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Developmental Change in the Nature of Attention Allocation in a Dual Task

Nelson Cowan, Angela M. AuBuchon, Amanda L. Gilchrist, Christopher L. Blume, Alexander P. Boone, and J. Scott Saults

Department of Psychological Sciences, University of Missouri

Younger children have more difficulty in sharing attention between two concurrent tasks than do older participants, but in addition to this developmental change, we documented changes in the nature of attention sharing. We studied children 6–8 and 10–14 years old and college students (in all, 104 women and 76 men; 3% Hispanic, 3% Black or African American, 3% Asian, 7% multiracial, and 84% White). On each dual-task trial, the participant received an array of colored squares to be retained for a subsequent probe recognition test and then an easy or more difficult signal requiring a quick response (a speeded task, clicking a key on the same side of the screen as the signal or the opposite side). Finally, each trial ended with the presentation of the array item recognition probe and the participant's response to it. In our youngest age group (6–8 years), array memory was often displaced by the speeded task performed under load, especially when it was the opposite-side task, but speeded-task accuracies were unaffected by the presence of an array memory load. In contrast, in older participants (10–14 years and college students), the memory load was maintained better, with some cost to the speeded task. With maturity, participants were better able to adopt a proactive stance in which not only present processing demands but also upcoming demands were taken into account, allowing them to balance the demands of the two tasks.

Keywords: attention, working memory, dual-task performance, proactive processing, reactive processing

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Ristic and Enns (2015) noted that research on the development of attention has relied on "seven widely used laboratory paradigms of attention" and that although a lot of information has come from these procedures (Rueda, 2013), the wealth of information "was not matched by a similar refinement in theory" (Ristic & Enns, 2015, pp. 24–25). It appears that all agree that the control of attention improves with development, but theoretical details of that improvement remain to be understood. We contribute to the theory of attention development during the elementary school years with evidence supporting a recent suggestion that what develops is proactive control. With development, according to that theory, the control of attention becomes more proactive, taking into account what will be required in the near future, as opposed to reactive, focusing on what is required at present, with less regard for what will be required after that (on the concept, see Braver, 2012; on its childhood development, see Chevalier et al., 2014, 2015; Morey, Hadley, et al., 2018; Morey, Mareva, et al., 2018). To illustrate these terms, if you ask children to recite their phone number and then repeat a novel message, a child using proactive processing is one who tries to retain the novel message in memory while repeating the phone number, whereas a child using reactive processing is one who does not think about the need to repeat the novel message until it may be too late and may have been forgotten. In what follows, we pursue a key question about proactive processing and its childhood development.

Development of Proactive Processing?

Our previous research left open a key question about the development of proactive processing. Cowan et al. (2010) proposed that the control of attention requires sufficient working memory, based on the finding that 7-year-old children could focus attention on more-relevant items in an array to be remembered for later probe-item recognition, at the expense of less-relevant items, and adults also could when the array size was small (two more-relevant and two less-relevant items). However, 7-year-olds' attention control

Nelson Cowan https://orcid.org/0000-0003-3711-4338
Angela M. AuBuchon https://orcid.org/0000-0002-6746-4462
Amanda L. Gilchrist https://orcid.org/0000-0002-7237-2538
J. Scott Saults https://orcid.org/0000-0003-4428-807X

Angela M. AuBuchon is now at Boys Town National Research Hospital, Omaha, Nebraska. Amanda L. Gilchrist is now at the Department of Psychology, Cottey College. Alexander P. Boone is now at School of Psychological Science, Oregon State University.

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Correspondence concerning this article should be addressed to Nelson Cowan, Department of Psychological Sciences, University of Missouri, McAlester Hall, Columbia, MO 65211, United States. Email: cowann@missouri.edu

broke down when they were faced with a larger array size (three more-relevant and three less-relevant items). Thus, participants might become less proactive in their approach to an attention-demanding task as working memory is overloaded. It is possible that this breakdown in a proactive stance could occur at all ages in childhood but with different points of overload given that young children have a smaller working memory capacity (e.g., Cowan et al., 2005, 2010, 2011; Riggs et al., 2011). Alternatively, it is possible that the change from a reactive to a proactive stance is independent of working memory capacity and has more to do with young children's inability to keep in mind and/or react to future demands, regardless of the working memory load.

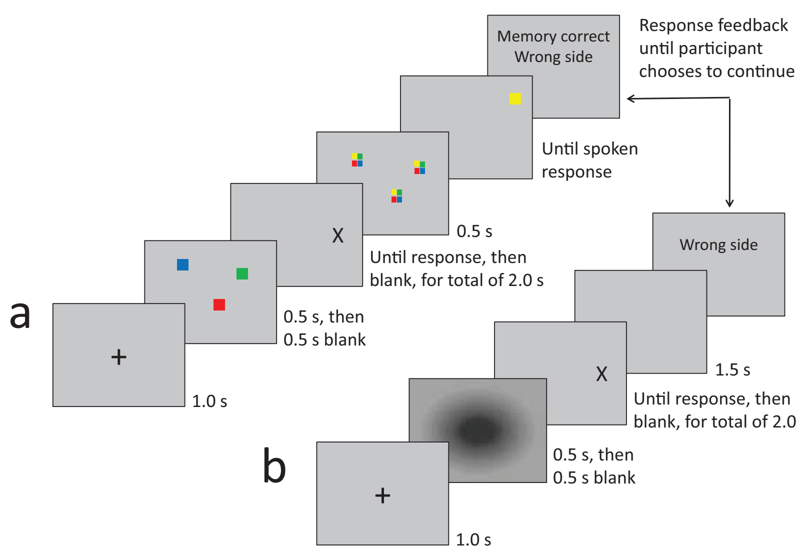
Present Task and Competing Predictions

In the present work, we made the attention control process and its relation to a working memory load explicit by presenting dual-task trials. First, participants encoded a variable number of array items for later recognition of a single-item probe that matched or mismatched the corresponding array item (a version of the change-detection task of Luck & Vogel, 1997; Pashler, 1988). While retaining the array memory load, participants carried out an easy or more difficult speeded task. The easy task was to press a key on the same side as a signal, and the harder task was to press a key on the opposite side (similar to tasks used by Bunting et al., 2008; Friedman & Miyake, 2004). This speeded task was followed by a probe recognition test of working memory for an item from the array. Single-task trials also were carried out for both tasks for comparison with the dual-task trials. The procedure is illustrated in Figure 1.

Proactive Control and Task Accuracy

In the dual-task procedure just described, if the speeded task requires attention that must be shared with maintenance of the array items in working memory, then there should be interference between the two tasks. However, the relative impairment of the two tasks carries information about how the tasks were carried out. (a) Proactively allocating attention toward maintenance of the array should come at a cost to the concurrently executed speeded task (see H_{p1} row in Table 1). The cost should be greater when the array materials absorb more of attention and when the speeded task is the opposite-side task, which requires attention to inhibit and prevent a prepotent, incorrect same-sided response. Impairment in the speeded task can be measured both in terms of the inaccuracy of the response and in terms of the response time for correct responses. (b) In contrast, if the participant does not proactively try to preserve the memory load when faced with the concurrent speeded task (H_{p2} row in Table 1), performance on the speeded task will not be impaired, but the performance on the working memory task will be more severely impaired, compared to a single-task situation. What presumably occurs in that situation is that information that is only passively held in working memory, without any contribution of attention, can be lost during the retention interval and may be recalled less frequently than would be the

Figure 1
Illustration of the Stimulus Presentation Method



Note. (a) A three-item array trial with a right-hand side stimulus. Trial block instructions indicate whether the correct key-press response is same or opposite side. The correct array probe response in the example is "different." For one group of participants, the X side stimulus was replaced by a tone in the left or right earphone. (b) A zero-item array trial; a fuzzy disk appears in place of array items. Side stimulus as in Series (a); no array-related memory or response requirement. For half of the participants, the left- or right-side X was replaced by a tone on the left or right.

Table 1
Hypotheses About Task Processing and Its Development

Type of task preparation and performance	Effect Type 1. Speeded-task performance: Effect of increasing set size of prior array	Effect Type 2. Speeded-task performance: Effect of opposite- (as compared to same-) side speeded task	Effect Type 3. Array change-detection performance: Effects of side task on array change detection	H_{d1}. Proactive or reactive stance that is equivalent in all age groups (if one adjusts for memory capacity)	H_{d2}. Increasingly proactive stance across age groups (regardless of memory capacity)
H_{p1}. Active, attention-demanding, proactive task maintenance and preparation	With increasing set size, lower speeded-task accuracy, slower responses due to more shared attention	Less accurate, slower performance on opposite-compared to same-side task, especially after larger arrays	Relatively mild loss of array memory during speeded task, though worse if opposite-side task	Proactive maintenance ($H_{p1;}$ three effects columns, this row) represented equally across all age groups	Proactive maintenance ($H_{p1;}$ three effects columns, this row) more applicable in older age groups
H_{p2}. Reactive performance on both tasks; no advanced preparation on a task until it is presented	Possible effect of 0 vs. 1 item (task switch); no further effect of array size as attention not used for array maintenance	Less accurate, slower performance on opposite-compared to same-side task; no effect of prior array size	Relatively severe loss of array memory during speeded task, especially opposite side	Reactive maintenance ($H_{p2;}$ three effects columns, this row) represented equally across all age groups	Reactive maintenance ($H_{p2;}$ three effects columns, this row) less applicable in older age groups

Note. There are two processing hypotheses described in the first column, marked H_{p1} and H_{p2}, and two developmental hypotheses described in the first row, marked H_{d1} and H_{d2}. Three kinds of effects are described in the first row, which differ according to the two processing hypotheses with different ramifications for the two developmental hypotheses. H = hypothesis.

case with attention-based maintenance of the information (e.g., Camos & Barrouillet, 2011).

Figure 2 illustrates the hypothetical outcomes of the experiment in terms of estimated items in working memory at the time of test according to the two hypotheses just enumerated, in the additional context of developmental changes in working memory capacity. The top panel depicts an expected outcome if the ability to take a proactive stance remains stable independently of developmental growth in working memory capacity (see H_{d1} column in Table 1). In this case, we would expect the number of items that can be held in working memory to increase with age. Moreover, the need to respond to a secondary task while maintaining those items would lead to decrements across all age groups (left panel). Performance on the secondary speeded task—at least on the difficult version—might also increase with development; it, too, would show a deficit in the situation in which a memory load is being held, compared to no memory load (right panel). This graph shows no interaction between age and the task condition, but that is not a necessary part of the prediction. Perhaps the absence of any interaction, as shown, would be expected if each participant were tested at their span in the array task. However, we varied the number of items in the working memory task, which should allow exploration of this more detailed question.

Alternatively, the bottom row of Figure 2 depicts developmental changes in both working memory capacity and proactive attention control (see H_{d2} column in Table 1). Again, capacity increases with development; however, the effects of the dual task change differentially for the two tasks as proactive attention control comes into play in more mature participants. In this case, the youngest children would maintain items in working memory with active use of attention only up to the point at which a difficult secondary task is presented. At that point, attention would be diverted to the secondary task, and forgetting of the memory load could occur inasmuch as its maintenance during performance of the difficult secondary task (the opposite-side key-press task) is only passive in the youngest children according to this hypothesis, with no devotion of attention to working memory maintenance during that time. As shown in the bottom row of Figure 2, the youngest children would show a pattern in which the effect of the difficult speeded task on memory is severe (left panel), but with no effect of the memory task on performance of the difficult, opposite-side speeded task (right panel). As shown in the figure, the intermediate age group would presumably perform in a manner intermediate between the adult's proactive stance and the young children's reactive stance, showing some proactive preservation of the memory load and some cost to the secondary task, though with results shifted toward memory loss compared to the adults. Importantly, this hypothesis predicts an interaction of task condition (single vs. dual task) with age group and specifies that the interaction should occur in opposite directions across age groups for the two tasks (Figure 2, bottom row). Again, our manipulations of the number of array items to be remembered and of the speeded-task difficulty allow us to explore variations of this second hypothesis.

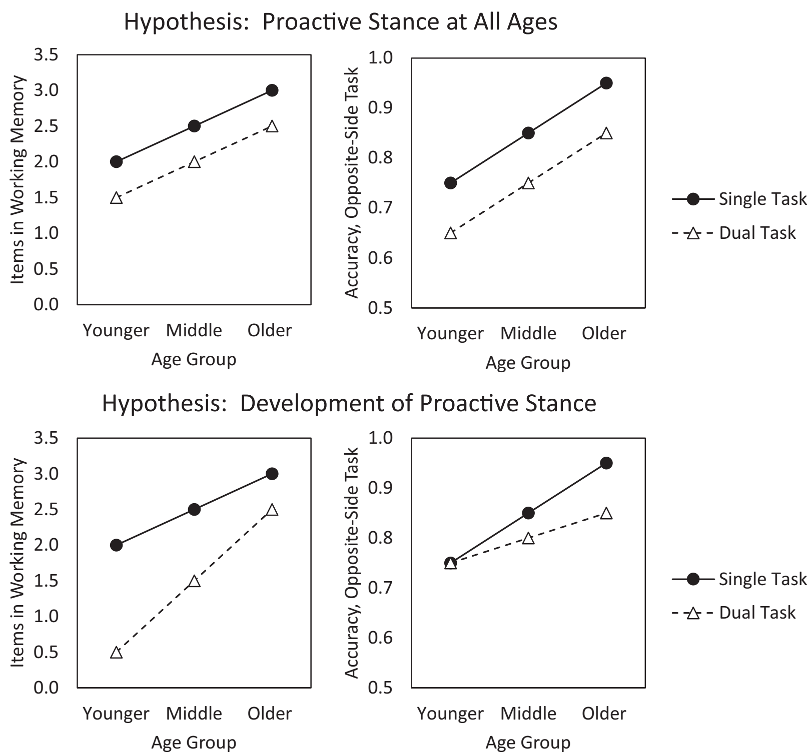
Proactive Control and Speeded-Task Response Time

Comparing Zero Versus One Array Item

Another set of predictions can be made with regard to the response times in the secondary speeded task. A proactive participant in our dual-task situation will not only anticipate that the array items must be maintained for later recognition but also anticipate that the speeded task is coming up and prepare for that task in anticipation of the signal. Although all participants may show some slowing of responses in the speeded task when it follows an array compared to when it follows no array, the amount of this slowing should be reduced by proactive preparation for the

Figure 2

Illustration of Performance on the Working Memory Task (Left-Hand Panels) and the Difficult Version of the Speeded Task, the Opposite-Side Task (Right-Hand Panels) According to Two Different Hypotheses About the Development of a Proactive Stance (Top Versus Bottom Rows of Panels)



Note. See text for explanation.

speeded task. A more reactive participant will have to do mental preparation for the speeded task only after its signal arrives, which should take longer than being prepared ahead of time, an effect similar to what has been termed a task switch cost (e.g., Meiran, 1996). As indicated in Table 1 (H_{p2} row), the relative slowing when under a one-item load compared to no load should be greater for reactive participants. If young children are reactive and do not prepare for the speeded task like older participants (Table 1, H_{d2} column), then they should show much longer speeded-task response times than older children and adults when they have just engaged in a different task, array memory encoding (i.e., a larger difference between no load vs. a one-item load in speeded-task response times). If, on the other hand, young children proactively prepare for the upcoming speeded task like adults do (Table 1, H_{d1}), then their task switch costs should be in the same range as older children and adults.

Comparing Arrays of One to Four Items

Additional predictions shown in Table 1 are made for further increases in array size between one, two, three, and four array items. The reactive strategy (H_{p2}) would be to stop trying to maintain the array during the speeded task, whereas the proactive strategy (H_{P1}) would be to keep trying to maintain it while doing the speeded task, in anticipation of the memory test. Consequently, the array size between one and four items should matter for the speeded task only in proactive participants, who, according to H_{d2}, would be the older participants. To make all of these comparisons fair, we measure the cost of maintaining a memory load in a relative manner, as a proportion of the individual's overall response times.

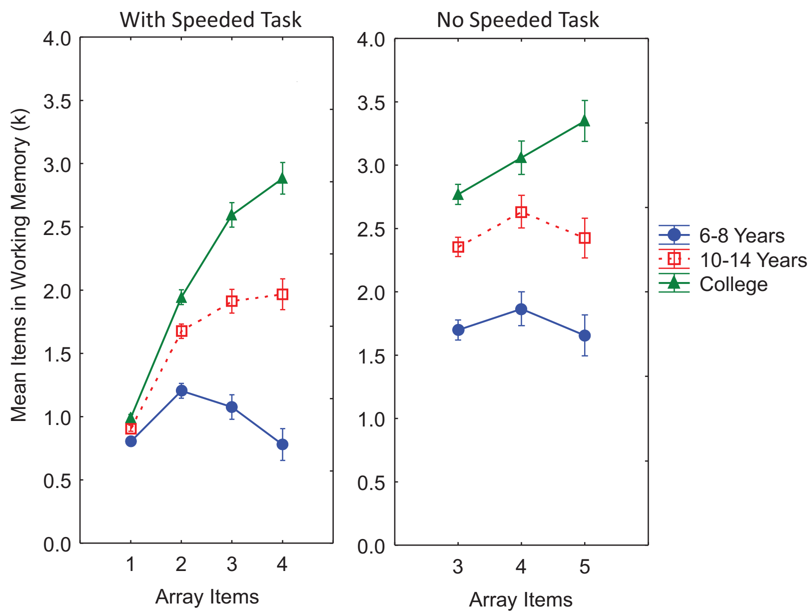
Method

Statistical Power and Sample Size

Our most important type of result is an interaction of age by condition. Using the G*Power program (Faul et al., 2007), we found that a hypothetical sample size of 138 divided among three age groups would allow a power of at least 0.81 to detect that sort of interaction with an effect size f of 0.3 and $p < .05$, when the within-participant variable has at least three levels (as in our analyses, e.g., three speeded-task conditions that can accompany the array memory task). Our final sample of 180 participants provides additional security and results in power for this type of interaction of 0.91. Beyond power calculation, After Figures 3 through 5 describe aspects of accuracy in various ways, Figure 6 shows that the overall pattern of accuracy results was stable in that

Figure 3

Mean Items in Working Memory (k Measure) in Each Age Group (Graph Parameter) for Each Array Set Size Used (x-Axis) When a Speeded Task Was Present (Left Panel) or Absent (Right Panel)



Note. Data with speeded task present are restricted to trials in which the speeded-task response was correct to ensure that the intended processing interference was present and was averaged across same- and opposite-side signals. Error bars are standard errors of the mean. See the online article for the color version of this figure.

it was quite similar across subgroups receiving visual versus auditory speeded tasks.

Participants

The study was approved by the institutional review board of the University of Missouri under Project 99–04-095, "The Development of Short-Term Memory for Speech Attributes." The final sample of 180 participants comprised those who saw visual speeded-task signals, including children 6–8 years old (*M* = 2,817 days, *SD* = 290; 13/30 female), children 10–14 years old (*M* = 4,115 days, *SD* = 440; 16/30 female), and college students (*M* = 6,857 days, *SD* = 146; 25/35 female) and those who heard auditory speeded-task signals, including children 6–8 years old (*M* = 2,679 days, *SD* = 303; 14/28 female), children 10–14 years old (*M* = 4,278 days, *SD* = 418; 18/32 female), and college students (*M* = 7,008 days, *SD* = 314; 18/25 female). Children included three (3%) Hispanic, four (3%) Asian, three (3%) Black or African American, 12 (10%) multiracial, and the rest White; college students included two (3%) Hispanic, one (2%) Asian, two (3%) Black or African American, one (2%) multiracial, and the rest White. For comparison, the 2010 U.S. Census showed Columbia, Missouri to be 3% Hispanic, 5% Asian, 11% Black or African American, 3% multiracial, 1% from other races, and the rest White. Individuals with known learning disorders were excluded. All participants received Raven's Progressive Matrices before the main experiment, and the three age groups had means of 32.53 (*SD* = 8.41), 40.95 (*SD* = 9.18), and 40.08 (*SD* = 6.94), respectively.

Apparatus, Stimuli, and Procedure

The experiment with Phases 1 and 2 together took about 45 min. Each participant was computer tested individually in a sound-attenuated booth.

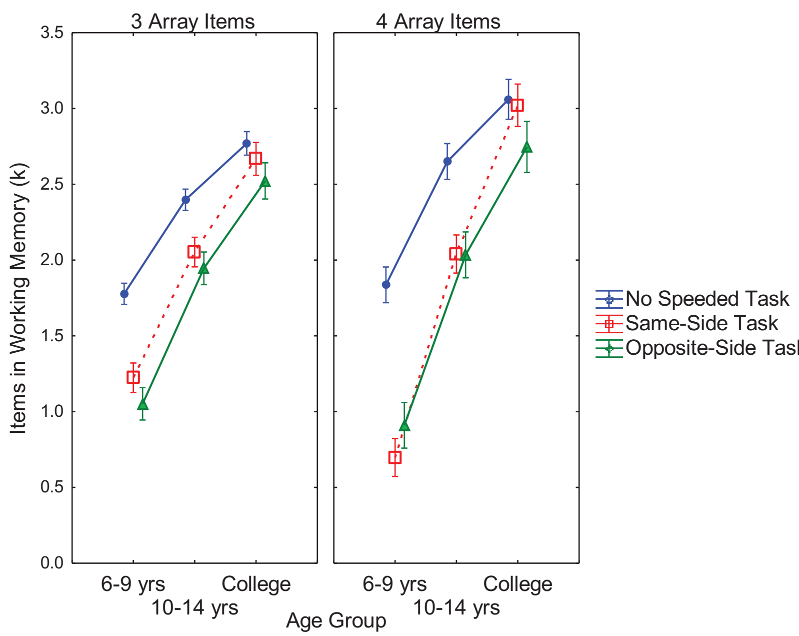
Phase 1: Array Memory Alone

Phase 1 included set sizes appropriate to assess single-task capacity. Participants received arrays of three, four, or five colored squares on each trial for subsequent recognition of a probe square (a task based on a change-detection procedure of Luck & Vogel, 1997), with no additional task. Twelve practice trials were followed by 48 test trials. Each array lasted 0.5 s and was followed by a blank screen for 0.5 s and then multicolored squares in the same locations as the array items for 0.5 s, serving to mask sensory memory. These were followed immediately by a single-item probe, either the same color as the array item that had appeared at that location or a color different from all other array items. The participant verbally indicated "same" or "different," a response that was recorded by the experimenter.

Each item in an array was a different color drawn from the set: white, black, red, green, blue, violet, yellow, cyan, and brown. The arrays were 83 mm wide and 63 mm high and, at a viewing distance of 50 cm, subtended a width of 9.5° and a height of 7.2°

Figure 4

Items in Working Memory (k Measure) in Each Age Group (x-Axis) for Three-Item Arrays (Left Panel) and Four-Item Arrays (Right Panel) for All Three Speeded-Task Conditions (Graph Parameter)



Note. Data with a speeded task present are restricted to trials in which the speeded-task response was correct to ensure that the intended processing interference was present. Error bars are standard errors of the mean. See the online article for the color version of this figure.

in visual angle. Each colored square subtended 0.74° in width or height, and the minimum separation between the centers of squares was 2.2°.

Phase 2: Dual Task

In Phase 2 of the experiment, the speeded task was interpolated between the array and the mask (Figure 1a). There were six blocks of 20 trials, with blocks alternating between same-side and opposite-side instructions; the first condition was randomly selected for each participant. For the visual group, an X appeared either on the left or right side of the computer monitor, and the task was to use the index finger of the appropriate hand to press a key on either the same side or the opposite side of a response box, depending on the instruction for that trial block, as quickly as possible. Responses slower than 2 s were met with feedback indicating "too slow" and were counted as incorrect. The X was 137 mm (15.6°) from the center of the screen and subtended 1.4° in height and width. For the auditory group, instead of an X to the left or right on the screen, there was a 500-Hz sine wave tone (with a 10-ms linear onset ramp), played at ~70 dB(A) in the left or right headphone channel. In either case, the signal continued until a key was pressed or the 2-s time limit arrived.

A certain range of set sizes was needed to characterize dual-task performance across groups. On each trial, there was an array with zero, one, two, three, or four colored squares to remember. The "zero-item array" was actually an elliptical gradient with a dark center fading to light and filling the display area (Figure 1b). Participants were instructed that they need not remember it. Thus, these trials reflect single-task performance of the same-side and opposite-side speeded task but with timing cues that would occur with presentation of an array.

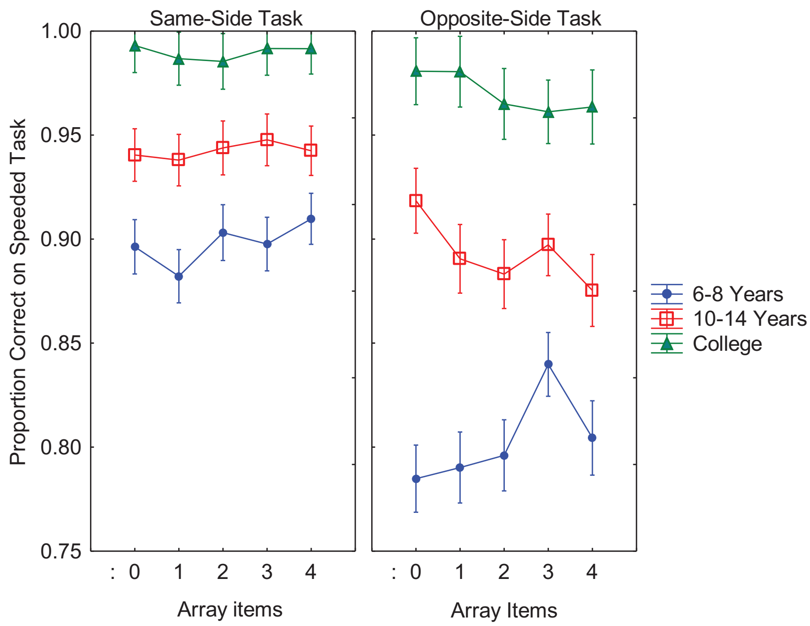
The Phase 1 array memory set sizes (three to five) are known to be in the right range to measure each participant's capacity limit given age and individual differences (e.g., Cowan et al., 2005). In contrast, given the poorer performance across a longer retention interval (Pertzov et al., 2017) that includes a secondary speeded task that may cause interference, set sizes one to four were expected to be better for finding any effect of the speeded task, while avoiding floor and ceiling effects for at least some of these set sizes in most participants.

Analysis of Array Items in Working Memory

In recent years, a useful technique that has become available is the numerical estimation of the number of items in working memory in array-item-recognition tasks like ours, using a simple model to take into account the contribution of guessing (Cowan, 2001; Rouder et al., 2011). If the array includes N items and the participant retains k of them in working memory, the probed item will be in working memory with probability k/N. If it is not in working memory, a guess must be made. It can be shown (Cowan, 2001) that according to this simple model, the capacity can be estimated using a combination of the proportion of hits, h, defined as correctly detected new probe items that were not in the array

Figure 5

Proportion of Correct Responses on the Same-Side Speeded Task (Left Panel) and Opposite-Side Speeded Task (Right Panel) for Each Array Set Size (x-Axis) in Each Age Group (Graph Parameter)



Note. Error bars are standard errors of the mean. See the online article for the color version of this figure.

and the proportion of false alarms, *f*, defined as responses in which the participant incorrectly indicated that the probe item was new. In particular,

$$k = N(h - f).$$

The metric *k* estimates the number of items in working memory. It is not a direct estimate of the participant's working memory capacity because it is limited to the number of items in the array, which can be smaller than capacity. Using this metric with set sizes that exceed the likely *k*, one can estimate the capacity requirement of an intervening processing task, the estimate being the reduction in *k* in the array memory task observed when the intervening task is inserted.

Results

We first examined performance on the array memory tasks, including the effects of the speeded secondary task on array memory. Next, we examined performance on the secondary speeded and same- and opposite-side tasks, including the effects of a memory load on accuracy in those tasks. Then, we examined accuracy on the two tasks jointly in more detail. Finally, we examined response times in the speeded task as a function of memory load. In all of the analyses, the key issue was whether the effect of one task on another is the same across age groups or changes with age. We therefore report age group effects in detail and provide additional results of the analyses in the online supplemental materials.

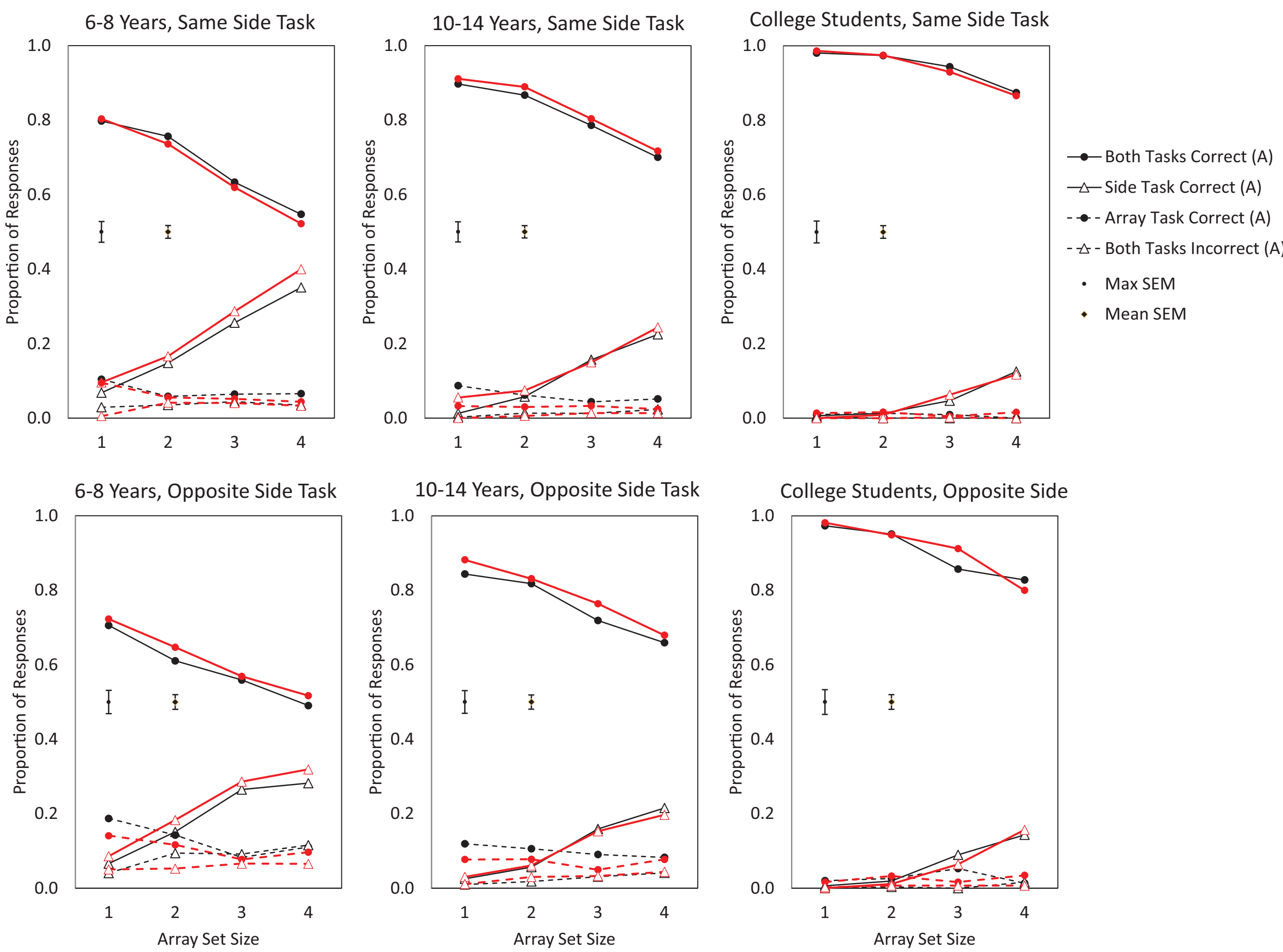
Array Items in Working Memory

Figure 3 shows the estimated number of array items in working memory (*k*) in each age group and condition. The left-hand panel of the figure presents the array task results in the presence of the speeded task, and the right-hand panel presents the array task when presented alone in order to facilitate a comparison of set sizes three and four, the set sizes included in both phases of the experiment. As shown in the figure, there was clearly a developmental increase in the number of items in working memory. That increase can be seen both in the presence of a secondary task (left panel, averaged across same- or opposite-side task) and in the absence of a secondary task (right panel).

Performance on arrays with three or four items could be compared across the three different secondary task conditions (no task, same-side task, and opposite-side task) using trials in which the speeded side-task response was correct. The results of that comparison are shown in Figure 4 for three-item arrays (left panel) and four-item arrays (right panel). It can be seen that the effects on working memory of performing either speeded task (same or opposite side) during the memory load were more severe for younger participants, regardless of the array size. These observations were confirmed in an analysis of variance (ANOVA) that included within-participant factors of the set size (three or four) and the secondary task (no task, same side, or opposite side) and between-participants factors of age group and modality group (visual or auditory speeded-task stimuli). There was a large main effect of age group $F(2, 174) = 93.833$, $p < .001$, $\eta_p^2 = 0.52$.

Figure 6

Combination of Speeded-Task (Top Row, Same-Side Task; Bottom Row, Opposite-Side Task) and Array Memory Response Accuracy (Graph Parameter) in Conditions in Which Both Tasks Were Present, for Each Age Group (Columns of Panels) at Each Array Size (x-Axis)



Note. In the graph parameter legend, the first four markers show the auditory (A) speeded-task responses in black; red lines and markers depict the corresponding data for the visual speeded task. The last two markers indicate standard errors (*SEM*; maximum for all points shown and mean of all points shown). Notice the high degree of similarity between visual and auditory speeded-task data (black vs. red lines) and the raised values of the array task only correct (dashes and solid dots) in the children.

There was also an interaction of the set size by age group, $F(2, 174) = 5.84$, $p = .004$, $\eta_p^2 = 0.06$, inasmuch as younger participants could hold no more items in working memory when the set size increased from three to four, whereas older participants, on average, increased in items in working memory when the set size increased from three to four (see Figure 4).

Most critically, there was a large interaction between the speeded-task condition and the age group, $F(4, 348) = 6.79$, $p < .001$, $\eta_p^2 = 0.07$. The figure shows little difference between array performance in the presence of same- versus opposite-side speeded tasks but a great difference between those situations and array memory performance when there was no speeded task, and especially so in younger participants. Post hoc pairwise tests by the Holm method help to clarify the interaction shown in Figure 4. Specifically, the youngest age group showed a severe effect of a speeded side task on array memory regardless of the set size, $p < .001$, for no side task compared to same- or different-side tasks but no significance between the latter two. The older children showed a numerically smaller effect but again with $p < .001$ for no side task versus either same- or different-side tasks and no significance between the latter two. These findings are consistent with H_{p2} of Effect Type 3 in Table 1, reactive processing. In contrast, the adults showed little or no effect of the speeded task on array memory and no significance for all three comparisons, consistent with H_{p1} of Effect Type 3 in Table 1, proactive processing.

No other effect involving age group approached significance. These results are consistent with the hypothesis depicted in the bottom left panel of Figure 2 and the H_{d2} column of Table 1, that a proactive stance develops with age, though assertion of the validity of that hypothesis also depends on the pattern of results for the secondary speeded task.

Speeded-Task Accuracy

Figure 5 shows same-side speeded-task accuracy (left panel) and opposite-side speeded-task accuracy (right panel) for each age group (graph parameter) as a function of the memory load (*x*-axis). Clearly, accuracy was lower in the opposite-side task compared to the same-side task, as one would expect from previous findings (e.g., Bunting et al., 2008; Friedman & Miyake, 2004). One can also see that the memory load had little detrimental effect on same-side task performance. What is of most interest is the effect of the memory load on opposite-side task performance. For the older two age groups, the general trend is a drop in task accuracy as a function of the concurrent memory load, consistent with H_{p1} of Effect Type 2 in Table 1. In contrast, for the youngest age group, if anything, there was an increase in accuracy on the opposite-side task as the memory load increased; at least, there was not a decrease, consistent with H_{p2} of Effect Type 2, reactive processing.

This general pattern of findings was supported by an ANOVA with the side of speeded task (same vs. opposite side) and the concurrent memory load (zero, one, two, three, or four items) within participants and with age group and speeded-task modality as between-participants factors. There was a large effect of age group, $F(2, 174) = 33.55$, $p < .001$, $\eta_p^2 = 0.28$. The age group interacted with the side of the task, $F(2, 174) = 16.35$, $p < .001$, $\eta_p^2 = 0.16$, inasmuch as the disadvantage for the opposite-side speeded task was much larger for younger participants. The age group also interacted with the array size, $F(8, 696) = 2.09$, $p = .035$, $\eta_p^2 = 0.02$.

Simple main effects of array size for each age group and side task separately produced positive results for the opposite-side task: marginal ($p = .07$) in the youngest children versus $p < .05$ in the older children and college students and no significance for the same-side task in each age group. Like the results for array memory, these results for speeded-task performance are more consistent with the hypothesis in which a proactive stance increases with childhood development (Table 1, H_{d2} column; Figure 1, bottom right) in that the youngest children's opposite-side key-press response was at most weakly impacted by the dual task of having items in the memory array (i.e., set sizes one to four) relative to single-task performance when no items were in the array; in contrast, older children's and adults' opposite-side responses clearly declined in the presence of an array memory load.

Combination of Array Memory and Speeded-Task Accuracy

Figure 6 gives a more complete view of the set of experimental results for dual-task, dual-response trials by plotting separately the proportion of trials in which the array memory response was correct or not and in which the speeded-task response was correct or not. One impressive aspect of the figure is that it shows how closely the results matched for participants receiving an acoustic speeded-task signal and those receiving a visual speeded-task signal, demonstrating considerable precision of measurement.

Each column of panels reflects a different age group, with same-side trials in the top row of panels and the opposite-side trials in the bottom row. It is clear that most errors occurred in the array memory task (lines with open symbols) except at the lower set sizes, during which children made some errors in the speeded task (dashed lines). For the opposite-side speeded task, at small set sizes of one or two items, children made more errors in the speeded task than they did at larger set sizes. An analysis of trials with an error only on the side task (with age group and side-task modality between participants and with array size and same or opposite type of side task within participants) showed, in addition to all main effects except side-task modality, an interaction only of age group with set size, $F(6, 522) = 6.04$, $p < .001$, $\eta_p^2 = 0.07$. In the younger children, the proportions of trials of this type at the four array set sizes were .13, .09, .07, and .08, respectively, clearly decreasing across set sizes. In older children, the proportions were more nearly flat at .08, .07, .05, and .06, respectively. Finally, in adults, the proportion was .02 at all four array set sizes. Simple main effects of set size for each age group showed an effect for the younger children, $p < .001$, and for the older children, $p = .011$, but there was no significance for the adults.

Figure 6 shows that the pattern was similar for the auditory and visual side tasks (black and red dashed lines with solid points, respectively). The pattern suggests that a large memory load may result in more alertness or task engagement in young children, actually facilitating opposite-side speeded-task performance compared to small memory loads. Similar findings have been observed in adult studies, in which a working memory load can sometimes facilitate performance on another task (de Fockert & Bremner, 2011; Hoffmann et al., 2013; Levinson et al., 2012). One interpretation is that the children were not always engaged at higher array set sizes and sometimes dropped the array from memory entirely, giving up, so that a larger proportion of correct responses for larger arrays were just lucky guesses. If this is the case, then, for the young children, the effective memory load on trials used in the analyses was actually higher (on average) at the lower set sizes, which would explain the greater effect of smaller arrays on speeded side-task accuracy compared to larger arrays.

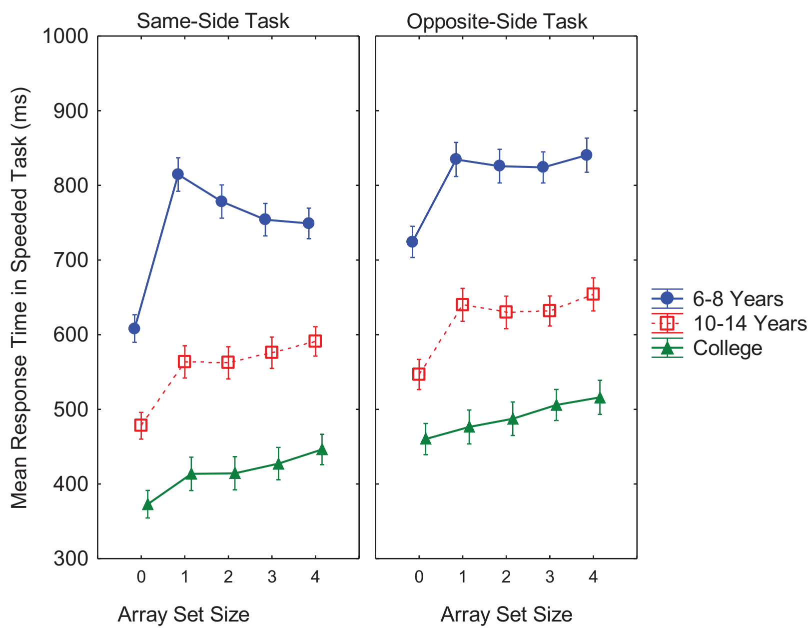
Speeded-Task Response Time Switch Costs

The results we have discussed indicate that young children do not show a proactive stance; speeded-task accuracy was not impaired by the presence of a memory load or by larger memory loads compared to smaller ones (see Figure 5), whereas array memory performance was severely affected by the presence of a speeded task during the retention interval for memory (see Figure 4). All of this is in keeping with a process in which younger children essentially abandon the array memory load while the speeded task is performed. However, at least two interpretations of this finding can be distinguished. It might be that the young children never actively maintain the array memory load, in which case they can approach the speeded task with no burden. Alternatively, young children may actively maintain the array memory until the signal for the speeded task is presented, at which time the child would have to change task sets from memory maintenance to speeded-task key-press performance. There should be some cost to that change.

Figure 7 shows that response times for accurate speeded-task key presses increase markedly in the youngest children between

Figure 7

Mean Response Times for Correct Same- and Opposite-Side Speeded-Task Responses (Left and Right Panels, Respectively) for Trials With Each Number of Items in the Visual Array (x-Axis) for Each Age Group (Graph Parameter)



Note. Error bars are standard errors of the mean. See the online article for the color version of this figure.

no memory load and a present memory load. This occurs in both the same-side (left panel) and opposite-side (right panel) speeded task. This cost to speeded-task response times of maintaining a memory load becomes somewhat smaller in older children and almost disappears in the adults. Thus, in some sense, as suggested for H_{p2} in Table 1, young children do think about the arrays, and there is a cost of that when switching to the speeded task. With maturation and presumably a proactive stance, that switch cost greatly decreases (Table 1, H_{p1} row for a proactive stance and H_{d2} column for its increase with development). As further suggested for an increasingly proactive stance with development, the effect of increasing memory load beyond one item was greater in adults than in the children. Last, the cost of maintaining a memory load is somewhat greater in the same-side condition than in the opposite-side condition, probably due to an especially fast, prepotent response in the same-side condition with no memory load.

To statistically assess these observations regarding the costs of a memory load in a fair manner despite age differences in overall response times, we calculated the relative switch cost to the response time as follows, where response time $(RT)_N$ is the individual's mean response time for the speeded task with a memory load of N items, $1 \leq N \leq 4$.

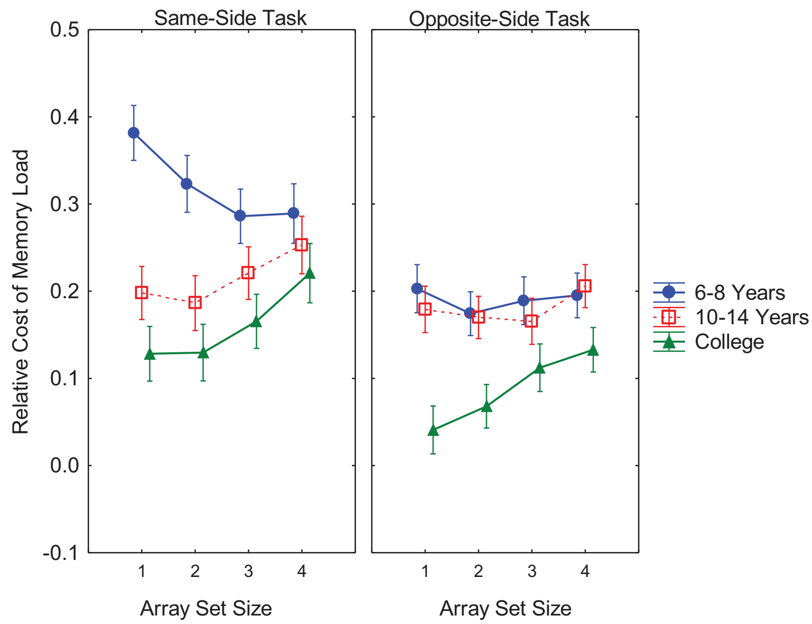
$$Relative\ Cost = (RT_N - RT_0)/RT_0$$

First, we compared groups on the relative increase in response time going from zero to one array item. The means corresponding to this analysis are the one-item means in Figure 8. The figure shows that the cost was greater for younger participants and for the same-side compared to the different-side task. The latter occurred because the response times were faster for the baseline (one-item array) same-side task compared to the different-side task, making the one-array load more costly by comparison (see Figure 7). In an analysis with age groups between participants and with the same versus different side of the speeded task within participants, there was an age effect, $F(2, 177) = 17.61$, $p < .001$, $\eta_p^2 = 0.11$; an effect of the side of the task, $F(1, 177) = 24.17$, $p < .001$, $\eta_p^2 = 0.04$; and an interaction of these factors, $F(2, 177) = 5.87$, $p = .003$, $\eta_p^2 = .02$. The basis of the interaction appears to be that the older children showed costs that looked more like the college students in the same-side task but more like the younger children in the opposite-side task, an interesting developmental transition.

Results for the relative measure across array sizes are also shown in Figure 8. An ANOVA of relative costs was conducted with the same factors as the previous analysis but also with the array size (one, two, three, and four) and speeded-task signal modality as additional within-participant factors. This analysis yielded an overall main effect of age group, $F(2, 174) = 8.68$, $p < .001$, $\eta_p^2 = 0.09$, because the relative cost of a memory load beyond one item decreased with development. The means (with standard error of the mean) for the three age groups were 0.26 (0.02), 0.20 (0.02), and 0.12 (0.02), respectively. Age group also interacted with the effect of the speeded task, $F(2, 174) = 3.74$, $p = .026$, $\eta_p^2 = 0.04$, inasmuch as the cost of a memory load for younger children was especially large for the same-side speeded

Figure 8

Mean Relative Cost of Response Times for Correct Same- and Opposite-Side Speeded-Task Responses (Left and Right Panels, Respectively) for Trials With Each Number of Items in the Visual Array (x-Axis) for Each Age Group (Graph Parameter)



Note. Error bars are standard errors of the mean. See the online article for the color version of this figure.

task. This pattern might occur because making a same-side speeded-task response under no memory load is especially fast and automatic, with little need for attentional control, whereas the addition of a memory load requires a task set change (see Figure 7).

Age group interacted with array set size, $F(6, 522) = 6.30$, $p < .001$, $\eta_p^2 = 0.07$. For the youngest children in the same-side speeded task, the cost was actually greatest when the array size was small, whereas that was not the case for older participants, who showed a greater cost for greater loads (Figures 7 and 8). Separate ANOVAs for the different age groups produced, in the younger children, effects of the task, $p < .001$, and the array set size, $p = .026$; in the older children, an effect of the set size, $p = .005$; and in the adults, effects of the task and the set size, both ps $< .001$. No interactions approached significance in these analyses by age group.

It seems possible that young children's engagement with the memory load would be greater for smaller loads because children facing a larger array may sometimes entirely give up on memory maintenance. Regardless of the basis of this paradoxical, positive effect of array size on speeded-task response speeds in the young children, overall, the evidence suggests that they are not preparing well for the speeded task and that they therefore suffer a long task switch cost when the speeded-task signal arrives after having looked at an array. That cost is greatly diminished with development, even when measured relative to the baseline response time to adjust for age differences in overall speed of processing, as we have done (see Figure 8).

Last, in the 6–8-year-old children only, there was a main effect of the speeded-task modality, $F(1, 56) = 7.86$, $p = .007$, $\eta_p^2 = 0.12$. The mean relative cost of a memory load (with standard error of the mean) was 0.33 (0.04) for a visual speeded task but only 0.18 (0.04) for the auditory speeded task. The basis of the effect appeared to be a slowdown in responding for auditory as compared to visual signals even without a memory load. For example, for the same-side stimuli with no array memory load, the youngest children responded with a mean time of 551 ms in the group with visual signals as compared to 665 ms in the group with acoustic signals, and the slowdown caused by a one-item load was 149 versus 263 ms in the two groups, resulting in no difference between modalities with a one-item load. The group difference in same-side response time with no memory load was much smaller in the older children (visual, 460 ms; auditory, 496 ms) and adults (visual, 346 ms; auditory, 400 ms), and costs going to a one-item load were comparable in the two modalities. The differences between the modalities were also seen in the younger children with opposite-side signals with no memory load (visual, 669 ms; auditory, 779 ms; costs going to a one-item load 74 vs. 147 ms), and in that case, there was a hint of a similar pattern in the older children (visual no load, 510 ms; auditory no load, 583 ms; costs going to a one-item load 75 vs. 111 ms) and adults (visual no load, 416 ms; auditory no load, 505 ms; costs going to a one-item load, 6 vs. 27 ms). The slower responding to auditory, as compared to visual, signals under no load, especially in the young children, could reflect difficulty in localizing the acoustic signal, or it could reflect the time to switch attention from the visual display to the acoustic signal, and the basis of development in this regard is an important question for future research.

Discussion

The present findings allow a better understanding of how, with development, children appear to become more proactive and less reactive in their use of attention. In doing so, the current study helps to address an ongoing debate about the nature of the development of attention. There has been a lot of interest recently in the theoretical explanation of the development of selective attention, as well as in its practical consequences. Most investigators agree that the ability to control attention improves with age. Reviews have focused on further questions: distinguishing the relatively late development of executive attention from earlier-developing, stimulus-driven forms of attention (Rueda, 2013); development of attention as part of a dynamic system rather than as a static gatekeeper (Ristic & Enns, 2015); similarities and differences between auditory and visual attention (Godwin et al., 2019); and the importance of both interference and redundancy between modalities (Bahrick & Lickliter, 2014). There has been recent research on the developmental trajectory of sustained attention (Betts et al., 2006) and of the ability to allocate and share attention (Irwin-Chase & Burns, 2000), as well as on the relation of practical and social functioning to working memory loads and attention (Doebel, 2020; Hilton et al., 2020). Extant research, however, leaves open some fine-grained questions about just what changes in children's use of attention.

In the present dual-task procedure, a visual memory load (an array of colored squares based on Luck & Vogel, 1997) was followed by an easy or difficult task to be carried out as quickly as possible while retaining the memory load. The easy task was to press a key on the side of a signal, and the difficult task was to press a key on the opposite side (cf. Bunting et al., 2008; Friedman & Miyake, 2004). Then, based on the items maintained in working memory, a recognition probe was to be judged present in the previous array or absent from it. The general expectation was that the two tasks would interfere with each other compared to performance of the tasks in single-task situations and that this interference might be larger for younger children. Beyond that expectation, however, we were able to examine several more detailed questions.

Development of Working Memory and Attention Overload?

First, we could reassess the proposal stated by Cowan et al. (2010, 2011) that younger children can allocate attention as well as adults except when working memory is overloaded. This overload would occur at a lower load for children than for adults. We can look at this question taking speeded-task performance as a measure of attention reallocation and control. The results, though, are not fully favorable to this hypothesis. Performance of the speeded task showed an age difference in both accuracy and response time even with no memory load (Figures 5 and 7). Moreover, contrary to the notion of an overload account, the effect of a load was to decrease, not increase, age differences in accuracy on the opposite-side speeded task (see Figure 5). It is true that the introduction of a memory load increased the response times more for younger children than for older children or adults, but in contrast to an overload notion, for the same-side speeded task, this increase was highest with a one-item memory load, and for the opposite-side task, the effect of memory load was flat between one and four items (see Figure 8). It appears to us that the conclusion of Cowan et al. (2010, 2011) does not carry much explanatory power in the present situation.

Development of Proactive Attention Control and Working Memory Capacity

The main opposing hypotheses set out in the introduction (and in Figure 2 and Table 1) have to do with a proactive stance increasing with development along with working memory capacity (Figure 2, bottom panels) versus a proactive stance not specifically increasing with development (Figure 2, top panels). The results are nicely in line with the notion of a development of a proactive approach to allocating attention. When young children received either the auditory or visual signal to cue the key press, they showed signs of not having prepared for that signal. They ideally would have prepared for it by adopting a task set that facilitated the speeded-task key press, while also supporting maintenance of the memory load before, during, and after that key press.

Present Findings

First, unpreparedness in young children is suggested by the dramatic slowing of responses for both same- and opposite-side signals of any load compared to doing the speeded task under no load (Figures 7 and 8). This slowing, which we have referred to as a switch cost, was enormous for young children, much smaller for older children, and very small for adults. In contrast, the effect of increasing memory loads on the speeded task was much more important for older participants (Figures 7 and 8), presumably because of a more active, attention-demanding attempt to retain the loads during the speeded task (Table 1, developmental H_{d2}).

Second, had attention control been recruited for maintenance of the memory load in young children, it should have supported recall, but the cost would be reduced accuracy on the speeded key-press task. In line with a developmental increase in the proactive use of attention control, key-press accuracy decreased only for the older two groups of participants (see Figure 5), not for the younger group of children. Moreover, in terms of performance on the working memory task, the presence of a speeded task, regardless of its level of difficulty, severely affected the youngest children, slightly affected the older children, and did not affect the adults at all (see Figure 4). These results are what one would expect if the children (especially the younger ones) had been maintaining the memory load as well as they could until a side signal arrived, at which point attention switched to the side signal and maintenance of the memory load was to some extent sacrificed. Children perhaps could not maintain the memory load very well while also making the speeded-task response or perhaps lost the goal to do so. Older children and adults appear to have continued maintenance of the array better, though at an expense to performance in the speeded key-press task that grew with the memory load.

Comparison to Previous Findings

The present findings complement previous findings in several ways. Chevalier et al. (2014) administered lists of spoken animal names to be retained and then recalled by pointing to pictures on a screen. Response times showed that younger children began pointing with only short preparatory delays, maintaining a similar rate throughout the list, whereas older children and adults prepared for longer before pointing to the first item and then selected the remaining list items relatively quickly. This pattern suggests that younger children planned each response as it was being made but that older children and adults first planned, then executed, their entire response. This developmental increase in proactive planning seemed to reach an asymptotic level by about the ages at which the present research started, however, so our study documents the continuation of development toward a proactive mode longer than the procedure that Chevalier et al. used.

Chevalier et al. (2015) distinguished between 5- and 10-year-old children, which has potential implications for the age groups included in our study. They presented a cue indicating that a target object was to be categorized according to either shape or color. The cue could coincide with the target, making planning ahead impossible; it could start earlier than the target but stay on during the target, making planning ahead optional; or it could start earlier and end before the target was presented, in which case the task can only be carried out successfully by remembering the cue and, in that sense at least, planning ahead. In 5-year-olds, the optional-planning response times (and physiological responses) looked like those in the no-planning condition, suggesting a reactive stance. In 10-year-olds, in contrast, the optional-planning response times looked like those in the condition practically requiring planning for successful performance, suggesting a more proactive stance. Based on our results, in this task, further developmental change would be expected between 10-year-olds (matching the low end of our middle group) and adults, who Chevalier et al. did not include.

Morey, Mareva, et al. (2018) examined eye movements in children 5–7 and 8–11 years old and adults while they tried to remember spatial arrays. It was found that the younger children spent the most time looking at the locations that had been occupied by these items during the retention interval. This suggested that young children do try to remember but do so in a manner that is based on the stimuli and not through more successful, covert methods.

Similar to Morey, Mareva, et al. (2018), we claim that our children 6–8 years old tried to remember the arrays but were unable to maintain these arrays while carrying out a secondary side-press task. As a result, their key-press responses were greatly delayed but correct, and then their array memory responses were greatly impaired by this speeded key-press task, as if they were unable to maintain the items actively after an interruption (cf. Morey, Hadley, et al., 2018). In contrast, for our adults, the opposite-side-press accuracy was impaired by the memory load, and performance on the memory task was not impaired by either speeded key-press task, indicating more capability of balancing the two tasks. Of course, this was accomplished at an overall higher level on both tasks compared to the children. The middle group showed an intermediate pattern of performance.

Limitations and Future Directions

For convenience, our sample excluded children under 6 years, 9-year-olds, and those 15–16 years old. The adults were students at a state college, which might underrepresent both extremes of the population. It is possible that noncognitive factors played a role; for example, the youngest age group might have lost interest in the array memory task when it had a number of items way above capacity. That loss of interest might explain why, in those children, smaller arrays paradoxically had more relative cost on the side-task speed than did larger arrays, when all responses were correct (see Figure 8). Alternatively, the items in large arrays could be lost due to ineffective encoding by young children rather than loss of interest (resembling a phenomenon observed in low-span adults by Cusack et al., 2009). This paradoxical effect in the younger children, in which smaller arrays were more damaging to speeded side-task performance than were larger arrays, warrants further study.

Conclusion

We used a dual task with a visual working memory load and a brief, discrete, time-sensitive, attention-demanding secondary task to examine the dynamics of attention allocation from 6 years of age to adulthood. The results indicate that there are differences in the way attention can be allocated that becomes more flexible and proactive and that this developmental change is not totally the direct consequence of previously documented developmental increases in working memory capacity. It is still possible that there are links between capacity and a proactive stance if that stance requires that some capacity be diverted from the tasks at hand in order to regulate the transitions between tasks. Similar findings exist for adult aging (Rhodes et al., 2019), suggesting that physiology rather than learning may underlie this developmental change. It is not yet clear to what extent incentives or training can move an individual from a reactive to a proactive stance. We hope that we have provided some methodological tools that will allow further exploration of the basis for the developmental growth of important cognitive skills.

References

Bahrick, L. E., & Lickliter, R. (2014). Learning to attend selectively: The dual role of intersensory redundancy. *Current Directions in Psychological Science*, *23*(6), 414–420. https://doi.org/10.1177/0963721414549187

Betts, J., Mckay, J., Maruff, P., & Anderson, V. (2006). The development of sustained attention in children: The effect of age and task load. *Child Neuropsychology*, *12*(3), 205–221. https://doi.org/10.1080/09297040500488522

Braver, T. S. (2012). The variable nature of cognitive control: A dual-mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106–113. https://doi.org/10.1016/j.tics.2011.12.010

Bunting, M. F., Cowan, N., & Colflesh, G. H. (2008). The deployment of attention in short-term memory tasks: Tradeoffs between immediate and delayed deployment. *Memory & Cognition*, *36*, 799–812. https://doi.org/10.3758/MC.36.4.799

Camos, V., & Barrouillet, P. (2011). Developmental change in working memory strategies: From passive maintenance to active refreshing. *Developmental Psychology*, *47*(3), 898–904. https://doi.org/10.1037/a0023193

Chevalier, N., James, T. D., Wiebe, S. A., Nelson, J. M., & Espy, K. A. (2014). Contribution of reactive and proactive control to children's working memory performance: Insight from item recall durations in response sequence planning. *Developmental Psychology*, *50*(7), 1999–2008. https://doi.org/10.1037/a0036644

Chevalier, N., Martis, S. B., Curran, T., & Munakata, Y. (2015). Metacognitive processes in executive control development: The case of reactive and proactive control. *Journal of Cognitive Neuroscience*, *27*(6), 1125–1136. https://doi.org/10.1162/jocn_a_00782

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, *24*(1), 87–114. https://doi.org/10.1017/S0140525X01003922

Cowan, N. (2020). *Developmental change in the nature of attention allocation in a dual task*. Open Science Framework. Retrieved November 10, 2020, from https://osf.io/8p2e9/?view_only=6cf44f9598854544b15976b9d0bf67a5

Cowan, N., AuBuchon, A. M., Gilchrist, A. L., Ricker, T. J., & Saults, J. S. (2011). Age differences in visual working memory capacity: Not based on encoding limitations. *Developmental Science*, *14*(5), 1066–1074. https://doi.org/10.1111/j.1467-7687.2011.01060.x

Cowan, N., Elliott, E. M., Saults, J. S., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. A. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology*, *51*(1), 42–100. https://doi.org/10.1016/j.cogpsych.2004.12.001

Cowan, N., Morey, C. C., AuBuchon, A. M., Zwilling, C. E., & Gilchrist, A. L. (2010). Seven-year-olds allocate attention like adults unless working memory is overloaded. *Developmental Science*, *13*(1), 120–133. https://doi.org/10.1111/j.1467-7687.2009.00864.x

Cusack, R., Lehmann, M., Veldsman, M., & Mitchell, D. J. (2009). Encoding strategy and not visual working memory capacity correlates with intelligence. *Psychonomic Bulletin & Review*, *16*, 641–647. https://doi.org/10.3758/PBR.16.4.641

de Fockert, J. W., & Bremner, A. J. (2011). Release of inattentional blindness by high working memory load: Elucidating the relationship between working memory and selective attention. *Cognition*, *121*(3), 400–408. https://doi.org/10.1016/j.cognition.2011.08.016

Doebel, S. (2020). Rethinking executive function and its development. *Perspectives on Psychological Science*, *15*(4), 942–956. https://doi.org/10.1177/1745691620904771

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175–191. https://doi.org/10.3758/BF03193146

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, *133*(1), 101–135. https://doi.org/10.1037/0096-3445.133.1.101

Godwin, K. E., Erickson, L. C., & Newman, R. S. (2019). Insights from crossing research silos on visual and auditory attention. *Current Directions in Psychological Science*, *28*(1), 47–52. https://doi.org/10.1177/0963721418807725

Hilton, D. C., Jarrett, M. A., Rondon, A. T., Tutek, J., & Mulla, M. M. (2020). Increased working memory load in a dual-task design impairs nonverbal social encoding in children with high and low attention-deficit/hyperactivity disorder symptoms. *Child Psychiatry and Human Development*, *51*, 127–137. https://doi.org/10.1007/s10578-019-00915-3

Hoffmann, J. A., von Helversen, B., & Rieskamp, J. (2013). Deliberation's blindsight: How cognitive load can improve judgments. *Psychological Science*, *24*(6), 869–879. https://doi.org/10.1177/0956797612463581

Irwin-Chase, H., & Burns, B. (2000). Developmental changes in children's abilities to share and allocate attention in a dual task. *Journal of Experimental Child Psychology*, *77*(1), 61–85. https://doi.org/10.1006/jecp.1999.2557

Levinson, D. B., Smallwood, J., & Davidson, R. J. (2012). The persistence of thought: Evidence for a role of working memory in the maintenance of task-unrelated thinking. *Psychological Science*, *23*(4), 375–380. https://doi.org/10.1177/0956797611431465

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*, 279–281. https://doi.org/10.1038/36846

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*(6), 1423–1442. https://doi.org/10.1037/0278-7393.22.6.1423

Morey, C. C., Hadley, L. V., Buttelmann, F., Könen, T., Meaney, J.-A., Auyeung, B., Karbach, J., & Chevalier, N. (2018). The effects of verbal and spatial memory load on children's processing speed. *Annals of the New York Academy of Sciences*, *1424*(1), 161–174. https://doi.org/10.1111/nyas.13653

Morey, C. C., Mareva, S., Lelonkiewicz, J. R., & Chevalier, N. (2018). Gaze-based rehearsal in children under 7: A developmental investigation of eye movements during a serial spatial memory task. *Developmental Science*, *21*(3), Article e12559. https://doi.org/10.1111/desc.12559

Pashler, H. (1988). Familiarity and visual change detection. *Perception & Psychophysics*, *44*, 369–378. https://doi.org/10.3758/BF03210419

Pertzov, Y., Manohar, S., & Husain, M. (2017). Rapid forgetting results from competition over time between items in visual working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*(4), 528–536. https://doi.org/10.1037/xlm0000328

Rhodes, S., Jaroslawska, A. J., Doherty, J. M., Belletier, C., Naveh-Benjamin, M., Cowan, N., Camos, V., Barrouillet, P., & Logie, R. H. (2019). Storage and processing in working memory: Assessing dual task performance and task prioritization across the adult lifespan. *Journal of Experimental Psychology: General*, *148*(7), 1204–1227. https://doi.org/10.1037/xge0000539

Riggs, K. J., Simpson, A., & Potts, T. (2011). The development of visual short-term memory for multi-feature items during middle childhood. *Journal of Experimental Child Psychology*, *108*(4), 802–809. https://doi.org/10.1016/j.jecp.2010.11.006

Ristic, J., & Enns, J. T. (2015). The changing face of attentional development. *Current Directions in Psychological Science*, *24*(1), 24–31. https://doi.org/10.1177/0963721414551165

Rouder, J. N., Morey, R. D., Morey, C. C., & Cowan, N. (2011). How to measure working-memory capacity in the change-detection paradigm. *Psychonomic Bulletin & Review*, *18*, 324–330. https://doi.org/10.3758/s13423-011-0055-3

Rueda, M. R. (2013). Development of attention. In K. Ochsner & S. M. Kosslyn (Eds.), *The Oxford handbook of cognitive neuroscience, Vol. 1: Core topics* (pp. 296–316). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199988693.013.0015

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