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Developmental Changes in Item and Source Memory: Evidence From an ERP Recognition Memory Study With Children, Adolescents, and Adults

Volker Sprondel, Kerstin H. Kipp, and Axel Mecklinger
Saarland University

Event-related potential (ERP) correlates of item and source memory were assessed in 18 children (7–8 years), 20 adolescents (13–14 years), and 20 adults (20–29 years) performing a continuous recognition memory task with object and nonobject stimuli. Memory performance increased with age and was particularly low for source memory in children. The ERP difference between first presentations of objects and nonobjects, reflecting generic novelty processing, showed only small developmental changes. Regarding item memory, adults showed the putative ERP correlates of familiarity and recollection, whereas ERP effects in children and adolescents suggested a strong reliance on recollection. ERP correlates of source memory refined with age, suggesting maturation of strategic recollection between childhood and adolescence and the development of postretrieval control until adulthood.

The development of recognition memory from childhood into young adulthood can be characterized as a continuous increase in memory accuracy, both in terms of quantity and quality (Ofen et al., 2007). Still an important question is whether age-related changes in behavioral performance are due to different memory functions developing at different rates. In the present study, we investigated the development of item and source memory by means of event-related potentials (ERPs).

Item and Source Memory and Their ERP Correlates

Among episodic memory functions, memory for events (item memory) can be distinguished from memory for the origin of a particular event (source memory). Item memory tasks require the discrimination between previously studied and new events and can be solved via the reliance on the relative familiarity of old and new items. Conversely, in source memory tasks, subjects are required to retrieve contextual details of a study episode, such as the color in which an item was presented in, for which recollection is necessary. In addition, source memory relies to a greater degree upon controlled memory processes (Johnson, Hashtroudi, & Lindsay, 1993). These include strategic search operations for the task-relevant source-defining attributes, as well as monitoring and evaluative processing of the retrieved memory contents.

ERPs provide an important methodological approach for the study of item and source memory development. ERPs that are lime-locked to the onset of a memory test stimulus show more positive waveforms for old (studied) compared to new (not studied) conditions, known as the ERP old/new effect. Based on differences in scalp topography, time course and sensitivity to experimental variables, a family of old/new effects has been identified which provide correlates of the processes that underlie item and source memory in adults (Friedman & Johnson, 2000; Mecklinger, 2000).

The ERP correlates of item memory have been identified within the dual-process framework, according to which recognition memory is based on two subprocesses: familiarity and recollection. Familiarity is viewed as a fast assessment of the global similarity between study and test materials and is reflected by a midfrontal old/new effect

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Correspondence concerning this article should be addressed to Volker Sprondel, Department of Psychology, Saarland University, P.O. Box 151150, D-66123 Saarbrücken, Germany. Electronic mail may be sent to v.sprondel@mx.uni-saarland.de.

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between 300 and 500 ms. This effect has been found for new words that share perceptual and conceptual features with studied words and are erroneously endorsed as ''old'' (Curran, 2000; Nessler, Mecklinger, & Penney, 2001). Further evidence linking the midfrontal effect to familiarity comes from its sensitivity to variables influencing familiarity strength, such as response criterion (Azimian-Faridani & Wilding, 2006), response confidence (Woodruff, Hayama, & Rugg, 2006), word frequency (Stenberg, Hellman, Johansson, & Rosén, 2009), and response speed (Mecklinger, Brunnemann, & Kipp, 2011). The effect has also been dissociated from recollection, since it is not modulated by the amount of retrieved source information (Wilding, 2000). A second ERP old/new effect observed over parietal sites between 400 and 700 ms is generally taken to index recollection because it is sensitive to the amount of retrieved information. This claim is further supported by the sensitivity of the parietal old/new effect to manipulations of recollection, including the accuracy of source judgments (Wilding, 2000; Wilding & Rugg, 1996) and the depth of study processing (Rugg et al., 1998). For an overview of the empirical evidence supporting the functional dissociation between the ERP signatures of recollection and familiarity, see Rugg and Curran (2007).

Of additional interest to the data reported here are reports of a frontal old/new effect for the P200 component (Curran & Dien, 2003; Mecklinger & Jäger, 2009). Discussion of this ERP modulation has centered the possibility that it reflects perceptually based matching processes related to implicit memory (Evans & Federmeier, 2007).

ERP correlates of source memory have often been observed in studies using exclusions tasks (see Jacoby, 1991). This procedure requires subjects to respond ''old'' to items from one of two study sources (*targets*) and to respond ''new'' to items from the other source (*nontargets*) as well as to new (unstudied) items. Although task instructions emphasize only target retrieval, recollection of nontarget information (in the following: *strategic recollection*) can be used to reject nontargets and, in this way, is beneficial for source task performance. This view receives support from paradigms in which reliable parietal old/new effects have been observed for nontargets (Fraser, Bridson, & Wilding, 2007; Wilding, Fraser, & Herron, 2005). A further electrophysiological correlate of source memory observable for nontargets is a late right-anteriorly distributed old/new effect (e.g., Dzulkifli & Wilding, 2005). This right-frontal effect is frequently observed in memory retrieval tasks requiring a high amount of cognitive control for monitoring the outputs of retrieval processes and, by this, is taken to reflect postretrieval monitoring processes (Hayama, Johnson, & Rugg, 2008; Werkle-Bergner, Mecklinger, Kray, Meyer, & Düzel., 2005).

The Development of Item and Source Memory

The close relation between source memory and control functions has promoted the idea that the development of source memory follows a more protracted time course than the development of item memory (Cycowicz, Friedman, Snodgrass, & Duff, 2001). An increasing number of neuroimaging studies suggests that the control processes responsible for source memory are supported by the prefrontal cortex (PFC; e.g., Raye, Johnson, Mitchell, Nolde, & D'Esposito, 2000). Given the delayed maturation of the PFC in late adolescence until young adulthood (Gogtay et al., 2004; Sowell, Thompson, Tessner, & Toga, 2001), such processing might be attenuated in younger age groups relative to adults.

In line with this are reality monitoring experiments that indicate that children experience particular difficulties in source monitoring when sources are highly similar to one another (Lindsay, Johnson, & Kwon, 1991). For instance, 8-year-old children were found to make more source misattributions than adults when discriminating between imagined and actual actions that involved the same actor but not if these actions involved different actors (Lindsay et al., 1991). Presumably, as source similarity increases, so does the need to draw upon control processes that select and evaluate task-relevant source information. This is in accordance with the view that memory control processes are less matured in preadolescent children (Cycowicz et al., 2001).

Developmental recognition memory studies using ERP measures are scarce and to some extent are heterogeneous in their methodologies. However, in item memory tasks, the ERP correlate of recollection is reliably observable in school-aged children (Cycowicz, Friedman, & Duff, 2003; Czernochowski, Brinkmann, Mecklinger, & Johansson, 2004; van Strien, Glimmerveen, Martens, & de Bruin, 2009). Using an item memory task with picture items, Cycowicz et al.(2003) showed similar centro-parietal old/new effects for children, adolescents (aged 10 and 13 years, respectively), and adults. Similarly, using pictures as retrieval cues, Czernochowski et al. (2004) demonstrated left-parietal old/new effects for children aged 6–8 and 10–12 years, albeit at a longer latency relative to young adults. These findings suggest that recollection is available for item memory judgments by middle childhood.

The ERP correlate of familiarity is less reliably observed in younger age groups (Czernochowski, Mecklinger, & Johansson, 2009; Friedman, de Chastelaine, Nessler, & Malcom, 2010; Hepworth, Rovet, & Taylor, 2001). To compare ERP indices of item and source memory in 10- to 12-year-olds and adults, Czernochowski et al. (2009) employed a continuous recognition memory paradigm that was previously designed by Schnider and colleagues to measure memory for temporal context independently from item memory (see Schnider, 2003, for a review). In the item memory task, only adults showed an early old/new effect reflecting familiarity-based remembering. A second age-related difference was that a large frontally distributed negativity associated with new items in the children's group was positively correlated with memory accuracy. The specificity of this finding to new items allows for the possibility that children adopted a task-specific encoding strategy by which more attention is devoted to the novelty than to the oldness of the test items (Czernochowski et al., 2009).

However, in a recent study, an early frontal old/new effect was observed in 8- to 10-year-old children and adults when ERPs were recorded under speeded response conditions that fostered familiarity-based remembering (Mecklinger et al., 2011). This suggests that children are able to recruit familiarity-based processes under experimental conditions in which recollection is not yet available.

With respect to the ERP correlates of source memory, considerable age differences between children and adults have been observed. Two ERP studies have examined source memory in 6- to 12-year-old children and young adults by defining sources either by the study modality of the test items (photos vs. spoken words; Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005) or by the temporal order of item presentation in the continuous recognition paradigm mentioned above (Czernochowski et al., 2009). While the adults' ERP data showed reliable effects of nontarget retrieval (Czernochowski et al., 2005, 2009) and postretrieval monitoring (Czernochowski et al., 2005), in the children groups these ERP effects were absent and were accompanied by elevated false alarm rates for nontargets.

Taken together, these ERP findings suggest different developmental trajectories for item and source memory. For item memory, ERP old/new effects in children indicate that familiarity and recollection are available at early school age. In contrast, the controlled retrieval of source information is considerably less efficient and ERP correlates of source memory cannot reliably be observed up to the age of 12 years.

Aims and Predictions

The first goal of the present study was to examine the developmental trajectories of item and source memory and their respective ERP correlates during childhood and adolescence. ERP data on the mechanisms mediating source memory in adolescents are highly relevant for a comprehensive understanding of the development of item and source memory. As various types of cognitive control functions mature by the age of 10 (Paus, 2005), we wanted to investigate how these putative age-related improvements in cognitive control map onto developmental changes in source memory. A special focus of the present study, therefore, was on the early adolescent years, achieved by comparing the behavioral and ERP correlates of item and source memory in children (7–8), adolescents (13–14), and young adults. Similar to Czernochowski et al. (2009), we employed a version of the continuous recognition memory task reported by Schnider, Valenza, Morand, and Michel (2002) with two successive runs. The first run served as a measure of item memory, whereas source memory was tested by means of an exclusion task in the second run.

We expected different age-related patterns of memory performance for item and source memory, characterized by particularly low source discrimination for children. Adolescents were expected to show higher performance measures relative to children especially for source memory. On the other hand, regarding the prolonged maturation of the PFC throughout and beyond adolescence (Sowell et al., 2001), the adolescents' source memory performance might fall in between those of the child and the adult groups.

Based on previous developmental ERP studies, we expected larger age differences for the ERP correlate of familiarity than recollection in the item memory task. In addition, since P200 repetition effects have been recently reported in school-aged children using continuous word recognition (van Strien et al., 2009), comparable early old/new modulations were expected in the item memory task, irrespective of age. For source memory, a parietal old/new effect for nontargets should be present in adults but not in children. Furthermore, the later right-frontal old/new effect taken to reflect postretrieval monitoring should be present for nontargets in the adult group. As was the case with the predictions for source memory performance, adolescents were expected to exhibit evidence of both strategic recollection and of postretrieval monitoring, although these effects might be less evident compared to adults.

The second goal of the study was to explore electrophysiological correlates of visual novelty processing in children. Czernochowski et al. (2009) suggested that the frontal negativity, an often observed characteristic of children's visual ERPs (Czernochowski et al., 2005; Marshall, Drummey, Fox, & Newcombe, 2002), is related to the detection of novel events that are especially salient for children with respect to semantic learning. Novelty or saliency processing has also been taken to account for a similar frontal negative deflection, the Nc, in response to unfamiliar events in infants (de Haan, Johnson, & Halit, 2003) and 4-year-olds (Carver et al., 2003). It is possible, therefore, that the frontal negativity in children reflects a similar process to the visual ''novelty N2'' in adults (Folstein & van Petten, 2008). This component is particularly sensitive to the mismatch between an unfamiliar stimulus and preexperimentally existing knowledge (Daffner et al., 2000).

To examine age-related changes in the neural correlates of generic novelty processing, we employed two kinds of pictures in the memory task: unfamiliar nonobjects and familiar objects. We compared the ERPs to first presentations of nonobjects to first presentations of objects (in the following: *generic novelty effect*). If frontal ERPs in children are particularly sensitive to generic novelty, there should be larger negativities to nonobjects compared to objects and this effect should be different from the neural correlate of immediate novelty/familiarity processing, that is, the comparison between first and second presentations of familiar objects.

Throughout the task, nonobject and object items were presented in an intermixed fashion and with the same number of repetitions. As the majority of previous developmental ERP memory studies have used preexperimentally familiar stimulus materials, all predictions regarding the effects of item and source memory were tested with object items only, to assure comparability with these studies.

Method

Participants

Eighteen 7- to 8-year-old children (mean age = 8.1 ± .5; 10 male), twenty 13- to 14-year-old adolescents (mean age = 13.7 ± .6; 10 male), and twenty 20- to 29-year-old adults (mean age = 24.4 ± 3.6; 9 male) participated in the study. Seven additional subjects (five children, two adolescents) were excluded from the analyses because a relatively low performance level and a high level of electrooculogram (EOG) artifacts led to an insufficient number of artifact-free ERP trials in at least one of the relevant experimental conditions. The data from one other child was excluded because of extremely low performance. All participants were right-handed and native German speakers. They reported to be in good health and having normal or corrected-to-normal vision. Participants (respectively children's and adolescent's parents) gave informed consent and received €8/hour for participation.

Stimuli

Two kinds of visual stimuli were used for the memory task: objects and nonobjects. Eighty-six object stimuli were selected from a colored version of the Snodgrass and Vanderwart line drawings (Rossion & Pourtois, 2004). Eighty-six nonobject stimuli were created by rearranging various colored pictures forming preexperimentally novel pictorial information. Figure 1 provides two examples from each of the two stimulus categories. In each category, 14 items were used as practice items, 30 as filler items, and 42 as experimental items. Each picture was framed within an area of 200 × 200 pixels.

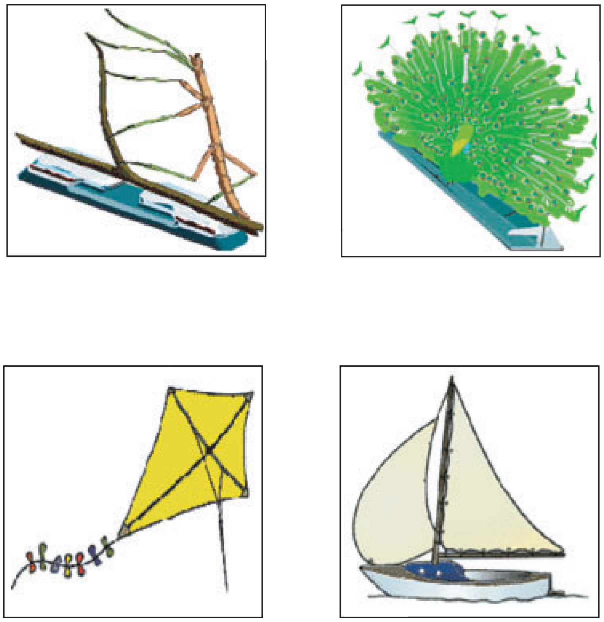

Figure 1. Two examples of the nonobject stimuli (top row) and the object stimuli (bottom row) used in the task.

Procedure

The participants sat in a comfortable chair located 1 m in front of a 19-in. computer monitor throughout the experiment. The whole session lasted for approximately 2½ hr, including setting up the EEG cap.

Before the first run, participants were told that they would see pictures depicting either known objects or rather fanciful figures, and that the pictures would be repeated at various points. The task instructions were to attend carefully to the pictures and judge each item for its repetition status by pressing the *new* button for first presentations and the *old* button for repetitions. Each index finger was assigned to one of two keys on an external key pad and the assignment of response key to old/new status was balanced across participants.

In the first run, 42 object and 42 nonobject items were presented in randomized order and repeated with lags varying between 10 and 15 intervening items. In order to include the lag manipulation and meet the experimental constraint that items featuring the same repetition status did not occur more than four times consecutively, 30 additional filler items (15 object and 15 nonobject items) were included. These items were also repeated at variable lags. The experimental conditions in the first run entering subsequent analyses were first presentations (new) of both object and nonobject stimuli and the repetitions (old) of objects. Nonobject repetitions were included in the procedure in order to equalize old/new probabilities.

Both runs were separated by a 10-min break. Prior to the second run, participants were told that they would now be presented with pictures, some of which either had already been seen in the first run or were new. The task instruction was to judge each item solely according to its within-run repetition status and to ignore across-run repetitions. That is, items repeated from the first run and presented for the first time in the second run had to be judged as *new* (nontargets). When these items were repeated within the second run, they had to be judged as *old* (targets).

Thus, each of the 42 objects and the 42 nonobjects studied in the first run was repeated two more times in the second run in a pseudorandomized order. In addition, 30 additional filler items (15 object and 15 nonobject items) were presented and repeated at variable lags. Items repeated as nontargets together with entirely new items (i.e., the filler items) had to be classified as *new*, whereas target repetitions and repeated filler items had to be classified as *old*.

The procedure in both runs was the same. Each stimulus was presented for 1000 ms at the center of the computer screen on a white background and was preceded by a fixation cross (300 ms) followed by a blank screen baseline period (200 ms). Responses were recorded within a period of 1500 ms after stimulus onset. Following each response, visual feedback was presented for 500 ms in the form of a happy face (correct) or a sad face (incorrect). The next trial began after a fixed intertrial interval of 1000 ms.

To insure participants' understanding of the procedure, practice phases with 28 items per phase were run prior to each of the two runs. Children and adolescents were encouraged to explain instructions to the experimenter in their own words and were corrected if necessary.

EEG Recording

EEG was recorded with 27 Ag/AgCl-electrodes (at the following sites, adapted from the standard 10–20 system: FP1, FP2, F7, F3, FZ, F4, F8, FC5, FC3, FCZ, FC4, FC6, T7, C3, CZ, C4, T8, CP3, CPZ, CP4, P7, P3, PZ, P4, P8, O1, O2) at a sampling rate of 250 Hz with a left mastoid reference, and was rereferenced offline to the mean of both mastoids. An EOG was recorded with additional electrodes located above and below the right eye and outside the outer canthi of the eyes. Electrode impedance was kept below 5 kΩ. EEG and the EOG were recorded continuously and were A-D converted with 16-bit resolution.

Offline data processing involved low-pass filtering at 30 Hz and high-pass filtering at 0.2 Hz. Prior to averaging, each recording epoch (1400 ms, including a 200 ms prestimulus interval for baseline correction) was scanned for artifacts which were identified whenever the standard deviation in a sliding 200 ms time window exceeded ±25 μV in one of the EOG channels. Ocular artifacts were corrected using a linear regression approach (Gratton, Coles, & Donchin, 1983). Trials containing muscular and/or technical artifacts were removed before averaging.

For each group, ERP averages were formed for correct judgments to new items, separately for objects and nonobjects. As mentioned before, ERPs to correctly judged old and nontarget items were averaged only for objects. Mean trial numbers (range) for new items (objects, nonobjects) were: children, 27 (19–39), 23 (18–33); adolescents, 30 (23–39), 28 (18–36); adults, 33 (34–39), 33 (23–41). For old items the mean trial numbers (range) were: children, 23 (18–33); adolescents, 29 (21–35); adults, 32 (18–40). Mean trial numbers (range) for nontargets were: children, 21 (17–33); adolescents, 28 (21–37); adults, 29 (18–40). Although average trial numbers differed across conditions for children, the number of trials used for ERP averaging was in the range used in previous developmental ERP studies (Cragg, Fox, Nation, Reid, & Anderson, 2009; Czernochowski et al., 2005; Friedman et al., 2010) and was large enough to obtain equivalent signal-to-noise ratios across conditions and age groups (Picton et al., 2000).

Data Analysis

Trials that were not responded to were removed from behavioral analysis. Analogous to the analyses of the ERP data, memory accuracy was evaluated only for object stimuli, using Snodgrass and Corwin's (1988) discrimination index Pr (the proportion of false alarms subtracted from the proportion of hits of within-run repetitions). For item memory accuracy, false alarms to new items were subtracted from hits in the first run (Pr_Item =hits − false alarms). For source memory accuracy, we subtracted the false alarms to nontargets from the target hit rates in the second run (Pr_Source: Target hits − Nontarget false alarms). Response times were measured separately for new, old, nontarget and target items. Response bias was defined as Br (Snodgrass & Corwin, 1988) and was calculated separately for the item memory task (Br_Item = false alarms/1 − Pr_Item), and the source memory task (Br_Source = Nontarget false alarms/1 − Pr_Source). To examine age effects, repeated measures analyses of variance (ANOVAs) with the factor age (children, adolescents, adults) were conducted.

ERP data were collected from nine electrodes that covered trilateral frontal, central, and parietal recording sites (frontal: F3, Fz, F4, central: C3, Cz, C4, parietal: P3, Pz, P4), the regions at which old/new effects can be reliably recorded. Repeated measures ANOVAs were conducted on average amplitudes within specified time windows (see below) including the factors condition, and, as topographical factors, anterior–posterior (AP) (frontal vs. central vs. parietal) and laterality (left vs. central vs. right). In order to examine age differences for the ERP variables, the initial ANOVAs included the factor age (children vs. adolescents vs. adults). Subsidiary ANOVAs were then used to elucidate interactions between age, condition, and the topographical factors. Only effects including the condition factor are reported. In cases of violation of the sphericity assumption, Greenhouse–Geisser corrections (Greenhouse & Geisser, 1959) were applied to *p*-values. To compare effect sizes across electrodes, treatment magnitudes (η_p^2) were calculated.

To test our predictions, a variety of analyses were performed: For the test of generic novelty, first presentations of objects and nonobjects were contrasted in the condition factor (object vs. nonobject). For item memory analysis, the early and the late old/new effects were evaluated in the condition factor (old vs. new). For source memory analysis, the condition factor was specified according to the nontarget old/new effect (nontarget vs. new). In the second run, the overall probability of new items (i.e., the filler items) was much lower than the probability of nontarget items (15 vs. 42, i.e., 36%). Thus, consistent with Czernochowski et al. (2009), we held the probabilities of old and new stimuli constant for the analysis of the nontarget old/new effect by contrasting nontargets with new items from the first run.

As the P200 repetition effect, the effect of generic novelty, and the early old/new effect showed similar temporal characteristics across groups, these effects were examined in the same time windows across the three age groups (P200: 160–240 ms; generic novelty and early old/new effect: 350–450 ms). Visual inspection of the grand average waveforms showed that the late old/new effect was delayed for children relative to the two other groups. Similarly, there was a delay of the nontarget old/new effect for children and adolescents relative to adults. Therefore, group-specific time windows were used for the analyses of the latter effects (see Marshall et al., 2002). In the item memory analysis, the late old/new effect was measured between 650 and 800 ms for children and between 450 and 600 ms for adolescents and adults. In the source memory analysis, the time windows used for evaluating the nontarget old/new effect were 800–950 ms (children), 750–900 ms (adolescents), and 450–600 ms (adults). These time windows were selected on the basis of visual inspection of the waveforms for the time intervals in which the old/new differences were largest.

Results

Behavioral Results

Memory Performance

The behavioral data are summarized in Table 1. The ANOVA with the factors memory task (item

Table 1
Overview of Performance Data

	Children	Adolescents	Adults
Performance estimates			
Pr_Item	.63 (.17)	.78 (.11)	.87 (.08)
Pr_Source	.57 (.19)	.81 (.14)	.84 (.09)
Response times correct rejections			
New	822 (64)	650 (67)	611 (51)
Nontarget	837 (92)	680 (73)	629 (75)
Response times hits			
Old	845 (85)	692 (66)	633 (65)
Target	854 (91)	672 (60)	616 (78)
Bias estimates			
Br_Item	.38 (.16)	.41 (.21)	.42 (.19)
Br_Source	.52 (.12)	.45 (.20)	.52 (.20)

Note. Mean estimates of performance accuracy and response bias for each age group. Accuracy was calculated separately for item memory (Pr_Item = hits − false alarms) and source memory (Pr_Source = Target hits − Nontarget false alarms). Response bias was calculated separately for item memory (Br_Item = false alarms/(1 − Pr_Item) and source memory (Br_Source = Nontarget false alarms/(1 − Pr_Source). Reaction times (ms) are given for correct responses to new, old, nontarget, and target items. Standard deviations of means are given in parentheses.

vs. source) and age on the Pr-measures yielded an effect of age, $F(2, 55) = 22.06$, $p < .001$, and an interaction between memory task and age, $F(2, 55) = 3.40$, $p < .05$. Follow-up analyses revealed that children performed lower than adolescents and adults in both tasks (ps < .001). Adolescents performed lower than adults in the item memory task ($p < .05$), whereas there was no difference between these groups for source memory ($p = .54$). Children performed lower in the source than in the item memory task ($p < .05$), while this difference was not found for adolescents or adults (ps > .21). Thus, consistent with our prediction, the effects of age on memory performance differed between the two tasks and children showed particularly poor source discrimination performance.

The distinct age-related increase in source memory performance was verified in an analysis of covariance on the source memory estimate in which we introduced item memory performance as a covariate. An effect of age was obtained, $F(2, 54) = 5.24$, $p < .01$. The adjusted means for Pr_Source after the influence of the covariate was partialed out were .67, .80, and .75 for children, adolescents, and adults, respectively. These source memory scores differed between children and adolescents ($p < .01$), on a marginally significant level between children and adults ($p = .06$), but not between adolescents and adults ($p = .26$). These results confirm that the observed age differences in source memory are independent from differences in item memory.

Regarding response bias, the ANOVA with the factors memory task (item vs. source) and age revealed no age differences (Fs < 1.00). An effect of memory task indicated that the criterion for ''old'' judgments was more liberal across all three age groups in the source compared to the item memory task, $F(1, 55) = 8.10$, $p < .01$.

Post hoc analysis of nontarget forgetting rates. In the exclusion task, it is not possible to correctly distinguish between retrieved and forgotten nontargets, because some nontargets may be misclassified as *new*. One possible consequence of this is that source memory performance for adolescents may have been overestimated because the forgetting rate for old items in the item memory task was higher for this group than for adults. This possibility was explored in a post hoc analysis in which we evaluated response accuracy to nontargets according to their repetition lag. This lag was defined as the number of items that intervened between old items in the first run and nontarget presentations in the second run. Nontargets were divided into two categories: The 21 items with the shortest repetition lags (mean lag = 185 items) were compared to the 21 items with the longest lags (mean lag = 246 items). As memory strength declines over time, a stronger amount of nontarget forgetting in adolescents compared to the other groups should be reflected in an Age × Lag (short vs. long) interaction for nontarget response accuracy. For children, adolescents, and adults, the proportions of correct nontarget responses were .83, .96, and .96 for the short-lag condition, and .74, .91, and .87 for the long-lag condition, respectively. The ANOVA revealed no significant interaction between the factors age and lag ($p = .35$), making a nontarget forgetting account for the adolescents' nontarget retrieval performance unlikely.

Response Times

The ANOVA with the factors condition (new vs. old vs. nontarget vs. target), and age yielded main effects of condition, $F(3, 165) = 6.51$, $p < .01$, and age, $F(2, 55) = 55.16$, $p < .001$. Across groups, correct responses to new items were reliably faster than correct responses to old items ($p < .001$), nontargets ($p < .01$), and targets ($p < .05$). Children responded more slowly than adolescents and adults (ps < .001), whereas the difference between the adolescents' and adults' response times was only marginally significant ($p = .06$).

ERP Results

Generic Novelty Effect

The ERPs for first presentations of nonobjects and objects at Fz for each age group are shown in Figure 2A. For children and adolescents, a large negative-going deflection, peaking around 400 ms, was larger for nonobjects than objects from around 150 ms onward. Starting from around 200 ms, nonobjects were also more negative-going than objects in adults.

As can be seen from the topographical maps in Figure 2B, all age groups showed similar ERP effects of generic novelty, which were most pronounced at anterior recording sites. This suggests few developmental differences in the neural mechanisms of novelty processing, albeit the generic novelty effect appeared to be lateralized to left-frontal recording sites for children. These observations were confirmed by a series of statistical analyses.

The initial ANOVA with the factors age, condition, AP, and laterality revealed an effect of condition, $F(1, 55) = 17.92$, $p < .001$, and reliable interactions involving the age factor, among them the four-way interaction Condition × AP × Laterality × Age, $F(8, 220) = 2.34$, $p < .05$. To dissolve this interaction, follow-up analyses were performed separately for each group.

For children, an interaction of condition and AP was obtained, $F(2, 34) = 68.56$, $p < .001$, reflecting larger negativities to nonobjects than to objects at frontal sites, $F(1, 17) = 25.46$, $p < .001$. In addition, a three-way interaction (condition × AP × Laterality) was found, $F(4, 68) = 3.95$, $p < .01$: Follow-up analyses revealed that the difference between nonobjects and objects was largest at F3 ($\eta_p^2 = .613$). For adolescents, an effect of condition was found, $F(1, 19) = 12.38$, $p < .01$. A Condition × AP interaction, $F(2, 38) = 45.04$, $p < .001$, indicated a reliable generic novelty effect at frontal sites, $F(1, 19) = 38.81$, $p < .001$. For adults, an effect of condition, $F(1, 19) = 8.38$, $p < .01$, was embedded in a Condition × AP interaction, $F(2, 38) = 77.37$, $p < .001$, reflecting more negative ERPs for nonobjects compared to objects at frontal electrodes, $F(1, 19) = 37.99$, $p < .001$.

Item Memory

Grand average ERPs for new and old items at Fz, Cz, and Pz for each age group are depicted in Figure 3A. The topographies of the P200 repetition effect and the early and the late old/new effects are illustrated in Figure 3B. For all groups, ERPs to old items were more positive-going than for new items. At fronto-central regions, an old/new difference was seen for the P200 component across all three groups. From around 350–450 ms, adults showed more positive waveforms for old relative to new items, and this effect was especially pronounced at frontal sites. For children and adolescents, old/new effects in this time range were most pronounced at posterior recording sites. In a later time interval (600–800 ms in children, 400–600 ms in adolescents

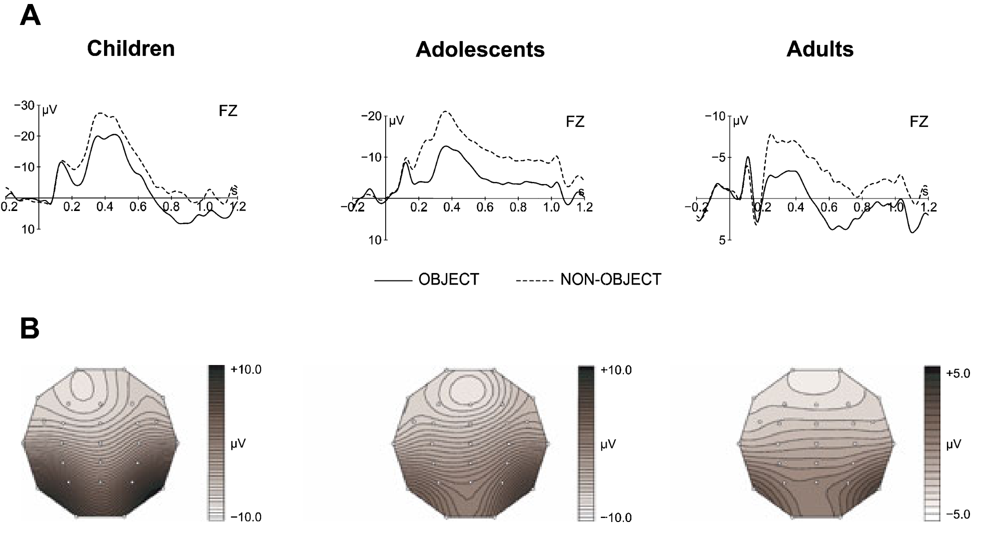

Figure 2. (A) ERP waveforms at Fz to first presentations of objects and nonobjects for children, adolescents, and adults. ERPs to objects are depicted in solid lines and ERPs to nonobjects in dashed lines. Note the different amplitude scaling across age groups. (B) Scalp topographies of the generic novelty effect (nonobject minus object) for children, adolescents, and adults.

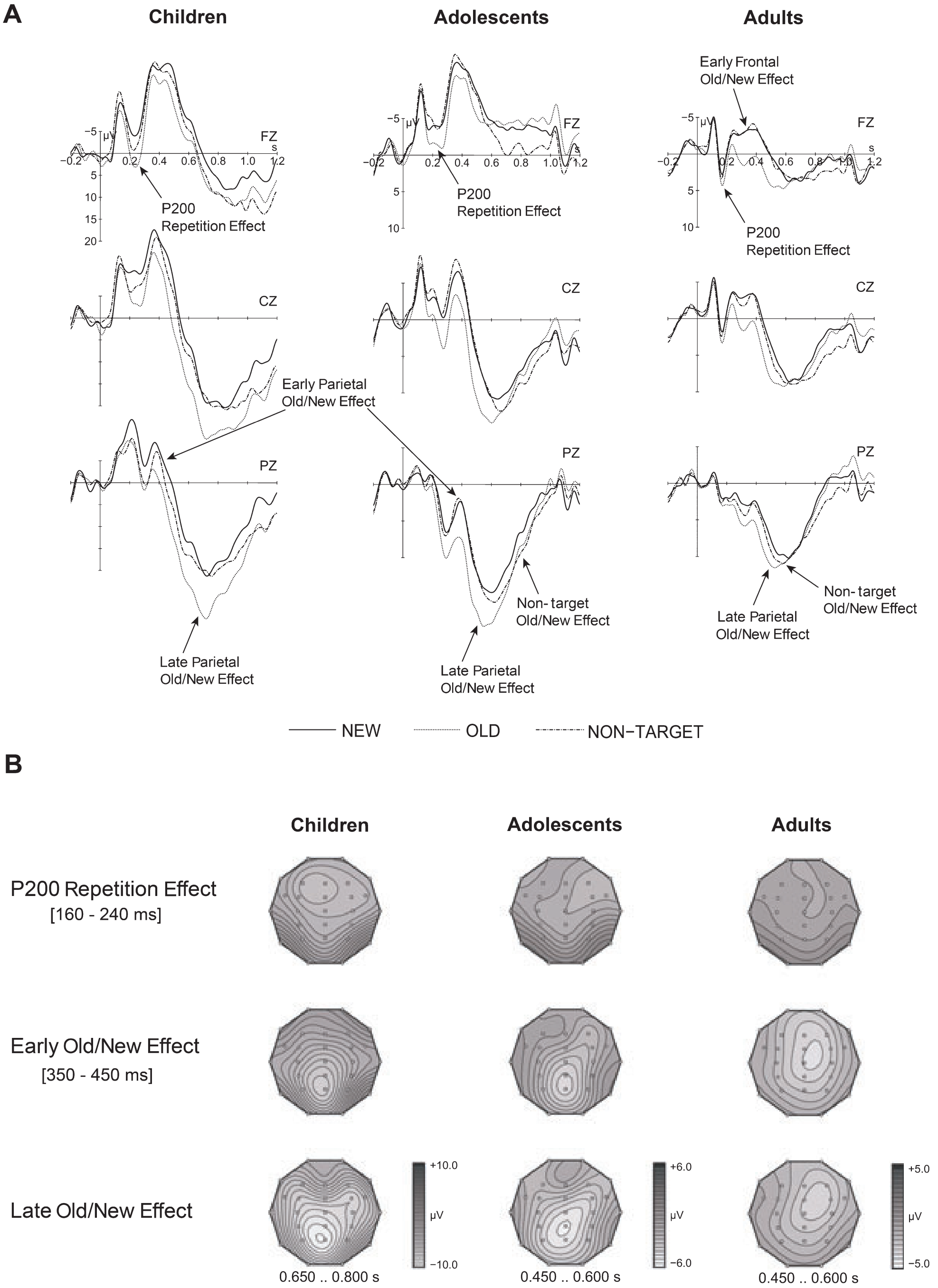

Figure 3. (A) ERP waveforms at midline electrodes (Fz, Cz, Pz) for children, adolescents, and adults. For the item memory task, ERPs to new items are depicted in solid lines and ERPs to old items in dotted lines. For the source memory task, ERPs to nontargets are depicted in dashed lines. Note the different amplitude scaling in children and the two older groups. Arrows at Fz point to the P200 repetition effect for all age groups and to the early frontal old/new effect for adults. Arrows at Pz point to the early parietal old/new effect for children and adolescents, to the late old/new effect for all age groups, and to the parietal nontarget old/new effect for adolescents and adults. (B) Scalp topographies of the P200 repetition effect and the early and the late old/new effects (new minus old) for children, adolescents, and adults. Note the group-specific time windows of the late old/new effect.

and adults), there was a pronounced parietal old/new effect for children and adolescents and a broadly, though right-frontally, accentuated effect for adults. The statistical analyses are described first for the P200 repetition effect, then for the early and the late old/new effects.

P200 repetition effect. In the ANOVA with the factors age, condition, AP, and laterality, an effect of condition, $F(1, 55) = 36.12$, $p < .001$, was embedded in interactions between condition and AP, $F(2, 110) = 8.20$, $p < .01$, condition and laterality, $F(2, 110) = 3.72$, $p < .05$, and condition, AP, and laterality, $F(4, 220) = 3.74$, $p < .05$. Apart from an Age × Condition interaction, $F(2, 55) = 5.16$, $p < .01$, indicating that children had the largest overall old/new difference ($\eta_p^2 = .597$) as compared to adolescents ($\eta_p^2 = .239$) and adults ($\eta_p^2 = .269$), there was no other interaction involving the Age factor (Fs < 1.40). Across groups, the P200 effect was largest at fronto-central recordings (Fz: $\eta_p^2 = .376$; Cz: $\eta_p^2 = .338$).

Early old/new effect. The initial ANOVA including the factors age, AP, and laterality revealed an effect of condition, $F(1, 55) = 46.69$, $p < .001$, and the four-way interaction Condition × AP × Laterality × Age, $F(8, 220) = 2.32$, $p < .05$. This interaction suggests that the early old/new effect differed in its topographic distribution across age groups. Further analyses conducted separately for each age group confirmed this view, as only adults showed an early midfrontal old/new effect, the putative ERP correlate of familiarity-based processing. In contrast, for children and adolescents, the early old/new effect was restricted to central and parietal locations.

For children, an effect of condition, $F(1, 17) = 12.70$, $p < .01$, and an interaction between condition, AP, and laterality, $F(4, 68) = 2.99$, $p < .05$, were obtained. No reliable old/new difference was obtained at Fz ($p = .08$), and effect size analyses revealed that the early old/new effect was largest at Pz ($\eta_p^2 = .544$). For adolescents, an effect of condition, $F(1, 19) = 11.43$, $p < .01$, and an interaction between condition, AP, and laterality, $F(4, 76) = 10.24$, $p < .001$, were found. As for children, the old/new difference at Fz was nonsignificant ($p = .16$), and the strongest old/new effect was obtained at PZ ($\eta_p^2 = .611$). For adults, an effect of condition, $F(1, 19) = 38.88$, $p < .001$, indicated more positive ERPs for old relative to new items across electrodes. A Condition × Laterality interaction, $F(2, 38) = 7.42$, $p < .01$, resulted from the fact that the early old/new effect was largest across midline sites ($\eta_p^2 = .708$).

Late old/new effect. The initial ANOVA including the factors age, condition, AP, and laterality revealed an effect of condition, $F(1, 55) = 36.72$, $p < .001$, and an interaction between condition, AP, and laterality, $F(4, 220) = 9.92$, $p < .001$. The four-way interaction Age × Condition × AP × Laterality was only marginally significant, $F(8, 220) = 1.18$, $p = .07$. As we were interested in age-related patterns of retrieval activity, group-specific analyses were performed. These showed reliable late old/new effects at parietal sites for all age groups, suggesting that the ERP correlate of recollection was not altered by age. Moreover, the analyses confirmed the late old/new effect for adults to be additionally elevated at right-frontal electrodes (see Figure 4A).

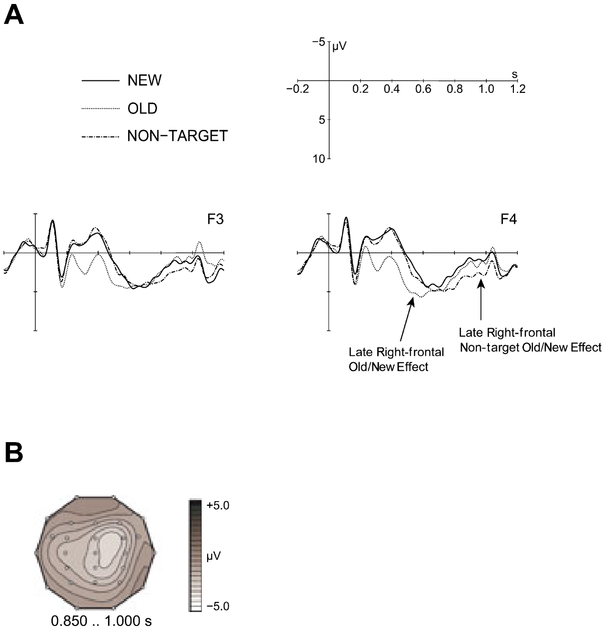

Figure 4. (A) ERP waveforms at left (F3) and right (F4) frontal electrodes for adults. ERPs to new items are depicted in solid lines, ERPs to old items in dotted lines, and ERPs to nontargets in dashed lines. Arrows at F4 point to the late right-frontal old/new effect in the item memory task and to the late right-frontal nontarget old/new effect in the source memory task. (B) Scalp topography of the late right-frontal nontarget old/new effect (new minus nontarget) for adults in the source memory task.

For children, an effect of condition was found, $F(1, 17) = 12.81$, $p < .01$. A Condition × AP × Laterality interaction, $F(4, 68) = 4.17$, $p < .05$, indicated that, although old/new differences were significant across sites, the largest effect size was evident at Pz ($\eta_p^2 = .455$). The identical pattern was found for adolescents, for whom an effect of condition, $F(1, 19) = 14.78$, $p < .01$, and a condition × AP × Laterality interaction, $F(4, 76) = 4.86$, $p < .01$, were obtained. The old/new effect was largest at Pz ($\eta_p^2 = .602$). For adults, an effect of condition, $F(1, 19) = 12.58$, $p < .01$, and a marginally significant Condition × AP × Laterality interaction, $F(4, 76) = 3.12$, $p = .05$, were obtained. While the late old/new effect was significant at all nine electrodes, it was largest at F4 ($\eta_p^2 = .586$).

Topographic profile analysis. The strong topographic similarity of the early and the late old/new effects in children and adolescents may suggest that the early effect reflects an early onsetting late parietal effect. In a topographic profile analysis, we assessed for each age group whether the early and the late old/new effect differed in topography. Differences in scalp distribution between the early and the late effect after amplitude normalization can be attributed to different neural generators and by this to different cognitive processes supporting both effects (McCarthy & Wood, 1985). For both children and adolescents, an ANOVA on the rescaled old/new difference waveforms including the factors time window (early vs. late), AP, and laterality revealed no interactions involving the factor time window (*F*s < 1.71). Thus, even though the old/new effects in children and adolescents spanned different ERP components during the early and the late time window, the topographic distribution patterns of these effects were highly similar across time windows. This suggests that the early parietal effect in children and adolescents most likely reflects early onsetting recollective processing. In contrast, for adults, an interaction between time window and laterality, $F(4, 76) = 4.04$, $p < .05$, indicated that the early and the late effects reflect qualitatively distinct processes.

Source Memory

Figure 3A shows the ERPs elicited by nontargets in the source memory task, together with the ERPs for new and old items for each age group. For adults, nontargets were more positive-going than new items at centro-parietal sites between 400 and 600 ms, an effect that was not seen for children and adolescents. Visual inspection suggests that for children and adolescents the ERP difference between nontargets and new items was delayed by about 300–400 ms.

As can be seen from Figure 4A, adults showed a late onsetting, right-frontally accentuated positivity to nontargets, which we take as the ERP correlate of postretrieval monitoring processes. Figure 4B depicts the topography of the nontarget/new difference for adults between 850 and 1000 ms, the time interval in which this effect was largest.

The source memory analyses revealed an increasing refinement of the ERP correlates of source memory as a function of age. Consistent with our prediction, there was no ERP evidence of strategic recollection for children. For adolescents, a broadly distributed pattern of more positive nontarget ERPs compared to new items was found. For adults, we observed two different old/new effects to nontargets, that is, a centro-parietal and a later right-frontal effect, presumably reflecting strategic recollection and postretrieval monitoring processes, respectively.

These observations were again confirmed by a series of statistical analyses. The ANOVA with the factors age, condition, AP, and laterality revealed an effect of condition, $F(1, 55) = 7.05$, $p < .05$, but no reliable interactions with the age factor (*F*s < 1.30). Nevertheless, within-group ANOVAs were performed, because the behavioral analysis suggests that children differ remarkably from the other groups in source memory accuracy. We therefore expected the ERP nontarget effects to vary across groups.

For children, no effects involving the condition factor were obtained (*F*s < 1.71). For adolescents, an effect of condition without further interactions was found, $F(1, 19) = 4.89$, $p < .05$, indicating a topographically widespread nontarget old/new effect between 750 and 900 ms. For adults, an interaction between condition, AP, and laterality emerged, $F(4, 76) = 4.84$, $p < .01$, reflecting more positive waveforms for nontargets relative to new items at Cz, $F(1, 19) = 5.19$, $p < .05$, and Pz, $F(1, 19) = 4.40$, $p = .05$.

The late right-frontal nontarget effect for adults was evaluated between 850 and 1000 ms. Since the effect extended to more lateral recording sites, we included six additional recording sites in the analysis (F7, T7, P7, F8, T8, P8) and grouped the resulting 15 electrodes into AP (three levels) and laterality (five levels) factors. The ANOVA revealed an effect of condition, $F(1, 19) = 20, 55$, $p < .001$. An interaction between condition, AP, and laterality was also found, $F(8, 152) = 2.19$, $p < .05$, indicating that the nontarget/new effect was reliable at F4, $F(1, 19) = 9.4$, $p < .01$, but not at F3 ($p = .07$).

Discussion

In the present investigation, we examined the development of item and source memory and their respective ERP correlates during childhood and adolescence. In addition, we investigated how the frontal negativities in children and adolescents were modulated by the generic novelty of events. The behavioral results regarding item and source memory performance in the three age groups will be discussed first, followed by the ERP effects of generic novelty, and of item and source memory.

Behavioral Results

Eight-year-old children, 14-year-old adolescents, and young adults performed a continuous recognition memory task, in which item memory was tested by the recognition of repeated picture items. Source memory in this task was operationalized by means of a memory exclusion task. Consistent with our prediction, memory performance improved with age and showed distinct age-related changes for item and source memory. As expected, in comparison to adolescents and adults, children showed particularly poor source discrimination abilities.

Due to the relatively long duration of the experiment, there may have been disproportional effects of fatigue on the children's source memory performance. However, when measured separately for the first, second, and last third of the second experimental run, there was no evidence for Pr_Source to decrease as a function of time for either age group.

The absence of age differences between adolescents and adults in source memory performance was further substantiated by a post hoc analysis of nontargets repeated with short and long repetition lags. This analysis revealed that the high source memory performance in adolescents did not result from enhanced nontarget forgetting. This suggests that the adolescents' ability of to recollect source information was relatively mature.

ERP Effects of Generic Novelty

For all age groups, the processing of generic novelty was reflected by larger negativities to unfamiliar nonobjects compared to familiar objects, with this effect being focused at frontal locations. The similarity of this pattern across the age groups suggests little developmental changes in the ERP correlate of generic novelty processing.

Importantly, the topography of the generic novelty effect was different from the ERP effect reflecting immediate novelty processing (the difference between first and second presentations of objects), which showed a more posterior distribution across all age groups (see Figure 2B). In this regard, the generic novelty effect bears similarities to the frontal novelty N2 (Folstein & van Petten, 2008). This N2 is more pronounced for generically unfamiliar than for familiar events, even when the latter occur with low probability in the immediate context (Daffner et al., 2000). Thus, the frontal negativity observed across age groups could reflect the allocation of attention to unfamiliar events that have no match in stored object representations.

In children, there was a left-frontal focus of the generic novelty effect that was not evident for adolescents and adults. In mental letter rotation tasks, a similar left lateralized ERP modulation in 7- to 8-year-old children has been taken to reflect a developmental shift from an analytic to a holistic mental rotation strategy in this age range (Heil & Jansen-Osmann, 2007; Jansen-Osmann & Heil, 2007). Thus, though preliminary, it is conceivable that the left lateralization of the generic novelty effect in children reflects a transition toward a more holistic processing mode in visual novelty detection.

ERP Effects of Item Memory

Item memory was associated with a P200 repetition effect that exhibited a similar fronto-central topography across age groups. van Strien et al. (2009) found P200 effects for verbal material in children, which was taken to reflect the processing of visual word forms. Thus, the pattern observed here suggests that the matching of perceptual stimulus aspects to stored memory contents (Evans & Federmeier, 2007) is fully matured at 8 years of age.

With respect to the early and the late old/new effects, we observed three developmental differences of note between children and adolescents on the one hand and adults on the other hand.

First, while only adults produced a reliable frontal old/new effect reflecting familiarity-based remembering, all age groups showed the ERP correlate of recollection. By this, our findings add to the existing evidence that recollection-based processes are mature in school-aged children (e.g., Cycowicz et al., 2003). Frontal old/new effects in children and adolescents were less evident in our study, a finding which is consistent with previous studies that found no ERP evidence of familiarity-based remembering in children in standard item memory tasks (e.g., Czernochowski et al., 2009). However, these findings are difficult to reconcile with studies using behavioral dual-process measures, which suggest that familiarity is available for children within the age range of the current study (Billingsley, Smith, & McAndrews, 2002; Ghetti & Angelini, 2008; Ofen et al., 2007) and even for preschool children (Anooshian, 1999).

A possible reason for this discrepancy may be that the majority of ERP studies with children were not sensitive enough to dissociate the ERP correlates of familiarity and recollection. For example, the current study as well as others that have used continuous recognition paradigms (Czernochowski et al., 2009; Hepworth et al., 2001; van Strien et al., 2009) employed highly familiar stimuli materials, for which the ERP correlate of familiarity is less reliably observed (Stenberg et al., 2009). Thus, due to a combination of relatively short retention intervals and high stimulus familiarity, familiarity may not have been sufficiently diagnostic for the children's recognition judgments. Consistent with this suggestion, the ERP correlate of familiarity has been observed in school-aged children when an adequate operational definition of familiarity, derived from its temporal dynamics, was employed (Mecklinger et al., 2011).

However, some of the available evidence nevertheless suggests that there may be developmental changes in familiarity-based processing. Using a memory task in which unfamiliar symbols were repeatedly studied and tested over four cycles, Friedman et al. (2010) observed similar midfrontal old/new effects in 13- to 14-year-old adolescents and adults but not in 9- to 10-year-old children. The absence of familiarity in children was also reflected by lower behavioral estimates of familiarity compared to adults. Thus, at least in some task situations, children appear to recruit familiarity-based processes for their memory decisions to a lesser extent than adults do. It remains to be determined whether the development of recognition memory is related to an increasing flexibility in the ability to use different retrieval processes with age.

The second observation was that children and adolescents showed an early parietal old/new effect presumably reflecting the early onset of recollection-based processes. Early onsetting recollective activity also occurred in the Friedman et al. (2010) study following multiple item repetitions. It is conceivable that in the present study recollection occurred earlier because participants may have used conceptual as well as perceptual retrieval cues (colored line drawings of objects). These presumably enhanced recollective processing and memory performance in children and adolescents. Thus, facilitated recollection supported by multiple retrieval cues may account for the early onsetting ERP correlate of recollection in children and adolescents.

Finally, the topographical distribution of the late old/new effect differed as a function of age. Children and adolescents showed the parietal topography often observed in developmental studies (Czernochowski et al., 2004; Czernochowski et al., 2009). For adults, the late old/new effect showed an unexpected right-frontal accentuation. This suggests that recollective processing in adults was temporally overlapped with postretrieval monitoring processes (Hayama et al., 2008). As this right-frontal positivity was not present in children and adolescents, it is possible that the adult's stronger use of familiarity relative to these groups increased response uncertainty and the need for monitoring memory decisions.

ERP Effects of Source Memory

The examination of nontarget old/new effects revealed evidence for developmental changes across all age groups in the neural correlates of source memory. A parietal nontarget old/new effect, the ERP correlate of strategic recollection, was obtained for adolescents and adults but not for children. This pattern closely parallels the age differences in source memory performance observed in this study. Thus, we replicated previous findings that the ability to strategically recollect source information is less matured in preadolescent children (Czernochowski et al., 2005; Czernochowski et al., 2009). Moreover, extending previous findings, our results suggest that strategic recollection undergoes an important step in development in early adolescence. By this, our data are consistent with reports of age-related improvements in other domains of cognitive control in this age range (Munoz, Broughton, Goldring, & Armstrong, 1998; Williams, Ponesse, Schachar, Logan, & Tannock, 1999).

Notwithstanding this suggestion, an important finding of the current study is that the very pattern of ERP effects in adults was neither observed in children nor in adolescents. That is, while the nontarget old/new effect showed the expected centro-parietal distribution in adults, this effect was topographically more diffuse in adolescents. Moreover, only adults showed the putative ERP correlate of postretrieval monitoring (the late right-frontal effect).

To provide further evidence for the view that this late nontarget effect reflects memory control processes, we analyzed the effect separately for nontargets repeated with short and long repetition lag (see the Behavioral Results section). As long-lag nontargets were found to induce more incorrect responses (.13) and longer response times (659 ms) compared to short-lag nontargets (.04; 583 ms), we assumed that response uncertainty would be higher for long-lag nontargets and that this should lead to increased monitoring demands. Accordingly, we hypothesized a relatively larger right-frontal old/new effect for long-lag nontargets between 850 and 1000 ms. The ANOVA revealed a Condition × AP × Laterality interaction for long-lag nontargets ($p < .05$), indicating a reliable old/new effect at right-frontal sites (F4, F8: $p < .05$). For short-lag nontargets, a Condition × Laterality interaction ($p < .01$) indicated an old/new effect restricted to midline sites ($p < .05$). This result confirmed our prediction that the late right-frontal effect is modulated by nontarget repetition lag and supports the view that it is related to post retrieval monitoring demands and coping with response uncertainty (Hayama et al., 2008).

Notably, the present study revealed an ERP correlate of memory control processes for adults but not for adolescents and therefore reveals developmental changes during adolescence that would not have been uncovered by using behavioral data alone. This suggestion is supported by the results of a developmental source memory study using response-locked ERPs (de Chastelaine, Friedman, & Cycowicz, 2007). As was the case with the present findings, no age differences in source discrimination between 13-year-old adolescents and adults were evident in the latter study; however, a target positivity prior to the response showed a right-frontal distribution in adults and was evenly distributed in adolescents. In line with our results, this finding points to the maturation and increasing refinement of the neural systems supporting postretrieval control processes which are not necessarily accompanied by improvements in memory performance.

Consistent with this view is the suggestion that activation patterns in the neural networks supporting specific cognitive functions become decreasingly diffuse and increasingly focal and refined during childhood and adolescence (Casey, Thomas, Davidson, Kunz, & Franzen, 2002; Casey et al., 1997; Konrad et al., 2005). The differences between adolescents and adults in the nontarget ERP effects could therefore reflect the relative immaturity in the refinement of the brain network supporting controlled memory retrieval. An important endeavor for future research is to explore the conditions under which the functional maturation of this network during adolescence leads to parallel behavioral and electrophysiological age-related changes.

Conclusions

Our findings provide further evidence for distinct developmental trajectories of item and source memory. The ERP old/new effects in adults suggested the presence of familiarity and recollection during item recognition and the use of control processes for item and source memory retrieval. The ERP effects in children and adolescents reflected a strong reliance on recollection-based processes for item recognition, while familiarity-based processes were attenuated. The development of source memory was reflected by an increase in strategic recollection between childhood and adolescence. Developmental changes in source memory during adolescence were borne out in terms of increasing topographic distinctness of the ERP correlate of strategic recollection and the electrophysiological manifestation of postretrieval monitoring. As a whole, these outcomes suggest that memory development reflects an increase in the differentiation of the available retrieval processes as well as their ERP correlates.

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