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The Cognitive Processes Underlying Event-Based Prospective Memory In School Age Children and Young Adults: A Formal Model-Based Study

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Abstract

Fifty 7-year-olds (29 female), 53 10-year-olds (29 female), and 36 young adults (19 female), performed a computerized event-based prospective memory task. All three groups differed significantly in prospective memory performance with adults showing the best performance and 7-year-olds the poorest performance. We used a formal multinomial process tree model of event-based prospective memory to decompose age differences in cognitive processes that jointly contribute to prospective memory performance. The formal modeling results demonstrated that adults differed significantly from the 7-year-olds and 10-year-olds on both the prospective component and the retrospective component of the task. The 7-year-olds and 10-year-olds differed only in the ability to recognize prospective memory target events. The prospective memory task imposed a cost to ongoing activities in all three age groups.

Keywords

children; prospective memory; multinomial model; formal model

Prospective memory, which is remembering to perform an action in the future, is a fundamental function of memory in our daily lives as adults, but children must also begin to remember on their own: remember to ask your mother about the field trip, remember to bring something for show and tell, remember an appointment with a friend. A child who does not develop the ability to successfully perform prospective memory tasks is likely to have difficulty interacting well with parents, teachers, and peers (McCauley & Levine, 2004; Meacham, 1982). The current study compares prospective memory in 7-year-olds, 10-year-olds, and young adults. This study is the first to apply a multinomial process tree model (Smith & Bayen, 2004) to decompose age differences in the cognitive processes that jointly

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contribute to age differences in prospective-memory performance from childhood to young adulthood.

Prospective Memory in Children

For the most part, existing studies show improvement in prospective memory performance during the elementary school years (e.g., Kerns, 2000; Martin & Kliegel, 2003; Maylor, Darby, Logie, Della Sala, & Smith, 2002; Meacham & Dumitru, 1976; Passolunghi, Brandimonte, & Cornoldi, 1995; see Kvavilashvili, Kyle, & Messer, 2008, and Kliegel, Mackinlay, & Jäger, 2008a for recent reviews). The two published studies that compared elementary school children and adults (Kliegel, Mackinlay, & Jäger, 2008b; Ward, Shum, McKinley, Baker-Tweney, & Wallace, 2005) found better performance for young adults than for children. The objective of the present study was to investigate the cognitive processes that underlie these age differences and that may thus explain developmental differences in prospective memory from school age to young adulthood. We included 7-year-olds, 10-year-olds, and adults in our study because age differences in prospective memory performance have been found in comparing these age groups.

Event-based prospective memory tasks

Prospective memory researchers frequently distinguish between time-based and event-based prospective memory tasks (see Kvavilashvili & Ellis, 1996 for alternative classifications). Time-based tasks must be performed after a set amount of time (e.g., take the cupcakes out of the oven after 20 minutes) or at a certain point in time (e.g., meeting your friend at 3:30 p.m.). Event-based prospective memory tasks involve remembering to perform an action when a particular target event occurs, such as remembering to give your mother a message when you see her.

When we perform event-based prospective memory tasks in our everyday lives this often involves interrupting some other activity to perform the task. For instance, a child may need to interrupt a conversation with one friend to hand a birthday invitation to another friend who passes by. In order to capture this aspect of real world prospective memory tasks, laboratory-based prospective memory tasks involve an ongoing task, such as judging if the color of a word matches the color of one of a several colored squares (Smith & Bayen, 2004, 2006). For the prospective memory tasks, participants are asked to make the prospective memory response when a target event occurs during the ongoing task. In the case of the Smith and Bayen studies, participants learned several target words and were asked to try to remember to press a specified key when a target word appeared during the ongoing color matching task.

Theoretical Perspectives on Event-Based Prospective Memory

Prospective memory performance involves both a prospective and a retrospective memory component. The prospective component refers to remembering *that* you have to do something. The retrospective component refers to remembering *when* you have to perform the intended action and remembering *what* the intended action is (Einstein & McDaniel, 1996). The main objective of our study was to determine whether age differences in event-based prospective memory are due to the prospective component, the retrospective component, or both.

Current theories of event-based prospective memory postulate that the prospective component is resource demanding (Smith, 2003, 2008), at least under some circumstances (McDaniel & Einstein, 2007). Therefore, studies on age differences in the availability of cognitive resources are relevant for our predictions. A number of studies have demonstrated that working memory span scores increase over the elementary school years (e.g., Case,

Kurland, & Goldberg, 1982; Conlin, Gathercole, & Adams, 2005; Towse, Hitch, & Hutton, 1998) and that these age groups do not perform as well as young adults on working memory measures (e.g., Cowan et al., 2003, 2005; Swanson, 1999). Furthermore, Cepeda, Kramer, and Gonzalez de Sather (2001) found an increasing developmental trajectory from the age of 7 to young adulthood on measures of perceptual speed, working memory and task switching.

While there is some disagreement in the literature as to whether the prospective component of event-based prospective memory tasks is *always* resource demanding (Smith, 2003, 2008), or only under particular circumstances (McDaniel & Einstein, 2007), current theories of prospective memory agree that non-focal prospective memory tasks rely on resource-demanding processes. A non-focal task is one in which the defining characteristics of the prospective memory target event are not processed as part of the ongoing task activities (McDaniel & Einstein). An example of a non-focal task would be the case in which the target event is a specific word, but the ongoing task involves processing the perceptual characteristics of the stimuli (e.g., the color in which the word is presented). Since children are less likely than adults to engage resource demanding, controlled strategic processes, age differences in the prospective component leading to age difference in task performance are likely to be exhibited in non-focal tasks (McDaniel & Einstein). We, therefore, chose to use a non-focal task in the current experiment.

In addition to investigating developmental differences in the prospective component, our experiment was designed to investigate one aspect of the retrospective component, namely the ability to correctly recognize when the action should be performed.¹ The prospective memory task used in our experiment involved recognizing particular pictures that served as prospective memory target events. Existing studies on age differences in recognition memory for pictures have yielded conflicting results (e.g. Cykowicz, Friedman, Snodgrass, & Rothstein, 2000; Dirks & Neisser, 1977; Mandler & Robinson, 1978; Pezdek, 1987). Thus, we remained neutral with respect to expectations of the effect of age on retrospective recognition of target events.

Investigating Age Differences in the Prospective and Retrospective Components

Typically, prospective memory performance is measured by calculating the proportion of prospective targets to which the participant made the designated prospective memory response. However, as noted above, observable prospective memory task performance requires both prospective and retrospective memory components. If we want to know whether children's difficulties with event-based prospective memory tasks have their roots in age differences in retrospective memory or in age differences in the prospective component, we must find a way to disentangle the retrospective and prospective components of the task.

We employed Smith and Bayen's (2004) mathematical model, namely a multinomial processing tree (MPT) model that was specifically designed to separately measure a prospective component (remembering *that*) and the target discrimination aspect of the retrospective component (remembering *when*) of an event-based prospective memory task in order to investigate potential age differences in both components. The MPT model employed in this study is the first formal model developed for investigating prospective memory (Smith & Bayen, 2004, 2005, 2006). Smith and Bayen successfully used this model

¹The retrospective component involves both recognition of target events and recall of the intended action. Smith and Bayen's (2004) multinomial model measures just the former. Thus, in this study we focus on retrospective recognition of the target events. We took steps to minimize and check for possible differences in recall of the action. First, we used a very simple action (press the space bar). In addition, we had participants practice the prospective memory response when the prospective memory instructions were given. Finally, all participants reported correctly the responses for the ongoing and prospective memory tasks during post-test questioning.

to disentangle differences between young versus older adults in the prospective and retrospective components (Smith & Bayen, 2006). The current study is the first application of a formal model to investigate the development of these components of event-based prospective memory in children.

The Task Paradigm—MPT models are tailored towards specific tasks, and we will first describe our task paradigm before we discuss Smith and Bayen's (2004) MPT model in detail. We developed a prospective memory task that the younger children were able to understand and perform and that was at the same time not so simplistic as to preclude comparison with adults. The task is an adaptation of a paradigm that Smith and her colleagues have used in a number of experiments with young and older adults (Smith & Bayen, 2004, 2006; Smith, Hunt, McVay, & McConnell, 2007). Through careful pilot testing, we developed a simplified version of the task appropriate for use with children. In this simplified version we used non-verbal materials only, used longer exposure times, decreased the complexity of the task, and included breaks.

For our ongoing task, we used a simplified color-matching task. On each trial of the task, a series of three colored squares appeared on the computer screen, followed by a colored picture. The participant was instructed to indicate, with a key press on the computer keyboard, whether the color of the picture was the same as one of the colors of the preceding squares. Participants performed two blocks of 66 color-matching trials (Figure 1). The color-matching task was performed alone in Block 1. We added an event-based prospective memory task in Block 2. For the prospective memory task, participants were supposed to press a specified key if they saw one of three target pictures during the ongoing color-matching task. A control group never received the prospective memory task, but performed the ongoing task alone in both blocks.

The Multinomial Model—MPT models are stochastic models that assume certain cognitive states or processes in participants. The probabilities of these states and processes are estimated from frequencies of observable categorical events. During the last 25 years, MPT models have been developed for a large variety of task paradigms (for a review, see Batchelder & Riefer, 1999). The application of MPT models is becoming increasingly popular in cognitive-aging research (for a review, see Spaniol & Bayen, 2004). Surprisingly, however, the use of MPT models as tools to shed light on issues of cognitive development in children has been relatively rare (Bender, Wallsten, & Ornstein, 1996; Brainerd & Reyna, 1998; Chechile & Roder, 1998; Howe & Brainerd, 1989). This is surprising because MPT models, as the current study demonstrates, are a very useful tool when attempting to disentangle different cognitive processes that may jointly contribute to age differences in task performance.

Figure 2 illustrates the MPT model of event-based prospective memory by Smith and Bayen (2004). The model serves to analyze the data from the combined color-matching plus prospective memory task (i.e., the data from the second task block of the paradigm described above). The model is a joint multinomial model consisting of four processing trees. Each of these processing trees (see Figure 2) represents the cognitive processes that lead to each of the possible responses on a given type of trial. As Figure 2 illustrates, there are four different trial types in the combined color-matching plus prospective memory task: 1) a prospective memory target picture is presented with a color match, 2) a prospective memory target picture is presented without a color match, 3) a picture that is not a prospective memory target (i.e., a distractor item) is presented with a color match, and 4) a picture that is not a prospective memory target is presented without a color match. In each trial, the participant has three response options: "Match", "Non-Match", and "PM Response" (prospective memory response). The model parameters (in *italics*) represent the cognitive processes that

lead to each of the possible responses. Parameter P represents preparatory attentional processes (i.e., the prospective component). Parameter M represents item recognition, that is, the probability to discriminate target pictures from distractor pictures (i.e., remembering *when* to perform the action, the retrospective component). Processes involved in item recognition memory measured by M are thought to be similar to processes involved in simple retrospective old-new recognition-memory tasks. Parameters C_1 and C_2 represent the ability to detect color matches and non-matches, respectively. Parameter c and g represent guessing probabilities.

The first processing tree in Figure 2 illustrates prospective memory target trials with a color match. For example, assume the picture of an airplane was designated as a prospective memory target item. In one trial, the airplane is presented in green color, and the preceding three color squares were yellow, green, and red. There is a probability C_1 for participants to detect the color match. In the example, this is the probability that the participant detects the match of the green color of the airplane with one of the colors of the three preceding squares. With probability P , participants engage in preparatory attentional processes. With probability M , the participant recognizes the prospective memory target, resulting in a correct “PM Response.” In the example, the participant recognizes that the airplane is a target item, and presses the PM response key. If participants engage in preparatory processes, but do not recognize the prospective memory target (with complementary probability $1-M$), they may guess, with probability g , that the picture is a prospective memory target (resulting in a “PM Response”), or with probability $1-g$ that it is not (and then respond “Match”). In the example, the participant does not remember whether or not the airplane is a target item, and therefore either guesses that it is a target, or guesses that it is a distractor. If the color match is detected (e.g., the participant detects that the airplane picture is in a color that matches one of the colors in the preceding squares), but preparatory processes do not occur (with probability $1-P$) a “Match” response is given. If a color match is not detected (e.g., the participant does not detect that the green color of the airplane appeared in one of the preceding squares, with probability $1-C_1$), participants may also engage in preparatory processes (with probability P), or not (with probability $1-P$). If they do, they will either recognize the prospective memory target (with probability M), or not (with probability $1-M$). In the latter case, they may guess that the picture (e.g., airplane) is a prospective memory target (with probability g) or that it is not (with probability $1-g$). In this latter case, participants either guess that the color matches (with probability c) resulting in a “Match” response or that it does not (with probability $1-c$), resulting in a “Non-Match” response. If participants do not engage in preparatory processes (with probability $1-P$), they also either guess that the color matches (with probability c), or that it does not match (with probability $1-c$).

The second processing tree in Figure 2 represents trials in which a prospective memory target picture is shown that does not match any of the three preceding squares in color. This tree includes the same parameters as the first tree with the one exception that it includes parameter C_2 instead of C_1 . Parameter C_2 represents the probability that participants detect the color-non-match. The third and fourth processing trees represent trials in which a picture that is not a prospective memory target is presented with a color match or a non-match, respectively.

Participants’ responses to the four types of trials are tallied, and the model parameters are estimated from these data via maximum-likelihood parameter estimation. To obtain an identifiable model, we set the same parameter restrictions as used previously by Smith and Bayen (2004, 2005, 2006). For the guessing parameters c (probability to guess that the color matches) and g (probability to guess that a picture is a prospective memory target), we set restrictions that assume that participants use probability matching. The probability of a

“Color-Match” guess (parameter c) is matched to the ratio of match trials to total trials (.5 in our experiment). The probability of a “PM Response” guess (parameter g) is matched to the ratio of prospective memory target trials to total trials (.1 in our experiment). This leaves four free parameters, P , M , C_1 , and C_2 . The assumptions implied in the parameter restrictions are theoretically motivated (Smith & Bayen, 2004) and can be tested via goodness-of-fit tests. In eight experiments involving adults of different ages, Smith and Bayen (2004, 2005, 2006) found a good fit of the four-parameter model to data from eighteen different experimental conditions.

Smith and Bayen (2004) validated the model in several experiments with adults. Experimental validation of MPT model parameters is obtained by showing that independent variables have expected and separable effects on specific model parameters (Batchelder & Riefer, 1999). Along these lines, Smith and Bayen (2004, Experiment 1) told one group of participants that the ongoing color-matching task was more important than the prospective memory task, and another group of participants that the prospective memory task was more important than the ongoing task. Model parameters were estimated for each group. As expected, Parameter P was higher in the group that thought the prospective memory task was more important. That is, in order to not miss a target, this group engaged in preparatory processes with higher likelihood than the other group. Parameter P is thus a valid measure of preparatory attentional processes. The same manipulation, as expected, did not affect retrospective-memory parameter M . In another experiment (Smith & Bayen, 2004, Experiment 3), we gave one group of participants more time to study the prospective memory targets than another group. As expected, this manipulation affected the M parameter of the model. That is, participants with longer study time were later more able to recognize targets and distractors. Study time did not affect the P parameter. This was also expected, because study time should not affect the likelihood to engage in preparatory processes. These experiments (and other experiments detailed in Smith & Bayen, 2004) thus showed that the model provides valid estimates of the prospective component (preparatory processes, Parameter P) and the retrospective component (recognition memory, Parameter M) in our task paradigm. A more detailed description of the technical aspects of the modeling is given by Smith and Bayen (2004).

In sum, the MPT model is a measurement model that enables us to separately measure a prospective component of the task in the form of preparatory attentional processes (represented by parameter P) and a retrospective component of the task (represented by parameter M which measures retrospective item recognition memory). Both components jointly contribute to prospective memory accuracy (as measured by proportion of targets correctly responded to). In the current study, we used the model to determine whether expected performance differences in our event-based prospective memory task between younger and older children and between children and adults have their roots in the prospective component of the task, or in the retrospective memory component of the task, or in both.

Measuring the Prospective Component: Cost to Ongoing Task Performance

The estimation of the P parameter of the MPT model is a relatively new method for measuring the prospective component of event-based prospective memory tasks. An indirect index of the prospective component that has been used more often in studies of event-based prospective memory in adults can be found by examining performance on the ongoing task.² If the prospective memory task requires cognitive resources then resources will be drawn

²An additional advantage to measuring preparatory attentional processes via the MPT model arises from the fact that changes in reaction times on the ongoing task are only an indirect indicator of preparatory attentional processes. Reaction times can be influenced by other factors such as the ease of making the recognition decision between target events and distractors.

away from the ongoing task. Assuming that the ongoing task is sufficiently demanding, performance on the ongoing task should suffer when the prospective memory task is embedded in the ongoing task relative to when the ongoing task is performed alone. Accordingly, a number of studies have found longer reaction times on non-target trials of an ongoing task when a prospective memory task was embedded in the ongoing task, as opposed to a control condition in which the ongoing task was performed alone. This cost has been demonstrated in prior studies with adults that involved a similar ongoing task as that used in the present study (Smith & Bayen, 2004, 2006; Smith et al., 2007), and in other studies employing similar paradigms (e.g. Burgess, Quayle, & Frith, 2001; Loft & Yeo, 2007; Marsh, Hicks, & Cook, 2006; West, Krompinger, & Bowry, 2005; but see Smith et al., 2007, for discussion of non-significant findings)

The one study we are aware of that investigated the cost associated with prospective memory performance in children (ages 10 to 19 years of age) was conducted by McCauley and Levine (2004). The focus of this study was on comparing the prospective-memory performance of children who had suffered traumatic brain injury (TBI) with those of controls, thus age comparisons were not made. Both the individuals with TBI and the controls showed a significant cost on reaction times associated with the embedded prospective memory task. Based upon these findings, combined with the assumption of several current theories of event-based prospective memory (McDaniel & Einstein, 2007; Smith, 2003, 2008) that the prospective memory task in the current experiment involves non-automatic processes, we predicted that all three age groups would show a cost to ongoing task performance.

Importantly, however, the cost method does not enable us to assess age differences in a resource-demanding prospective component for the following reason. Information processing increases in speed from childhood to adolescence (Kail, 1991). Younger children were, therefore, expected to perform the ongoing task more slowly than older children, and both groups of children were expected to perform the ongoing task more slowly than adults, leading to age differences in RT in the baseline block that involved the ongoing task only. As explained in Smith and Bayen's (2006) study of adult age differences in event-based prospective memory, interpretation of age differences in RT cost for age groups with unequal baseline RTs is not meaningful because there is likely a non-linear relationship between RT and the use of cognitive resources that RT is supposed to measure. Thus, comparisons of cost to RT do not provide information about the relative extent to which different age groups engage in resource demanding processes. We analyzed the cost to reaction time for each age group; however, we did not make predictions regarding relative costs between groups, given that baseline reaction times were expected to differ between the age groups.

Summary of Predictions

We predicted differences between all three age groups in observable prospective memory performance, with the best performance for adults. We further predicted a cost of our non-focal event-based prospective memory task on the ongoing task in all age groups.

Previous research has shown differences in working memory capacity between 7-year-olds and 10-year-olds and between both of these age groups and adults. In a non-focal event-based prospective-memory task, adults with higher working memory capacity had a higher estimate of model parameter *P* (measuring the prospective component of the prospective memory task) than did adults with lower working memory capacity (Smith & Bayen, 2005). Therefore, we predicted differences between all three age groups in estimates of the prospective component, *P*. The literature on retrospective picture recognition is mixed, thus,

we remained neutral regarding potential age differences in estimates of the retrospective memory component, *M*.

Methods

Design

The study included participants from three age groups: 7-year-olds, 10-year-olds, and adults. Figure 1 provides a schematic overview of the design, which included both a within-subjects baseline and a separate between-subjects control condition (Smith et al., 2007). In this design, all participants complete two blocks of the ongoing task. In Block 1, all participants perform the ongoing task alone. This provides a baseline measure to insure that our conditions (prospective memory vs. control) are well matched at the outset. The instructions in Block 2 of the ongoing task differed as a function of condition. For participants in the prospective memory condition, the prospective memory task is embedded in the Block 2 of the ongoing task. Participants in the control group perform the ongoing task alone in Block 2 (i.e., the control group never receives prospective memory instructions). Within each age group, we assigned about two thirds of participants to the prospective-memory condition, and one third to the control condition.

In addition to the within-subject variable of block (Block 1 and Block 2), the design included the within-subject variable of trial type. In each block of the ongoing task half of the trials were match trials and half were non-match. The order of match and non-match trials was random. Information regarding counterbalancing of stimuli can be found in the materials section.

Participants

We recruited 168 individuals to participate in the study: 61 7-year-olds, 62 10-year-olds, and 45 adults. Children were recruited by sending letters of invitation to parents in three public elementary schools in the city of Würzburg (State of Bavaria, Germany) and surrounding communities. The 7-year-olds were recruited from first-grade classes and the 10-year-olds from fourth-grade classes of the same schools. We obtained written consent from parents and written assent from children as well as permission from the Ministry of Education of the State of Bavaria and from the administrators of the respective schools. The children received a small toy as a token of appreciation for their participation. The adults were undergraduate psychology students at the Universität Würzburg, Germany, who received credit towards their degree requirement, or were recruited by word of mouth and volunteered their participation without compensation. Because the ongoing task involved color-matching, we screened participants for color blindness using the Ishihara test. We also asked participants about their prior experience with computers. No participant was color blind and all reported to have worked on a computer before.

From the original set of participants, we excluded two 7-year-olds because they did not understand the task instructions. One of them thought the target event was to see all three prospective memory target pictures simultaneously, and the other one thought he was supposed to press the space bar for every picture. We had to exclude a third 7-year-old because the experimental session was interrupted by a teacher. We also excluded outliers as determined by baseline performance on the color-matching task. Collapsing across condition (prospective memory and control) we computed the mean and standard deviation for the color-matching task in Block 1 separately for each age group. We excluded participants whose performance was more than two standard deviations above the mean reaction time and/or more than two standard deviations below the mean accuracy of their respective age group. We excluded these individuals because they did not follow the instructions to

respond both fast and accurately. This resulted in the exclusion of eight 7-year-olds, nine 10-year-olds and nine adults. The final samples are described in Table 1. Although, the “7-year-olds” were on average a bit older than seven years, and the “10-year-olds” were on average a bit older than ten years, we refer to these groups as the 7-year-olds and the 10-year-olds for simplicity. Within each age group, the ages of participants did not differ between the control condition and the prospective-memory condition, all $t_s < 1.0$.

Materials

Line drawings of objects were selected from the Snodgrass and Vanderwart (1980) picture set on the basis of the German norms published by Bates et al. (2003). Sixty-six pictures were selected such that the German picture labels contained no more than three syllables. Each picture was classified according to taxonomic category. Targets were selected from the largest of these categories in order to decrease the discriminability of targets and distractors, in an attempt to avoid ceiling effects. The six targets were assigned to two target sets.

Target and distractor pictures were matched according to norms on frequency, naming reaction time, and complexity as provided on the web page for the International Picture Naming Project (Bates et al., 2003). The German frequency of the distractor items ranged from 1.1 to 6.2, with a mean frequency of 2.9. The frequency of the target items ranged from 1.4 to 3.7 with a mean of 2.7. The average picture naming reaction time in a German sample ranged from 663 to 1264 ms, with a mean of 854 ms, for the distractor pictures, and from 768 to 1002 ms, with a mean of 864 ms, for the target pictures. Picture complexity ratings ranged from 6586 to 62243, with a mean of 15000 for the distractor pictures, while the complexity ratings ranged from 8241 to 24585, with a mean of 15907 for the target pictures. Thus, the target and distractor pictures were comparable on the dimensions of frequency, naming time, and complexity. An additional four pictures were selected for practice items.

The 60 distractor pictures were randomly, but evenly, divided into two sets of 30 pictures, one for the first block of color-matching trials and one for the second block. Each picture appeared twice during its designated block. The pictures appeared in a random order once (except that the targets appeared on designated trials), and then again in a different random order. Across participants within age group, the two sets of distractor pictures and the two sets of target pictures each appeared equally often in the first and second blocks. The appearance of each set of target pictures with each set of distractor pictures was also counterbalanced.

The color squares used for the color-matching task were 200 by 200 pixels. Squares were red, blue, green, or yellow outlined by a thin black line. The pictures were black line drawings filled in with red, blue, green, or yellow. Square and pictures were shown on a grey background.

Procedures

Participants were tested in individual sessions lasting approximately 35 minutes for 7- and 10-year olds and 25 minutes for the adults. At the beginning of the experiment, each of the four colors that were to appear during the color matching task was shown on the screen and named by the experimenter who then pressed the space bar to advance to the next color. The four colors were red, green, blue, and yellow. Following the introduction of the colors, the experimenter said that they would try the game at a very slow pace first. The experimenter presented two practice trials during which she controlled the pace of the presentation of the color squares and reviewed what the participant would be doing. The participants made their responses on the keyboard. On each of these slow paced trials the color squares appeared in the order red, green, and blue. The first slow practice trial was a color match trial with the

picture displayed in blue. The second slow practice trial was a color non-match trial with the picture displayed in yellow. Once participants understood the task and how they were to respond, the experimenter said that they would try two more practice trials at a fast pace. Two regularly paced practice trials (one match and one non-match, in random order) were presented at this time. The order of colors and match or non-match was random on these regularly paced practice trials. The practice pictures were used in this practice phase. After completing the two regularly paced practice trials, the experimenter could either advance the program, or repeat these last two practice trials (with different random orders of pictures and colors).

When the practice trials were completed and before the primary task began, a smiley face with a moderately happy face was presented. The experimenter explained that as the game progressed the smiley face would sometimes appear. The participant should try to do well, as this would make the face happier. Once the participant was ready to begin, the experimenter pressed the Enter key to begin the first block of color-matching trials.

On every trial of the color-matching task, three color squares were presented for 900 ms each and each square was followed by a 250-ms blank white screen. Then, a picture was presented and remained on the screen until the participant pushed a response button. Participants responded by pressing one of two keys on the computer keyboard. Labels were placed on the V and N keys. The two keys were labeled with a plus and a minus. The placement of the plus and minus labels on the V and N keys was counterbalanced. Participants were to press the plus key when the color of the picture matched the color of one of the squares on that trial and were to press the minus key if the color did not match. Participants were instructed to respond both fast and accurately. After the response, the screen was blank for 2300 ms before the next trial began. Pilot studies yielded that children tended to look down on the computer keyboard to enter their response and then needed some time to look up again for the next trial. We chose an intertrial interval that is longer than that commonly used in adult studies to ensure that all children had enough time to get ready for the next trial.

Block 1 included 66 trials of the color-matching task. Smiley faces were presented after the 33rd and 66th trial. Each smiley face was progressively happier. Smiley faces were shown for 30 seconds each along with the word *Pause*, allowing a break for the participant. Thus, the presentation of the smiley face rewarded participants for staying on task, helped keep them engaged and gave them a break. At the end of the 30 seconds, the display showed “Ready?” and the experimenter asked the participant to get ready to continue with the color matching task. When the participant was ready the experimenter pressed the Enter key to continue the task.

At the end of the first block, the experimenter praised the participant’s progress and said that they had finished the first half of the color-matching task. Between the first and second blocks, there was a 4-minute delay interval with a filler task to guard against ceiling effects in the prospective memory condition. Before the delay, the instructions differed for the control and prospective memory conditions. Participants in the control condition immediately proceeded to the instructions for the filler task. Participants in the prospective memory condition, on the other hand, received the prospective memory instructions before the delay interval. The experimenter explained that she would like for the participant to try to remember to perform another task while continuing with the color-matching task. The experimenter told the participants that they would see some pictures in a moment and that the participant should try to remember to press the SPACE key every time one of these pictures appeared during the rest of the color matching task. The experimenter pointed to the SPACE key and made sure that the participant could locate the key and asked the participant

to press the SPACE key. The participants were told that when they pressed the SPACE key, they did not need to press the plus key nor the minus key. They were further told that when a target appeared, and they erroneously pressed the plus or minus key, and then remembered that this was a target item, they could still press the SPACE key. The three target pictures were then shown for 3 seconds each, during which time the participant named each picture. The pictures were shown on the screen one at a time in black lines on white background. After the third target picture was presented, the screen was blank and the experimenter asked the participant to describe what they were supposed to do to ensure that the participant understood the instructions. Participants were reminded that they should continue to try to do well on the color-matching task. When the participant was ready, the experimenter pressed the Enter key and the instructions for the filler task were given.

The filler task was a tangram puzzle involving abstract visual patterns. The delay, including time for puzzle instructions, was four minutes. At the end of four minutes, the screen flashed a stop message to indicate that it was time to stop the puzzle. When the participant was ready, the experimenter pressed the Enter key to begin the second half of the color-matching task. Participants were not reminded of the prospective-memory task.

There were 66 trials in the second block of the color-matching task. The three target pictures appeared in random order in Trials 9, 21, and 32. The same target items were repeated in a new random order in Trials 44, 54, and 65. A random half of the trials including targets were match trials and the other half were non-match trials. The 30 trials including distractor pictures were also presented in random order in the first half of the second block, and repeated in a new random order in the second half.

The fourth smiley face (shown with the word *Pause*) and fifth smiley face (shown with the word *End*) were presented at the end of Trials 33 and 66 of the second block in both the control and experimental conditions. The fifth and final smiley face was the happiest, with a complete and large smile, indicating that the participant had achieved the goal of making the face happy.

Following completion of the second block of color-matching trials, the experimenter asked the participants a series of post-test questions. All participants were asked which key they were supposed to press if the color of the picture was a match and which key they were supposed to press if the color did not match. Participants in the prospective memory condition were also asked what key they were supposed to press if the picture was one of the target pictures. All responded correctly to these questions. Participants in the prospective memory condition completed a recognition memory task. The three target pictures were shown on a piece of paper simultaneously and intermixed with three distractor pictures taken from the second block of the color-matching task. The position of the targets in the 2×3 grid was counterbalanced. Participants were asked to circle all pictures they believed to be target pictures.

Results

An alpha level of .05 was used for significance tests, unless otherwise noted. All reported means are accompanied by upper and lower bounds of the 95% confidence interval in brackets.

Prospective memory performance

The analysis of prospective memory performance included only participants from the prospective memory conditions in each age group and only included trials from Block 2. We performed a repeated measures analysis of variance (ANOVA) to analyze the proportion of

prospective-memory targets correctly responded to, shown in Figure 3, as a function of age group and trial type (match vs. non-match).³ Trial type did not significantly affect performance, $F < 1$, $p > .99$, $\eta_p^2 = .00$, and did not interact with age group, $F(2,91) = 1.01$, $MSE = .03$, $p > .36$, $\eta_p^2 = .02$. Age significantly affected prospective memory performance, $F(2,91) = 14.22$, $MSE = .16$, $\eta_p^2 = .24$. The 7-year-olds responded to a significantly smaller proportion of the prospective-memory targets than either the 10-year-olds, $F(1,69) = 9.49$, $MSE = .10$, $\eta_p^2 = .12$, or the adults, $F(1,55) = 22.17$, $MSE = .10$, $\eta_p^2 = .28$. The 10-year-olds did not perform as well as the adults, $F(1,58) = 10.13$, $MSE = .04$, $\eta_p^2 = .15$.⁴

Post-test recognition memory

The analysis of post-test recognition of the prospective memory targets includes only participants in the prospective memory conditions in each age group. The hit rates (HR) and false alarm rates (FAR) from the responses given on the post-test target recognition task are shown in Table 2, along with HR–FAR, the item recognition measure based on the two-high threshold model of item recognition (Snodgrass & Corwin, 1988). We used this measure as our measure of target versus distractor discrimination because the item-recognition part of the MPT model of event-based prospective memory, which we used to analyze the data from the prospective memory task, is also based on a two-high threshold model of item recognition (Smith & Bayen, 2004).⁵ Thus, HR–FAR and the recognition memory parameter M of the MPT model should yield comparable patterns of results. An ANOVA produced a main effect of age, $F(2,91) = 11.08$, $MSE = .64$, $\eta_p^2 = .20$. Seven-year-olds had significantly lower recognition memory than did 10-year-olds, $F(1,69) = 10.93$, $MSE = .85$, $\eta_p^2 = .14$, and adults, $F(1,55) = 13.42$, $MSE = .85$, $\eta_p^2 = .20$. The 10-year-olds and adults did not differ significantly in their post-test target recognition, $F(1,58) = 2.52$, $MSE = .02$, $p > .11$, $\eta_p^2 = .04$. Interpreting the latter non-significant difference is complicated by ceiling performance for the adults. Fortunately, the results of MPT modeling (described below) were not subject to this limitation.⁶

Ongoing color-matching task performance

We examined performance on the ongoing task in order to examine any cost that might be associated with the embedding of the prospective memory task in Block 2 of color-matching

³As is customary, our analysis of prospective memory performance included all target events, even if the targets were not eventually recognized on the post-test questionnaire. Interpretation of post-test recognition results is complicated by the fact that target items that do receive a prospective memory response during the ongoing task are effectively receiving an additional rehearsal relative to targets that do not receive a prospective memory response during the ongoing task. Thus, post-test recognition of the targets can be influenced by whether or not the target received a prospective memory response earlier and therefore post-test recognition is not a pure measure of target memory. Nonetheless, we conducted an analysis of prospective memory performance, excluding targets that were not recognized on the post-test questionnaire. Prospective memory performance for the young adults, whose post-test recognition performance was perfect, remained .98 [.96, 1.00]. When conditionalized on post-test target recognition, the 10-year-olds' prospective memory performance increased by .02 for a mean of .84 [.76, .92], and the 7-year-olds improved by .04 to a mean of .62 [.48, .76]. The main effect of age, as well as all comparisons between age groups, remained significant, all $F_s > 8.68$, all $\eta_p^2_s > .11$.

⁴Prospective memory false alarms, which occur when participants incorrectly perform the prospective memory action on a distractor trial, were not common. The 7-year-olds made the prospective memory response on 3% [1%, 5%] of distractor trials. The rates were even lower for the 10-year-olds, 1% [0%, 2%], and adults, 1% [1%, 1%]. There was a trend for a difference in prospective memory false alarm rates of the 7-year-olds and both the 10-year-olds and adults, $F_s > 3.21$, $p_s < .08$, $\eta_p^2_s = .05$. The 10-year-olds and adults did not differ, $F < 1$, $p > .59$, $\eta_p^2 < .01$.

We also investigated the effects of distractor-target similarity on prospective memory false alarms by dividing the number of incorrect prospective memory responses that were made to related distractors by the total number of incorrect prospective memory responses made to any distractor (related and unrelated to target category). This measure was not affected by age group, $F < 1$, $p > .87$, $\eta_p^2 < .01$. Collapsing across age groups the mean was .64 [.50, .78].

⁵Analyses using the signal-detection theory based measure d' yielded comparable results to those obtained with HR–FAR. While some researchers believe that signal-detection models are preferable to 2-high threshold models (e.g., Wixted, 2007), others argue that both models are at least equally valid as measurement tools (Bröder & Schütz, in press).

⁶Separate analyses produced significant effects of age on both HR and FAR, $F_s > 7.65$, $\eta_p^2_s > .13$. The 7-year-olds had lower HR and higher FAR than both 10-year-olds and adults, all $F_s > 7.29$, all $\eta_p^2_s > .09$. The older children and adults did not differ in HR nor in FAR, both $F_s < 2.70$, both $\eta_p^2_s < .05$. Interpretation of the null effects is complicated by ceiling and floor effects on HR and FAR, respectively, in the young-adult data.

trials. The analysis of ongoing task performance included participants in both the prospective memory and control conditions and included data from Block 1 and Block 2. For both accuracy and reaction time, we examined performance on the four trials that immediately preceded each target trial. As is common when looking for costs in a prospective memory task (e.g., Smith, 2003; Smith & Bayen, 2004, 2006; Marsh, Hick, Cook, Hansen, & Pallos, 2003) we excluded target trials and trials that followed target trials in order to avoid finding a cost associated simply with having to carry out the action or thinking about just having performed the action.

Accuracy—Color-matching task accuracy was subjected to a $2 \times 2 \times 2 \times 3$ ANOVA with the within-subject factors of trial type (match and non-match) and block (first and second) and the between subjects factors of instruction condition (prospective memory versus control) and age group (7-year-olds, 10-year olds, and adults). The main effects of block, $F(1, 133) = 10.86$, $MSE = .01$, $\eta_p^2 = .08$, and age group, $F(2, 133) = 29.58$, $MSE = .02$, $\eta_p^2 = .18$, were qualified by a significant interaction of block and age group, $F(2, 133) = 5.22$, $MSE = .01$, $\eta_p^2 = .07$. No other effects reached significance. To investigate the interaction we conducted separate 2×3 ANOVAs for each block, collapsing over trial type, with the between subjects factors of instruction condition and age. The effect of age was significant for Block 1 baseline accuracy, $F(1,133) = 12.54$, $MSE = .01$, $\eta_p^2 = .16$, and, as expected, instruction condition was not significant and did not interact with age group, $F_s < 1$. Seven-year-olds were less accurate in Block 1, $Mean = .81$, $[.77, .85]$, than were 10-year olds, $Mean = .86$, $[.84, .88]$, $F(1,133) = 12.54$, $MSE = .01$, $\eta_p^2 = .16$. Seven-year-olds were also less accurate than adults, $Mean = .91$, $[.89, .93]$, $F(1,84) = 21.08$, $MSE = .01$, $\eta_p^2 = .20$. The numerical difference in accuracy between the 10-year-olds and adults was not significant, $F(1,87) = 1.94$, $MSE = .01$, $p > .16$, $\eta_p^2 = .02$.

There was also a significant effect of age in the analysis of Block 2 accuracy, $F(2,133) = 28.90$, $MSE = .01$, $\eta_p^2 = .30$. As in Block 1, the younger children, $Mean = .74$, $[.70, .78]$, had lower accuracy levels than did the older children, $Mean = .84$, $[.82, .86]$, $F(1,101) = 21.71$, $MSE = .01$, $\eta_p^2 = .18$, and lower than the adults, $Mean = .91$, $[.89, .93]$, $F(1,84) = 45.78$, $MSE = .01$, $\eta_p^2 = .35$. In contrast to accuracy in Block 1, the difference between the 10-year-olds and adults in accuracy in Block 2 was significant, $F(1,87) = 16.14$, $MSE = .01$, $\eta_p^2 = .16$. The effect of condition (prospective memory versus control) was not significant and did not interact with age in the analysis of Block 2 accuracy, all $F_s < 1$, all $ps > .53$, all $\eta_p^2s < .01$. Thus, the accuracy measure for the color-matching task did not show evidence of a cost, in line with previous studies using a similar task (e.g., Smith, 2003; Smith & Bayen, 2004; but see Experiment 1 of Smith & Bayen, 2006 for an exception). The lack of an increase in performance from the first to the second block does indicate that any increase in reaction time in the second block cannot be explained as a speed-accuracy trade-off.

Reaction times—The analyses of reaction times included only trials on which a correct response was made. Reaction times were subjected to a $2 \times 2 \times 3$ ANOVA with the within-subject factors of trial type and block and the between subject factors of instruction condition and age group. As with the analysis of color-matching accuracy, block and age interacted in the analysis of reaction times, $F(2,133) = 3.68$, $MSE = 80218$, $\eta_p^2 = .05$. Age also interacted significantly with trial type, $F(2,133) = 7.61$, $MSE = 30195$, $\eta_p^2 = .10$. Importantly, there was a significant interaction of block and condition, $F(1,133) = 49.32$, $MSE = 80218$, $\eta_p^2 = .27$.

We followed up the omnibus test with separate $2 \times 2 \times 3$ ANOVAs, with the within-subject factor of trial type and the between subjects factors of instruction condition and age group, analyses for each block. As expected, Block 1 baseline reaction times did not differ as a function of instruction condition, $F < 1$, and condition did not interact with any other

variables, all $F_s < 2.8$, $p > .10$, $\eta_p^2 < .03$. Therefore, the control condition and prospective memory conditions were well matched within each age group with respect to baseline performance. A significant main effect of age group, $F(2,133) = 140.88$, $MSE = 137871$, $\eta_p^2 = .27$, was qualified by a significant interaction of age group and trial type, $F(2,133) = 140.88$, $MSE = 21921$, $\eta_p^2 = .07$. The effect of age group was significant for both match and non-match trials, $F(2,136)s > 120.68$, $MSE = 78470$ and 79445 , $\eta_p^2 = .65$ and $.69$, respectively. For both the match and non-match baseline trials, the 7-year-olds had longer reaction times than did the 10-year-olds, who were, in turn, slower than the adults, all $F_s > 34.33$, all $ps < .001$, all $\eta_p^2s > .27$. We investigated the effects of trial type separately for each age group. For the 7-year-olds, reaction times were not affected by whether the trial was a match trial, $Mean = 1612$ ms [1504, 1720], or non-match trial, $Mean = 1671$ ms [1567, 1775], $F < 1.8$, $p > .18$, $\eta_p^2 = .04$. For the 10-year-olds, baseline reaction times were significantly longer on match trials, $Mean = 987$ ms [930, 1044], than non-match trials, $Mean = 942$ ms [881, 1003], $F(1,52) = 6.27$, $MSE = 8721$, $\eta_p^2 = .11$. Adults also had longer baseline response times to match trials, $Mean = 713$ ms [660, 766], than non-match trials, $Mean = 669$ ms [606, 732], $F(1,35) = 6.13$, $MSE = 5585$, $\eta_p^2 = .15$.

Response times for Block 2 of the ongoing task are shown in Table 3. In contrast to baseline performance, there was, as expected, a significant effect of condition in Block 2, $F(1,133) = 26.66$, $MSE = 297751$, $\eta_p^2 = .57$. The significant effect of age group, $F(2,133) = 89.32$, $MSE = 297751$, $\eta_p^2 = .57$, was qualified by a significant interaction of trial type and age group, $F(2,133) = 3.63$, $MSE = 34805$, $\eta_p^2 = .05$. We investigated the interaction with separate 2×2 ANOVAs, with the between-subject factor of condition and within-subject factor of trial type, for each age group. In the case of the 7-year-olds, the trend for an effect of trial type did not reach significance, $F(1,48) = 3.19$, $MSE = 68093$, $p < .09$, $\eta_p^2 = .06$, and trial type and condition did not interact, $F < 1.75$, $p > .18$, $\eta_p^2 = .03$. Importantly, there was a significant effect of condition for the 7-year-olds, $F(1,48) = 4.44$, $MSE = 523321$, $\eta_p^2 = .04$, indicating that the prospective memory task imposed a cost to the ongoing task. Similarly, the effect of trial type was not significant and did not interact with condition for the 10-year-old group, $F_s < 1$, $ps > .34$, $\eta_p^2s < .02$. The main effect of condition was once again significant, $F(1,51) = 11.84$, $MSE = 225144$, $\eta_p^2 = .19$. For the adults, the effect of trial type approached, but did not reach significance, $F(1,34) = 4.17$, $MSE = 7935$, $p < .06$, $\eta_p^2 = .11$, and trial type and condition did not interact, $F < 1$, $p > .82$, $\eta_p^2 < .01$. As with the children, the effect of condition was significant for the adults, $F(1,34) = 33.56$, $MSE = 8210$, $\eta_p^2 = .50$. Thus, as predicted, the addition of the non-focal prospective memory task imposed a cost to the ongoing task in all three age groups.

Multinomial Modeling Results

Based on the response frequencies in Block 2 for the prospective memory conditions, reported in the Appendix, we evaluated the fit of Smith and Bayen's (2004) multinomial model to our data and estimated model parameters with the help of the HMMTree computer program by Stahl and Klauer (2007). We performed a goodness-of-fit test for the four-parameter MPT model described in the introduction against the data. For this test, we used the log-likelihood ratio statistic, G^2 , which is asymptotically chi-square distributed (Hu & Batchelder, 1994). We conducted power analyses for this test with the G*Power 3 program (Faul, Erdfelder, Lang, & Buchner, 2007). Because of the large number of observations ($N = 6204 = 94$ participants $\times$ 66 observations per participant), the conventional α -level of .05 would have yielded a power of .99999 to detect even a small effect ($w = .1$, Cohen, 1988). Thus, in order to avoid rejecting a model because of minute deviations of the data from model predictions, we performed a compromise power analysis (Erdfelder, Faul, & Buchner, 1996; see Buchner, Erdfelder, & Vaterrodt-Plünnecke, 1995, and Vaterrodt-Plünnecke, Krüger, & Bredenkamp, 2002, for other examples of compromise power analyses for MPT

model tests). In this analysis, we set $\alpha = \beta$ because protection against both types of error seemed equally important. The compromise power analysis yielded a level of $\alpha = \beta = .0013$. Thus, values of $G^2(12)$ smaller than the critical value of 32.25 indicate an adequate fit of the model to the data. For our data $G^2(12)=29.46$.

Figure 4 shows the estimates of the four free model parameters for each age group. In order to compare the parameter estimates across age groups we conducted significance tests for each parameter by setting the value of a given parameter to be equal between two groups. If this constraint significantly reduces the fit of the model (as indicated by a test statistic $G^2(1)$ greater than 3.84 when alpha is set to .05), this means that the two groups differ significantly in the estimates of that particular parameter. The values of $G^2(1)$ are shown in Table 4 for each comparison. Seven-year-olds and 10-year-olds showed significant differences on all parameters but P . This means that the advantage for 10-year-olds relative to 7-year-olds in observable prospective memory performance was due entirely to a higher ability to correctly discriminate between targets and distractors. Both groups of children differed from adults in terms of preparatory attentional processes and in terms of retrospective-recognition memory. That is, children were less likely than adults to engage in preparatory attentional processing. Adults were also better at discriminating targets and distractors relative to both groups of children.

The parameters related to the ongoing task also showed age differences. Adults and 10-year-olds were better than 7-year-olds at detecting color matches and non-matches. Ten-year-olds were not as good as adults at detecting that a color matched, but were equally good as the adults at recognizing a non-match.

Discussion

We compared event-based prospective memory performance in 7-year-olds, 10-year-olds, and adults. Consistent with previous work involving similar age comparisons, adults were more likely to perform the prospective memory task than were both groups of children, and older children outperformed younger children (e.g., Kliegel et al., 2008b; Ward et al., 2005). We examined the effect of the embedded prospective-memory task on performance on the ongoing color-matching task. Consistent with studies involving young and older adults (e.g., Marsh et al., 2003; Smith, 2003; West et al., 2005) and one previous study involving children (McCauley & Levine, 2004), we found a significant cost to ongoing task performance in each age group. The demonstration of a cost to the ongoing task is important in that it provides an indirect indicator that participants engaged resource demanding processes (e.g., preparatory attentional processes) when they performed our non-focal prospective memory task. However, because of baseline reaction time differences among the age groups, we cannot use ongoing task performance to investigate potential age differences in the extent to which participants engage in these resource demanding processes. Therefore a different approach is needed to determine how the three age groups might differ in the cognitive processes that underlie prospective memory performance.

With this goal in mind, we applied Smith and Bayen's (2004) multinomial process tree model to the current data. This is the first application of a mathematical model to the investigation of age differences in prospective memory in children. The MPT model provides a means for independently measuring the prospective component (remembering *that* you have to do something) and the retrospective recognition component (remembering *when* you have to do something) of event-based prospective memory tasks. The model results showed that the adults differed from the 7-year-olds and the 10-year-olds on both the prospective component and the retrospective component of the task. The two groups of children differed from each other on the retrospective component, but not the prospective

component of the task. Thus, our predictions regarding age differences were only partly supported by the model-based results.

Based upon studies showing increased working memory spans in young adults relative to older children and older children relative to younger children (e.g., Case et al., 1982; Cowan et al., 2003, 2005), combined with evidence that working memory resource availability is related to the estimates of the prospective component P (Smith & Bayen, 2005), we expected to find age differences among all three age groups in the prospective component of the current task. Consistent with this prediction, estimates of P were higher for adults than for older and younger children. However, the observed difference in prospective memory performance between 7- and 10-year-olds was not due to an age related difference in the prospective component. We were able to show this because the formal model allows us to control for retrospective recognition-memory failure by measuring P independently of recognition memory. The difference in prospective memory performance between 7- and 10-year-olds was entirely due to differences in the ability to correctly discriminate targets and distractors, that is, to differences in the retrospective component. Results from the post-test target recognition test also show that 7-year-olds had poorer ability to discriminate targets and distractor items. However, only via formal modeling were we able to show that this age difference in retrospective memory was the *sole* basis for the differences in prospective-memory performance between 7- and 10-year-olds in this experiment. The multinomial modeling results, particularly those contrasting 7- and 10-year olds, thus provide a nice example of how formal modeling can increase the information gleaned from studies of prospective memory. Although all three age groups showed a cost to ongoing task performance, indicating that all three groups were devoting resources to the prospective memory task, there are limitations in interpreting the reaction time data due to baseline differences, as noted above. If we had simply observed prospective memory performance and ongoing task performance we could have speculated on factors that were contributing to the age difference, but the model provides a means of measuring the effects of age on the underlying processes.

Our results regarding children's monitoring in an event-based task converge with the findings from two studies that used time-based tasks and involved children in similar age ranges as those in our study. In both those studies, the prospective memory task had an explicit monitoring component. Kerns (2000) developed a driving video game that involves the prospective memory task of remembering to refuel a car with gas when the gas gauge fell below a quarter of a tank. Participants had to press a key in order to display the gas gauge (the explicit monitoring component). Kerns' study involved children ranging in age from 7 to 12 years. The 7-year-olds were more likely than the 12-year-olds to run out of gas (i.e., the younger children had more prospective memory failures, as in the current study), despite showing a similar pattern in checking the gas gauge as the older children.

The Kerns task involved a prospective component (remembering that something needed to be done) and retrospective components, namely remembering what to do (refuel the car) and when to do it (when the tank was less than a quarter full). The fact that the children in both age groups showed similar levels of checking the gas gauge indicates that the children were equally able to remember that they needed to do something, but the younger children may have been less successful at recognizing when they should carry out the action or at remembering what the action was. Therefore, just as with the 7-year-olds in the current study, the younger children in the Kerns study were apparently engaging in preparatory attentional processing, but failed to recognize the appropriate signals to carry out the intended action. However, since there were no separate measures of the prospective and retrospective components in Kerns' study, we cannot directly compare our study with Kerns' regarding the retrospective component.

In another study, Nigro, Senese, Natullo, & Sergi (2002) found no age effects on clock checking (i.e., the monitoring component) in a time-based task with children ranging from 7 to 11 years old. Clock-checking in the Nigro et al. study serves as an indicator of the prospective component: the children remembered *that* they needed to do something. As in the current experiment, the prospective component did not differ between younger and older children.

The results of the present study, the Kerns (2000) study, and the Nigro et al. (2002) study provide converging evidence that control processes involved in remembering *that* something must be done, although not fully developed by the age of 10, might not be undergoing dramatic changes in the early elementary school years. In a time-based task with 10-year-olds and 14-year-olds, Ceci and Bronfenbrenner (1985) found more monitoring in the older group. Consistent with these results, we found an increase in preparatory attentional processing for adults relative to children. Thus, the results from the current study, in conjunction with prior research, point to an improvement in the ability to remember *when* something must be done between the ages of 7 and 10, with continuing improvement into young adulthood of remembering both the *that* and the *when* aspects of event-based prospective memory.

The current results have implications for understanding performance differences in event-based prospective memory in children and adults. Even older children may not be able to remember to perform delayed intentions in complex situations as well as older adults. Therefore, children may require additional reminders relative to adults in order to increase successful task completion. For instance, a child's routine before going to bed could include the request by the parent that the child explicitly think about what she needs to bring to school the next day. In this way the parent is eliminating the need for the child to engage in preparatory attentional processing in the midst of the busy morning rush.

The difference in the retrospective component between younger and older children and adults points to the need to take steps to increase the discriminability between targets and distractors in order to compensate for differences in target recognition. Decreasing the similarity between targets and distractors has been shown to improve retrospective recognition of target events in a prospective memory task (Smith & Bayen, 2004). This could be applied to circumstance to aid children, especially younger children, in correctly recognizing the target signals for performing a future action. For instance, if a child needs to remember to bring a certain item for show-and-tell, it may be wise to place this item, in the absence of similar potentially distracting items, somewhere near the door on the way out of the house. However, if several children have similar items in this same location, this could decrease the discriminability of the particular signaling item for an individual child, thereby reducing the likelihood of successful remembering. The fact that both the retrospective and prospective components are developing from childhood to adulthood points to a need to consider multiple aspects of a task when trying to aid children in performance of these tasks. While our study points to task components that children have difficulties with and that may be targets for intervention and education, we have not empirically investigated ways to improve prospective memory performance in children. This is an important research task for the future.

There are other limitations to our study that point to the need for further research. One limitation is that we do not know *why* the younger children did not fare so well with regard to the retrospective recognition component. Possibly, they failed to spontaneously use encoding strategies (Sykes, 1976). Another possible explanation is based upon findings of lower working memory resources on the part of younger children (e.g. Case et al., 1982; Conlin et al., 2005; Towse et al., 1998). This may have an impact on encoding as well as

recognition of the target pictures. We know that the prospective memory component in our task paradigm requires working-memory resources (Smith & Bayen, 2005) and the young children did as well as the older children on this component of the task. Perhaps, by allocating a large part of their working memory resources to the prospective component, the retrospective component suffered. The younger children may have relied more on familiarity processes in picture recognition and less on resource-demanding recollective processes. Further research is needed to tease apart the underlying causes for age differences in different components of prospective memory tasks.

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Figure 1.
Schematic overview of the experimental design.

Figure 2.

Multinomial model of event-based prospective memory. PM = prospective memory; P = probability of engaging in preparatory attentional processes; M = probability of discriminating between targets and distractors (retrospective component); C_1 = probability of detecting a color match; C_2 = probability of detecting that a color does not match; g = probability of guessing that a word is a target; c = probability of guessing that a color matches. Adapted from "A multinomial model of event-based prospective memory" by R. E. Smith and U. J. Bayen, 2004, *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 30, p. 758.

Figure 3.

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Proportion of prospective memory target events receiving a prospective memory response.

Error bars represent 95% confidence intervals.

Figure 4.

Multinomial model parameter estimates. P = probability of engaging in preparatory attentional processes; M = probability of discriminating between targets and distractors (retrospective component); C_1 = probability of detecting a color match; C_2 = probability of detecting that a color is not a match. Error bars represent 95% confidence intervals.

Table 1

Sex and age of participants

	<i>N</i>	<i>N</i> control	Sex		Age	
			Female	<i>M</i>	Range	
7-year-olds	50	16	29	7;5	(6;8 – 8;0)	
10-year-olds	53	16	29	10;7	(9;5 – 11;11)	
Adults	36	13	19	24;2	(18 – 31)	

Note. *N* = total number; *N* control = number in control group. Age is in years; months. *M* = mean.

Table 2

Hit rates (HR), false alarm rates (FAR), and HR -- FAR in the post-test recognition task.

Age Group	HR -- FAR		HR		FAR	
	M	CI	M	CI	M	CI
7-year-olds	.70	[.56, .84]	.85	[.77, .93]	.16	[.08, .24]
10-year-olds	.94	[.88, 1.0]	.97	[.93, 1.0]	.04	[.00, .08]
Adults	1.0	-	1.0	-	.00	-

Notes. M = Mean; CI = 95% confidence interval

Table 3

Reaction times (in ms) for Block 2 of the ongoing color-matching task.

		Trial Type			
		Match		Non-match	
Age Group	Instruction Condition	<i>M</i>	CI	<i>M</i>	CI
7-year-olds	Control	1684	[1457, 1911]	1858	[1582, 2134]
	Prospective Memory	2085	[1918, 2252]	2111	[1909, 2313]
10-year-olds	Control	995	[879, 1111]	999	[860, 1138]
	Prospective Memory	1371	[1255, 1487]	1315	[1186, 1444]
Adults	Control	606	[528, 684]	557	[488, 626]
	Prospective Memory	1024	[928, 1120]	984	[874, 1094]

Notes. *M* = Mean; CI = 95% confidence interval

Table 4

$G^2(1)$ values for tests of differences in parameters across age groups.

Age Comparison	Parameter			
	<i>P</i>	<i>M</i>	<i>C</i> ₁	<i>C</i> ₂
7-year-olds vs. 10-year-olds	0.61	39.41 *	74.75 *	12.86 *
7-year-olds vs. adults	7.02 *	69.66 *	111.83 *	18.54 *
10-year-olds vs. adults	6.74 *	4.88 *	10.71 *	1.52

Notes.

* $G^2(1) > 3.84$ indicates a significant group difference in parameter estimates, $p < .05$. *P* = probability of engaging in preparatory attentional processes; *M* = probability of discriminating between targets and distractors (retrospective recognition memory); *C*₁ = probability of detecting a color match; *C*₂ = probability of detecting that a color does not match.

Appendix

Response Category Frequencies

Age Group	Item Type	Response Type		
		Match	Non-Match	PM Response
7-year-olds	PM Target, Color Matches	23	19	60
	PM Target, Color Does Not Match	18	25	59
	Distractor, Color Match	684	298	38
	Distractor, Color Does Not Match	195	799	26
10-year-olds	PM Target, Color Matches	18	5	88
	PM Target, Color Does Not Match	5	12	94
	Distractor, Color Matches	931	167	12
	Distractor, Color Does Not Match	163	936	11
Adults	PM Target, Color Matches	0	0	69
	PM Target, Color Does Not Match	2	1	66
	Distractor, Color Matches	617	68	5
	Distractor, Color Does Not Match	85	600	5

Note: PM = prospective memory. Empty cells were replaced by 1 when modeling the data.