_p^2 = .04$, Condition × Display Size, $F(4,368) = 1.30$, $p = .269$, $\eta_p^2 = .014$, Age × Display Size, $F(6,184) = 1.76$, $p = .11$, $\eta_p^2 = .05$, interactions. The Age × Condition × Display Size interaction was also non-significant, $F < 1$.

**Individual differences in preview search efficiency and EF**

To compare differences in strength of the preview benefit across age groups, we computed a measure independent of overall baseline search slope values – the preview efficiency (PE) index (Zupan et al., 2018; Blagrove & Watson, 2010). This was calculated as the difference between the average FEB slope and preview slope search conditions, divided by the difference between the FEB and HEB for each participant. A PE index value of 1 indicates a full preview benefit, while a PE index of 0 indicates an absence of a preview benefit; values are constrained to fall between 0 and 1.

$$PE = \frac{FEB\ slope - PREVIEW\ slope}{FEB\ slope - HEB\ slope} \qquad (1)$$

A between-subjects ANOVA revealed no differences in PE indices between age groups, $F$ (3, 92) = 1.76, $p$ = .160, with anecdotal evidence for the null, $BF_{01}$ =2.27. An inspection of indices revealed that nine out of 24 6-year-olds had a PE of 0, suggesting no preview benefit for moving stimuli. There were also five 8-year-olds, one 12-year-old, and four adults who did not show any preview benefit.

Next, we examined whether the development of EF contributes to individual differences in PE (Zupan et al., 2018). Four 6-year-olds did not complete a full set of EF measures. Table 3 shows the means and SDs of EF measures across age groups. Separate PE indices were computed for large and small display sizes for each age group as an exploratory analysis. This decision was based on a deviation from linearity of the preview search slope in 6-year-olds in Figure 1, and past research which suggested preview mechanisms for small and large display sizes may differ (e.g., Al-Aidroos et al., 2012; Zupan & Watson, 2019). Preliminary rank order, bivariate, and partial correlations between measures of chronological age, PEs, and EF (switching, inhibition, and 'both') efficiency are presented in Table 4. The results indicated that the overall PE index, in addition to PE indices for small display sizes had no significant relations with any EF measure, while PE indices for large display sizes were correlated to efficiency in the ‘Both’ condition. However, when age and control conditions were considered, this relation was no longer significant, but a relation between switching and PE for small display sizes emerged.

We further examined correlations between PE indices for large and small display sizes, EFs in each age group, while controlling for the ‘Control’ condition (i.e., baseline naming speed). The results (Table 5) indicate that PE indices for small display sizes were correlated with EF inhibition in 6-year-old children, while for adults, PE at large display sizes was correlated to performance in the ‘Both’ condition. No other correlations proved significant. There was also no correlation between PE indices for small and large display sizes in any of the analyses performed.

**Discussion**

The results of Experiment 1 revealed that 6 did not show a preview benefit with moving objects; in fact, nine (38%) 6-year-olds failed to show any preview benefit. In contrast, all older age groups were able to ignore moving distractors. Analysis of relations between EF and PE indices for small and large display sizes revealed moderate involvement of each EF ability in different instances when baseline naming speed was controlled. This included: (a) relations between PE indices at small display sizes and switching when age was also controlled, (b) relations between PE indices at small display sizes and inhibition in 6-year-olds, and (c) relations between PE indices at large display sizes, and the ‘Both’ condition (switching and inhibition combined) in the adult sample. PE indices for small and large display sizes were not correlated in any instance, suggesting that different mechanisms may underlie the preview benefit, dependent on display size (e.g., Al-Aidroos et al., 2012; Zupan & Watson, 2019). In Experiment 2, we consider whether feature-based inhibition can be maintained (the preview benefit Stage 2 maintenance process) over longer preview durations and present a partial replication of Experiment 1.

## Experiment 2: Time-Course of Time-Based Visual Selection with Moving Objects

The aim of Experiment 2 was to assess whether a preview benefit occurs over extended temporal durations for the age groups described above and provide a partial replication of Experiment 1 ( preview vs FEB conditions). Since the main aim of Experiment 2 was to test for the existence of a preview benefit relative to a FEB condition, a HEB condition was not included. This allowed us to keep the duration of the testing sessions similar to those of Experiment 1. Given that preview conditions comprise a longer two-step display (and that this would be extended in a second preview duration condition), adding a fourth condition (HEB) could have increased the likelihood of fatigue and compromised performance in younger participants. While a comparison between a preview and HEB can tell us if preview search is as efficient as if the old items had not been presented, a preview versus FEB comparison is sufficient to tell us if a preview benefit has occurred. Depending on the stimuli, preview search can be as efficient as if only new items were searched (e.g., Watson & Humphreys, 1997, 1998) or efficiency may fall between FEB and HEB baselines (Blagrove & Watson, 2010; Zupan & Watson, 2019).  Hence, the inclusion of an HEB condition depends on the research question(s) being examined. Accordingly, here we used a FEB, a 1000ms, and 2000ms duration preview condition.

### Method

**Participants**. Participants were 24 6-year-olds (13 male, age 5-6, *M* = 5 years, 9 months, *SD* = 3.68 months), 24 8-year-olds (11 male; age 5-6, *M* = 7 years, 8 months, *SD* = 3.59 months), 24

12-year-olds (10 male; age *M* = 12 years, 3 months, *SD* = 3.4 months), and 24 adults (10 male; 18 to 25 years, *M* = 20 years, 8 months, *SD* = 31.78 months). Children were newly recruited for this experiment from schools in Warwickshire, Oxfordshire, and West Midlands, via an opt-out procedure granted with the Head Teacher's agreement. Adults were also newly recruited and did not participate in any previous preview search experiments. All recruitment procedures were the same as in Experiment 1.

**Apparatus, Stimuli, and Procedure.** The apparatus and stimuli were the same as in Experiment 1, except that the HEB condition was replaced by an additional preview condition with a duration of 2000ms. The design and procedure were similar to those of Experiment 1, except that no EF measures were taken, thus all participants were tested in a single session.

## Results

Outlier RTs shorter than 200ms or longer than 10s were excluded from the analysis. This resulted in 3.78%, 1.19%, 0.28%, and 0% of data being removed for 6-year-olds, 8-year-olds, 12-year-olds, and adults, respectively. In addition, one 12-year-old completed one block of trials for each search task (i.e., rather than two), and so their results were based on average RTs and error rates from a single block for each condition.

**Time-course of time-based visual selection.**

Search slope statistics for Experiment 2 are presented in Table 6 and Figure 3 shows the mean correct RTs as a function of display size, condition, and age for Experiment 2.

Search slopes were analyzed using a 3(Condition: FEB, $PRE_{1000}$, $PRE_{2000}$) × Age (6, 8, 12, adults) mixed ANOVA. There was a main effect of condition, $F(2,184) = 7.50$, $p < .001$, $\eta_p^2 = .08$, and age, $F(3,92) = 31.24$, $p < .001$, $\eta_p^2 = .51$. Bonferroni-corrected pairwise comparisons indicated that all age groups differed in search performance ($p < .05$), except for 12-year-olds and adults ($p$ = 1). Search was slower in FEB in comparison to $PRE_{1000}$ ($p < .001$), but FEB did not differ from $PRE_{2000}$ ($p$ = .237). In addition, the two preview conditions did not differ ($p$ = .199), nor was there a Condition × Age interaction, $F < 1$. A Bayesian repeated-measures ANOVA found the best support for a model including condition and age, with strong evidence for the alternative, $BF_{10} = 4.501e^{+12}$, and no support for the interaction $BF_{incl}$ = .215. However, of note is that determining Bayes factors for repeated measures ANOVAs is somewhat an unresolved topic of research and is not that reliable (Wagenmakers et al., 2018). In addition, the presence of a preview benefit can be determined by comparing performance in a preview condition with an associated FEB (here a within-subjects comparison with each age group). Accordingly, we used further frequentist, supported by Bayesian analyses, to compare each of the two preview conditions with the FEB for each age group individually.

For 6-year-olds, paired $t$-tests suggested no difference between FEB and $PRE_{1000}$, $t(23)$ = 1.81, $p$ = .084, with anecdotal evidence in favour of the null, $BF_{01}$ =1.15. A Wilcoxon signed-rank test indicated no reliable difference between the FEB and $PRE_{2000}$, $W$ = 206, $p$ = .114. with substantial support for the null $BF_{01}$ = 3.45, indicating an absence of any preview benefit. In 8-year-olds, Wilcoxon signed-rank tests suggested that FEB search ($M$ = 45.72, $SD$ =18.56) was slower than $PRE_{1000}$ ($M$=27.37, $SD$ =27.74), $W$ = 257, $p < .005$, $r_{rb}$ = .71, with substantial support for the alternative, $BF_{10}$ = 3.71, but not different than $PRE_{2000}$, ($M$=44.69, $SD$ =42.16), $W$=213, $p$=.074, with substantial support for the null, $BF_{01}$ = 4.64. In 12-year-olds, paired $t$-tests indicated that FEB ($M$=27.95, $SD$=10.97) was slower than $PRE_{1000}$ ($M$= 20.99, $SD$= 11.31), $t(23)$=3.193, $p < .01$, Cohen's $d$ = .65, with strong evidence for the alternative, $BF_{10}$ = 10.45 and Wilcoxon signed-rank tests suggested that it was also slower than $PRE_{2000}$ ($M$=20.39, $SD$= 20.05), $W$=245, $p < .01$, $r_{rb}$ =.63, with anecdotal evidence for the alternative, $BF_{10}$ = 1.65. In adults, Wilcoxon signed-rank tests suggested that search in FEB (*M*= 21.4, *SD*=10.01), was slower than $PRE_{1000}$ (*M*=12.02, *SD* = 6.92), *W*=268, $p < .005$, $r_{rb} = .92$, with strong evidence for the alternative, $BF_{10} = 435.87$, and paired *t*-tests indicated tthat FEB is slower than $PRE_{2000}$ (*M* = 12.80, *SD* = 7.35), $t(23)= 4.17$, $p < .005$, Cohen's $d = .85$, with strong evidence for the alternative, $BF_{10} = 84.24$.

**Error rates.**

Errors were low overall and decreased as a function of age (Table 7), with 8.08%, 3.34%, 1.17%, and 0.04% errors for 6-year-olds, 8-year-olds, 12-year-olds, and adults, respectively. A 3(Condition: FEB, $PRE_{1000}$, $PRE_{2000}$) × 3 (4, 8, or 16 items) mixed ANOVA, revealed main effects of condition, $F(2,184) = 4.26$, $p < .05$, $\eta_p^2 = .04$, display size, $F(2,184) = 3.91$, $p < .05$, $\eta_p^2 = .04$, and age, $F(3,92) = 43.58$, $p < .001$, $\eta_p^2 = .59$. Fewer errors were made in the $PRE_{1000}$ condition in comparison to FEB and $PRE_{2000}$, $p < .05$, and at 16-item in comparison to 8-item displays, $p < .05$. Six-year-olds made more errors in comparison to all older age groups, $p < .001$, although no interactions proved significant, all *F*s < 1.3, all *p*s > .27.

**Replication.**

***RTs.*** Search slope statistics for a comparison of Experiment 1 and 2 are presented in Table 8. Figure 4 shows the mean correct RTs as a function of display size, condition, and age for a comparison of Experiments 1 and 2. To confirm whether the findings of Experiment 1 replicated, we conducted a 2 (Experiment) × 4 (Age) × 2 (Condition: FEB, Preview 1000) mixed ANOVA, with age and experiment as between-subject factors. This revealed a main effect of condition, $F(1,184) = 38.77$, $p < .001$, $\eta_p^2 = .174$, and age, $F(3,184) = 52.37$, $p < .001$, $\eta_p^2 = .461$. Importantly, there was no main effect or interaction that involved the experiment factor, *Fs* < 2.82, *p*s > .094. Bonferroni-corrected pairwise comparisons revealed that search was faster in the preview condition than in FEB, $p < .001$. With regards to age, the search was more efficient with age, *p*s < .001, except between 12-year-olds and adults, $p = .078$. There were also no interactions of Condition × Age, $F < 1$. A repeated-measures Bayesian ANOVA revealed that the best model was one with Condition and Age as main factors, $BF_{10} = 2.353e^{+27}$, with no support for the interaction, $BF_{incl} = 0.199$. However, as noted earlier, to supplement these results and given the uncertainties around repeated measures Bayesian ANOVAs, we compared the baseline FEB condition with preview in all age groups separately using frequentist *t*-tests or Wilcoxon signed-rank tests and Bayesian *t*-tests. The results revealed no preview benefit in 6-year-olds, $t(47) = 1.67$, $p = .055$, with anecdotal evidence in favor of the null, $B_{01} = 1.09$. A preview benefit was observed in 8-year-olds, $W = -4.10$, $p < .001$, $r_{rb} = .54$, with strong evidence for the alternative, $B_{10} = 49.02$, in 12-year-olds, $t(47) = 7.30$, $p < .001$, *Cohen's d* = 1.05, with strong evidence for the alternative, $B_{10} = 4.090e^{+6}$, and adults, $W = 5.58$, $p < .001$, $r_{rb} = 5.691e^{+6}$, with strong evidence for the alternative, $B_{10} = 5.691e^{+6}$ .

***Errors.***

Overall errors were low and decreased as a function of age (Table 9). There were 7.78%, 3.98%, 1.81%, and 0.09% of errors for 6-year-olds, 8-year-olds, 12-year-olds, and adults, respectively. A 2(Condition: FEB, $PRE_{1000}$) × 3 (4, 8, or 16 items) mixed ANOVA with age and experiment as between-subject variables showed a significant main effect of condition, $F(1,184) = 11.47$, $p < .005$, $\eta_p^2 = .06$, with Bonferroni – corrected post-hoc tests suggesting that more errors were made in the FEB condition, $p < .001$. There was a main effect of display size, $F(2,368) = 3.18$, $p = < .05$, $\eta_p^2 = .017$, but Bonferroni-corrected post-hoc tests did not suggest any significant differences, *p*s > .102. There was also a main effect of age, $F(3,184) = 26.25$, $p < .005$, $\eta_p^2 = .3$. Here, Bonferroni-corrected post-hoc tests suggested that 6-year-olds made more errors in comparison to all older age groups, all *p*s < .001, and that 8-year-olds made more errors than adults, $p < .005$. However, there was no main effect of Experiment, $F < 1$, and no interaction proved significant, all *F*s < 3, all *p*s > .05.

**Discussion**

Preview duration manipulations in Experiment 2, as well as the comparative analysis of Experiments 1 and 2, provided three key findings.  First, 6-year-olds predominantly did not show a preview benefit for moving objects at any duration, whereas 8-year-old children could ignore moving objects, but only for shorter durations, with the preview benefit abolished at extended (2000ms) durations. Finally, 12-year-olds and adults could ignore old moving objects at both preview durations. Overall, these results suggest that the ability to ignore old moving objects seems to develop for shorter durations from about 8 years of age and that children's ability to sustain this over longer durations continues to develop until 12 years of age.

## General Discussion

We examined the developmental trajectories of time-based visual selection for objects in motion. Experiment 1 suggested that the preview benefit did not occur in 6-year-olds but was fully present in the older age groups. This result was confirmed in a larger sample, with Experiments 1 and 2 combined. Individual differences in preview search efficiency also revealed moderate relations to EFs in 6-year-olds and adults. Finally, Experiment 2 revealed that the preview benefit was not obtained with an extended 2000ms preview duration for 6 and 8 -year-old children, suggesting the ability to maintain an inhibitory template for previewed moving items is not fully developed until 12 years of age.

**Developmental Trajectory of Time-based Visual Selection for Moving Objects**

We found that a preview benefit for moving objects at shorter 1000 ms durations emerged at approximately 8 years of age and that full development including the maintenance component, is only developed around 12 years of age. This suggests that time-based visual selection with moving objects, using feature-based inhibition emerges later than location-based inhibition with stationary objects, which is initially observed at the age of 6 and consolidates at the age of 8 (Zupan et al., 2018). The results of the current study are consistent with findings observed for stationary objects (Zupan et al., 2018), that the development of time-based visual selection occurs in stages. As visual marking consists of two stages, setting up and maintaining inhibition (Humphreys et al., 2002), the ‘setting up’ component appears to develop first, while the maintenance component follows. Such developmental trajectory confirms top-down accounts of this ability (Watson & Humphreys, 1997) as purely bottom-up accounts predict that the preview duration should have no effect. It also supports previous interpretations that ignoring moving objects via feature-based inhibition, is in general, more resource-demanding (Watson & Humphreys, 1998; Watson & Maylor, 2002).

**Individual Differences in Preview Efficiency for Objects in Motion**

Inspection of individual differences in PE for moving objects revealed nine 6-year-old children in Experiment 1 who did not demonstrate the preview benefit at all. This is somewhat consistent with observations of time-based visual selection for stationary objects (25%; Zupan et al., 2018). However, in the current study, some individuals in all age groups (including four adults), also did not exhibit a preview benefit for moving objects. This suggests that the absence of preview a benefit for objects in motion may also be a result of individual differences in the expression of this ability, not only its development. In other words, some individuals may *never* fully develop this ability.

**Time-based Visual Selection for Objects in Motion and EFs**

Several relations emerged between time-based visual selection and EFs, including a small correlation between switching and PE at small display sizes irrespective of age, moderate correlations between inhibition and PE for small display sizes in 6-year-olds, and inhibition and switching combined and PE for large display sizes in adults. From the current results, we can conclude that there is some association between PE for moving stimuli and EFs on a general level, which may include inhibitory functions. While the observed relationships are consistent with top-down accounts of time-based visual selection (i.e., *visual marking*; Watson & Humphreys, 1997), more research will be needed to fully confirm the role of EF in the development of this ability

An important distinction is that the associations observed here were broken down into PE for a small and large number of items. Previously, only overall PE was included in the analysis performed (Zupan et al., 2018), however, past research indicates that different mechanisms may underlie preview search at small vs large display sizes. This includes the role of visual working memory at small display sizes (e.g., Al-Aidroos et al., 2012), as well as preview benefit occurring only at small display sizes with perceptually complex stimuli such as illusory conjunctions (Zupan & Watson, 2019). The current study adds converging evidence from a developmental perspective suggesting that different mechanisms may be involved in preview search depending on the number of items involved. However, the precise nature of these different underlying mechanisms would need to be further established.

One possibility is that, in adulthood, the strength of the preview benefit is enhanced via the use of multiple EFs. Tentatively, this could suggest a shift from simple inhibition used to ignore a small number of moving items at the age of 6, towards coordinated use of multiple EFs (i.e., switching and inhibition) to ignoring a large number of moving items in adulthood. No associations were observed between short-term memory and the preview benefit. While it was found previously that visual working memory supports the preview benefit at small display sizes this contribution was deemed to be in addition to the inhibitory mechanism (Al-Aidroos et al., 2012) and perhaps does not play a strong role in preview search and its development in general.

Although the current study may indicate these directions, there is insufficient evidence for firm conclusions. However, the ‘stage is set’ for further investigation of the role and deployment of different EFs in preview search across development. A further consideration is that absence of association between PE and any EFs for 8- and 12-year-olds may be due to insufficient power to capture small effects. Future studies, powered specifically to examine individual differences in EFs and preview search for moving objects, may be able to confirm any developmental changes in underlying mechanisms.

## Strengths and Limitations

This study contributes to research examining the development of selective attention in temporal contexts for objects in motion, which to date, has been underexplored in childhood. A further strength of the study is the use of robust experimental procedures (i.e., Watson & Humphreys, 1997) to determine the presence of this ability, alongside an examination of individual differences. Since previous studies have determined inhibition as a mechanism behind time-based visual selection experimentally (e.g., Watson & Humphreys, 1997, 1998, 2000), we also show, for the first time in time-based visual selection research, relations between this attentional ability and inhibition measured as an EF.

However, a limitation is that sample sizes were powered for the main experimental procedures and detecting medium effects for the correlational analysis regarding relations with

EFs and short-term memory across age and thus preclude firmer conclusions. Further, given the apparent individual differences in the ability to ignore moving items, a longitudinal design could elucidate whether the more frequent absence of a preview benefit in 6-year-olds is due to variability in expression of this ability that may carry over into adulthood, rather than its developmental trajectory per se.

## Conclusion

The current study contributes to the literature on attentional development by showing that the feature-based mechanism for inhibiting previewed distractors in dynamic visual environments, develops around 8 years of age and is consolidated by 12 years. As such, it has a protracted developmental trajectory in comparison to time-based visual selection with stationary objects. We also highlight substantial individual differences in the presence of this ability across all age groups.  Moderate relations between preview efficiency and EFs, namely inhibition in 6-year-olds and adults are consistent top-down origins of time-based visual selection, albeit more research is needed to fully confirm their role in the development of this ability.

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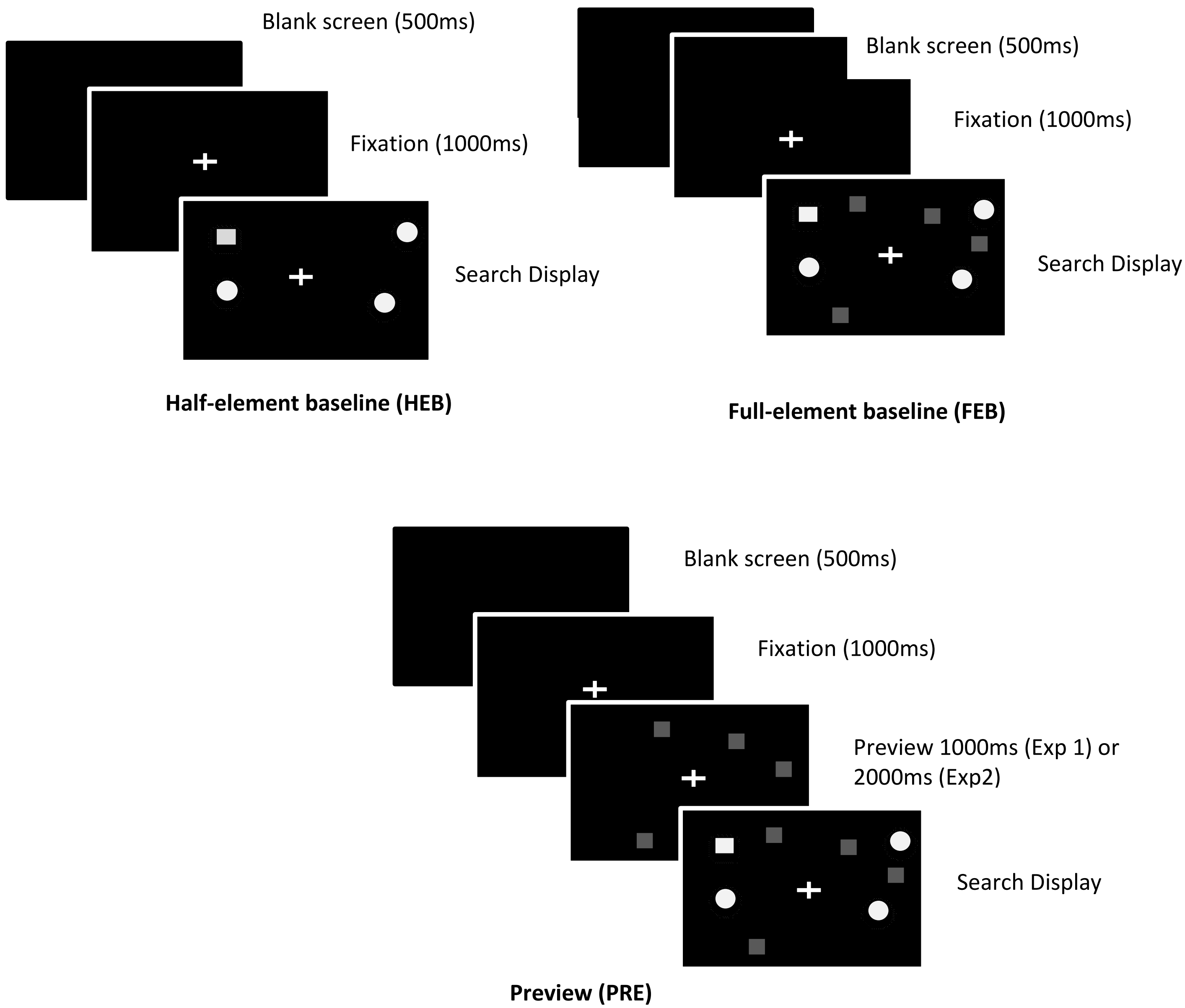


*Figure 1.* Schematic of a Half-element baseline (HEB), Full-element baseline (FEB), and Preview search. All stimuli were continuously moving down the screen gradually disappearing and then gradually reappearing at the top at the same horizontal location.

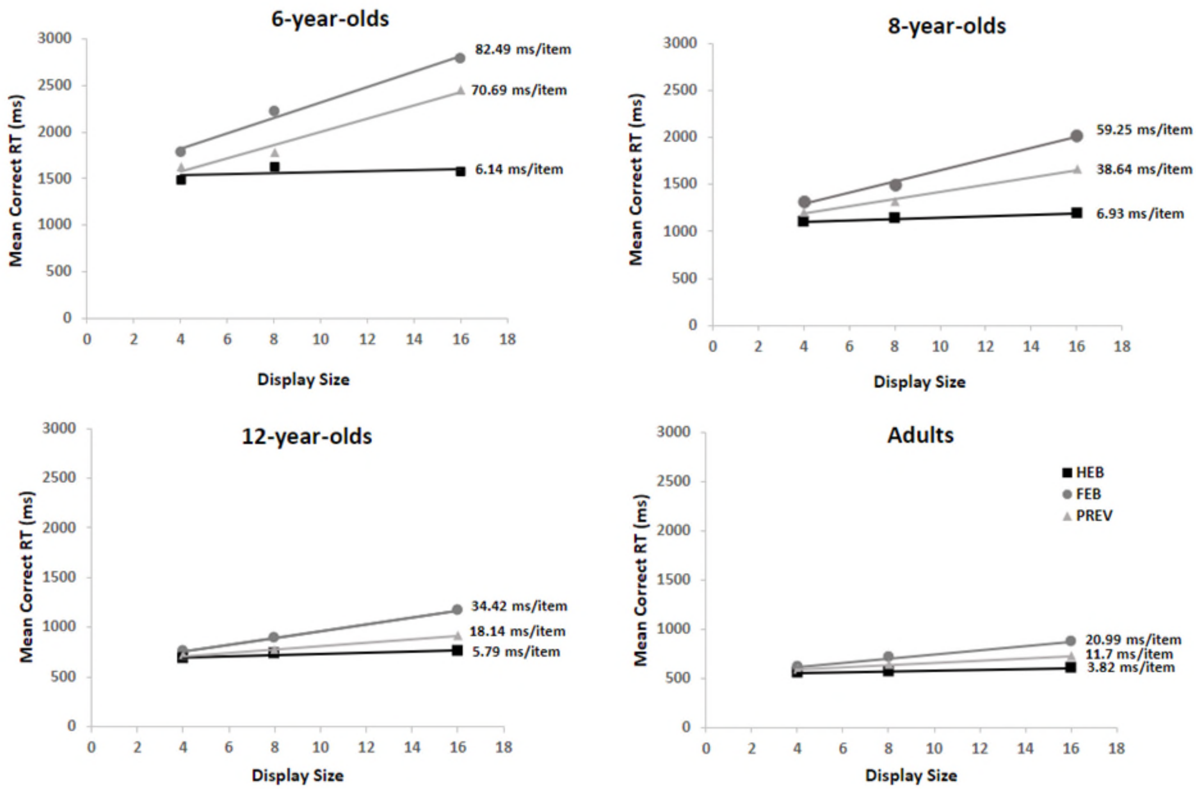


*Figure 2.* Mean correct reaction times (RTs) as a function of condition – full element baseline (FEB), half-element baseline (HEB, preview search (PRE), display size, and age for Experiment 1. Search slope values are reported next to the slopes.

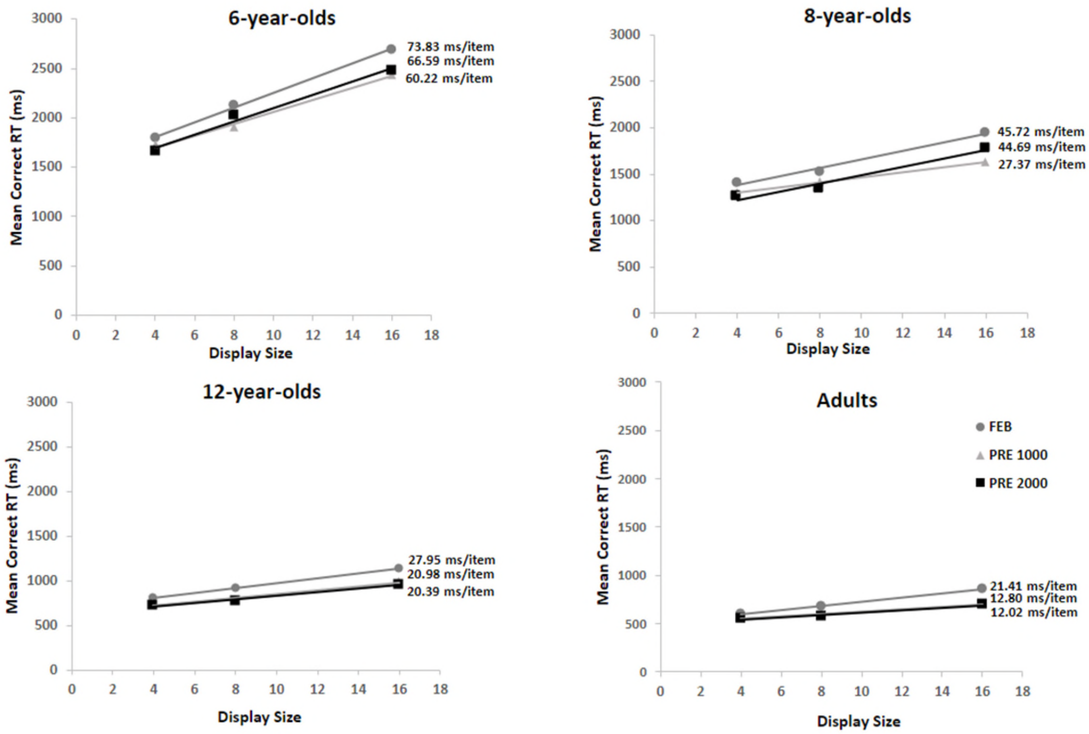


*Figure 3.* Mean correct reaction times (RTs) as a function of condition – full element baseline (FEB), half-element baseline (HEB), preview search (PRE), display size, and age for Experiment 2. Search slope values are reported next to the slopes.

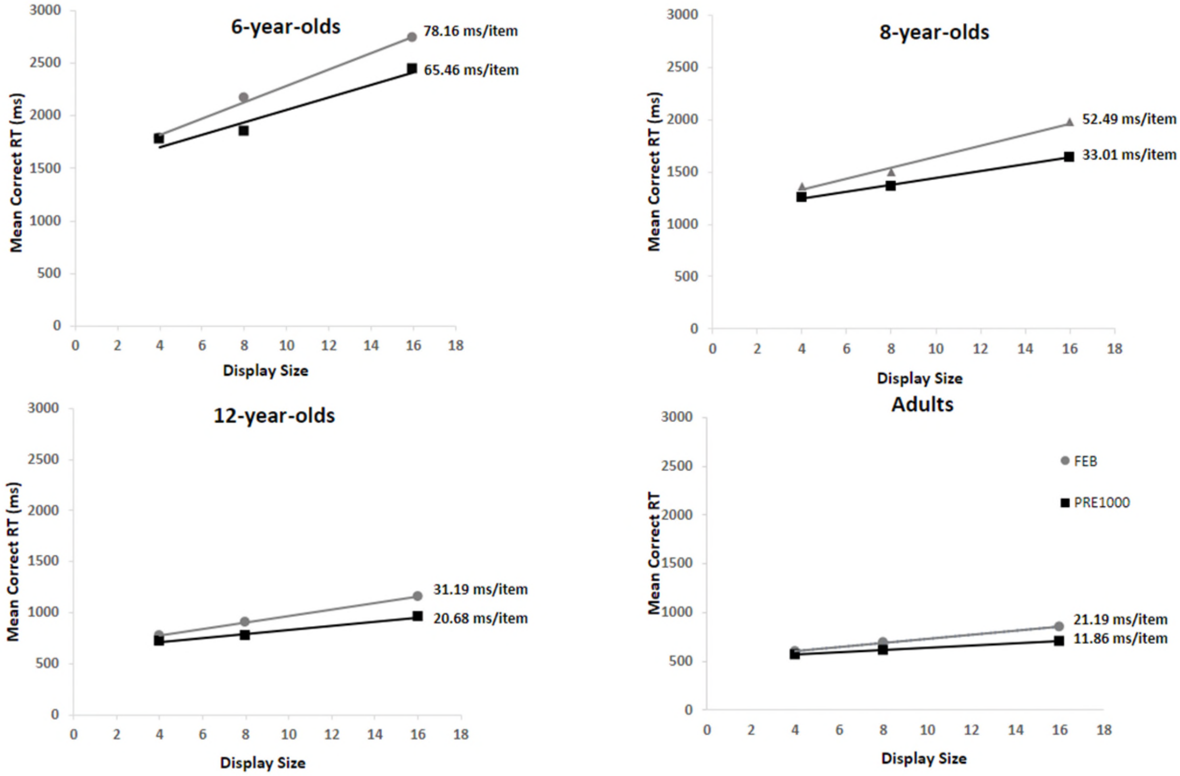


*Figure 4.* Mean correct reaction times (RTs) as a function of condition, display size, and age for 1000 ms preview Search (PRE1000) and Full-element baseline (FEB) from Experiments 1 and 2. Search slope values are reported next to the slopes.

Table 1. *Search slope statistics for Experiment 1*

| Group and descriptive characteristic | HEB | FEB | Preview |
|---|---|---|---|
| 6-year-olds | | | |
| Slope (ms/item) | 6.14 | 82.49 | 70.69 |
| Intercept | 1506.20 | 1493.3 | 1297.6 |
| $R^2$ | .28 | .99 | .98 |
| 8-year-olds | | | |
| Slope (ms/item) | 6.93 | 59.25 | 38.64 |
| Intercept | 1076.7 | 1052.9 | 1030.1 |
| $R^2$ | .98 | .99 | .99 |
| 12-year-olds | | | |
| Slope (ms/item) | 5.79 | 34.42 | 18.14 |
| Intercept | 670.30 | 617.49 | 636.75 |
| $R^2$ | .83 | .99 | .99 |
| Adults | | | |

| | | | |
|---|---|---|---|
| Slope (ms/item) | 3.82 | 20.99 | 11.70 |
| Intercept | 542.4 | 536.91 | 544.71 |
| $R^2$ | .99 | .99 | .99 |

Table 2. *Mean percentage error rates for Experiment 1*

| | Display size | | |
|---|---|---|---|
| Group and Condition | 4 | 8 | 16 |
| 6-year-olds | | | |
| HEB | 6.94 | 8.68 | 7.81 |
| FEB | 7.29 | 7.47 | 8.51 |
| Preview | 5.38 | 9.72 | 8.51 |
| 8-year-olds | | | |
| HEB | 4.17 | 2.43 | 3.65 |
| FEB | 5.90 | 5.21 | 6.25 |
| Preview | 3.65 | 3.82 | 3.13 |
| 12-year-olds | | | |
| HEB | 1.22 | 1.04 | 1.39 |
| FEB | 2.08 | 2.60 | 2.95 |
| Preview | 1.74 | 1.22 | 1.04 |
| Adults | | | |
| HEB | .69 | 1.39 | .17 |
| FEB | .69 | 1.22 | 1.91 |
| Preview | .69 | 1.04 | 1.22 |

Table 3. *Means and SDs (reported in parenthesis) for EF tasks for 6-, 8-, 12-year-olds, and adults for Experiment 1.*

| Age group | Control | Inhibition | Switching | Both | Digit recall | Block recall |
|---|---|---|---|---|---|---|
| 6-year-olds | .94 (.25) | .96 (.21) | .37 (.14) | .41 (.16) | 25.75 (3.47) | 19.92 (3.16) |
| 8-year-olds | 1.27 (.31) | 1.19 (.31) | .54 (.16) | .56 (.19) | 27.04 (4.95) | 21.63 (2.63) |
| 12-year-olds | 1.81 (.31) | 1.96 (.28) | .78 (.15) | .79 (.21) | 32.08 (5.89) | 26.79 (4.85) |
| Adults | 2.43 (.43) | 2.47 (.66) | .97 (.21) | 1.12 (.25) | 36.42 (6.52) | 30.58 (5.36) |

Table 4. *Relations between chronological age, EF measures (Control, Inhibition, Switching, Both), Digit recall and Block recall, and preview efficiency (PE) in Experiment 1. Values above the diagonal indicate bivariate correlations (Spearman's for age and Pearson's for the remaining variables) across measures, while values below the diagonal indicate partial correlations controlling for chronological age and baseline naming speed (the 'Control' condition in Shape School extended). Values in brackets indicate $BF_{10}$.*

a Spearman's rank-order correlations are used between age and other measures

$^{*}$ $p < .05$ $^{**}$ $p < .005$ $^{***}$ $p < .001$

| **Age, EFs and PEs** | **Control** | **Inhibition** | **Switching** | **Both** | **Digit recall** | **Block recall** | **PE** | **PE small DS** | **PE large DS** |
|---|---|---|---|---|---|---|---|---|---|
| **Age**[a] | .832$^{***}$ (1.56e$^{+24}$) | .767$^{***}$ (>1000) | .719$^{***}$ (>1000) | .739$^{***}$ (>1000) | .588$^{***}$ (>1000) | .671$^{***}$ (>1000) | .118 (.26) | .079 (.28) | .128 (.29) |
| **Control** | | .877 $^{***}$(1.23e$^{+27}$) | .826$^{***}$ (1.06e$^{+21}$) | .746$^{***}$ (4.62e$^{+14}$) | .569$^{***}$ (4.02e$^{+6}$) | .743$^{***}$ (2.78e$^{+14}$) | .049 (.15) | .063 (.16) | .099 (.20) |
| **Inhibition** | | | .804$^{***}$ (9.26e$^{+18}$) | .835$^{***}$ (1.03e$^{+22}$) | .599$^{***}$ (4.135e$^{+7}$) | .706$^{***}$ (2.08e$^{+12}$) | .109 (.22) | .078 (.17) | .162 (.42) |
| **Switching** | | .220* (1.93) | | .803 (7.95e$^{+18}$) | .433$^{*}$ (1220.45) | .664$^{***}$ (1.64e$^{+10}$) | .039 (.14) | -.075 (.17) | .084 (.18) |
| **Both** | | .516* (>1000) | .411$^{***}$ (596.94) | | .506$^{***}$ (58494.28) | .667$^{***}$ (2.64e$^{+10}$) | .011 (.13) | .007 (.13) | .215$^{*}$ (1.06) |
| **Digit recall** | | .192 (1.17) | -.193 (1.19) | .035 (.25) | | .506$^{***}$ (60299) | -.043 (14) | .157 (.39) | .057 (.15) |
| **Block recall** | | .142 (.56) | .095 (.35) | .221 (2.00) | .122 (.45) | | .100 (.20) | .049 (.15) | .024 (.13) |
| **PE** | | .095 (.35) | -.068 (.29) | -.089 (.48) | -.141 (.56) | .074 (.30) | | .011 (.13) | .281 (1.42) |
| **PE small DS** | | .052 (.27) | -.236* (2.67) | -.061 (.28) | .139 (.69) | -.004 (.24) | .042 (.26) | | -.011 (.13) |
| **PE large DS** | | .138 (.54) | -.028 (.247) | .196 (1.25) | -.024 (.25) | -.087 (.33) | .268* (5.61) | -.067 (.29) | |

Table 5. *Partial correlation coefficients (baseline naming speed controlled) for PE for small display sizes (4-8 items) and measures for EF and PE for large display sizes (8-16 items. Values in brackets indicate* $BF_{10}$.

| Executive functions | **6-year-olds** | | **8-year-olds** | | **12-year-olds** | | **Adults** | |
|---|---|---|---|---|---|---|---|---|
| | **PE 4-8** | **PE 8-16** | **PE 4-8** | **PE 8-16** | **PE 4-8** | **PE 8-16** | **PE 4-8** | **PE 8-16** |
| Inhibition | .615** (12.26) | -.015 (.47) | -.249 (.77) | -.047 (.45) | .268 (.85) | .282 (.91) | .002 (.44) | .230 (.71) |
| Switching | -.115 (.52) | -.094 (.51) | -.239 (.74) | -.304 (1.03) | -.368 (1.58) | .149 (.54) | -.340 (1.30) | .038 (.45) |
| Both | -.035 (.48) | -.147 (.53) | -.029 (.44) | .023 (.44) | -.011 (.44) | .245 (.76) | .232 (.72) | .448* (3.14) |
| Digit recall | .102 (.51) | .027 (.48) | -.030 (.44) | -.189 (.61) | .268 (.84) | -.269 (.85) | .301 (1.01) | .133 (.52) |
| Block recall | .189 (.61) | .082 (.50) | -.290 (.95) | -.271 (.86) | -.005 (.44) | .121 (.50) | .032 (.44) | -.306 (1.04) |

Table 6. *Search slope statistics for Experiment 2*

| Group and descriptive characteristic | FEB | PRE 1000 ms | PRE 2000 ms |
|---|---|---|---|
| 6-year-olds | | | |
| Slope (ms/item) | 73.83 | 60.22 | 66.59 |
| Intercept | 1513.1 | 1458.8 | 1434 |
| $R^2$ | .99 | .99 | .99 |
| 8-year-olds | | | |
| Slope (ms/item) | 45.72 | 27.37 | 44.69 |
| Intercept | 1199.1 | 1196.9 | 1044.2 |
| $R^2$ | .98 | 1 | .97 |
| 12-year-olds | | | |
| Slope (ms/item) | 27.95 | 20.99 | 20.39 |
| Intercept | 692.11 | 643.13 | 624.31 |
| $R^2$ | .99 | .98 | .99 |
| Adults | | | |
| Slope(ms/item) | 21.41 | 12.02 | 12.80 |
| Intercept | 506.84 | 499.87 | 484.74 |
| $R^2$ | .99 | .99 | .98 |

Table 7. *Mean percentage error rates for Experiment 2*

| | Display size | | |
|---|---|---|---|
| Group and Condition | 4 | 8 | 16 |
| 6-year-olds | | | |
| FEB | 8.33 | 7.99 | 9.90 |
| PRE 1000ms | 6.94 | 5.38 | 7.99 |
| PRE 2000ms | 7.47 | 8.51 | 10.24 |
| 8-year-olds | | | |
| FEB | 2.95 | 4.34 | 3.65 |
| PRE 1000ms | 3.47 | 1.91 | 3.47 |
| PRE 2000ms | 3.41 | 3.21 | 2.95 |
| 12-year-olds | | | |
| FEB | 1.74 | 1.74 | 2.60 |
| PRE 1000ms | 1.39 | .87 | 1.74 |
| PRE 2000ms | 1.91 | 1.04 | 2.26 |
| Adults | | | |
| FEB | 1.22 | 1.04 | 1.04 |
| PRE 1000ms | 0.69 | 0.35 | 0.69 |
| PRE 2000ms | 1.04 | 1.04 | 1.56 |

Table 8. *Search slope statistics for comparison of Experiment 1 and 2*

| Group and descriptive characteristic | FEB | Preview 1000ms |
|---|---|---|
| 6-year-olds | | |
| Slope (ms/item) | 78.16 | 65.46 |
| Intercept | 1503.2 | 1378.2 |
| $R^2$ | .99 | .98 |
| 8-year-olds | | |
| Slope (ms/item) | 52.49 | 33.01 |
| Intercept | 1126 | 1113.5 |
| $R^2$ | .99 | .99 |
| 12-year-olds | | |
| Slope (ms/item) | 31.19 | 20.68 |
| Intercept | 654.8 | 624.72 |
| $R^2$ | .99 | .99 |
| Adults | | |
| Slope (ms/item) | 21.19 | 11.86 |
| Intercept | 521.87 | 522.29 |
| $R^2$ | .99 | 1 |

Table 9. *Mean percentage error rates for a comparison Experiment 1 and 2*

| | Display size | | |
|---|---|---|---|
| Group and Condition | 4 | 8 | 16 |
| 6-year-olds | | | |
| FEB | 7.81 | 7.73 | 9.20 |
| PRE 1000ms | 6.16 | 7.55 | 8.25 |
| 8-year-olds | | | |
| FEB | 4.43 | 4.77 | 4.95 |
| PRE 1000ms | 3.55 | 2.87 | 3.29 |
| 12-year-olds | | | |
| FEB | 1.91 | 2.17 | 2.77 |
| PRE 1000ms | 1.56 | 1.04 | 1.39 |
| Adults | | | |
| FEB | .96 | 1.13 | 1.48 |
| PRE 1000ms | .69 | .69 | .96 |