



## PAPER

# Age-related changes in the control of episodic retrieval: an ERP study of recognition memory in children and adults

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## Abstract

*We examined developmental aspects of the ability to monitor the temporal context of an item's previous occurrence while event-related potentials (ERPs) were recorded. In a continuous recognition task, children between 10 and 12 years and young adults watched a stream of pictures repeated with a lag of 10–15 intervening items and indicated recurrences. In a second run, these already familiar pictures were repeated as non-targets along with new pictures, while subjects were instructed to indicate only recurrences within the run. Young adults were able to maintain high performance levels in both tasks, whereas children had longer response times and committed a large number of false alarms to non-targets. ERPs in both age groups showed similar parietal old/new effects for target repetitions within runs. In addition, adults' ERPs showed similar old/new effects at frontal electrodes for repetitions and non-targets, presumably reflecting assessments of familiarity, whereas for children repeated relative to first presentations were associated with more negative-going waveforms at anterior frontal recording sites. Together, these results suggest a continuing maturation of the brain networks assessing novelty or familiarity. Recollection as indexed by parietal old/new effects appeared similar between young adults and children, but the development of controlled episodic retrieval, resulting in recollection of non-target information, appears to continue well into adolescence.*

## Introduction

In everyday life, the temporal order of events is a very common feature to guide memory retrieval, for instance when the day's activities are recapitulated. To organize events according to their temporal order is the first step to building higher-order relationships between events, such as causality. Children learn to organize their first reports of what just happened according to temporal order around 2 years of age (Fivush, 1997), and yet in certain cases this basic ability can be prone to errors, especially when the same item is presented repeatedly in different experimental contexts.

In so-called source memory tasks, episodic information about the context of an item's previous presentation needs to be specified along with or following an 'old-new' decision during the retrieval phase in a recognition task. Behavioral studies indicate that item as well as source memory performance increases with age during childhood, with a steeper increase in performance for source as compared to item information (see Gathercole, 1998; Ruffman, Rustin, Garnham & Parkin, 2001). Notably, even preschool children appear capable of source monitoring for a few selected items (e.g. Giles, Gopnik & Heyman, 2002), although studies based on larger item numbers suggest

an ongoing improvement in source memory during until at least late childhood. For instance, Cycowicz and colleagues (2001) compared item and source recognition memory for pictures in children aged 7–8 years and young adults. Participants studied red or green line drawings twice, and were required to retrieve either whether the items had been previously presented or the color in which it had been presented. In both groups, memory for the study color of the pictures was lower than item memory. Both item and source memory was lower for children relative to young adults, but the increase in children's source memory performance was statistically independent of their lower item memory performance.

In a variety of studies in young adults, perceptual features of an item are used to specify its source, e.g. the left/right orientation of a line-drawing (e.g. Curran & Cleary, 2003) or the male or female voice of a speaker reading a list of words (e.g. Wilding & Rugg, 1996). In order to successfully perform a source memory task, it is not sufficient to rely on differences in familiarity that merely allow the distinction between old and new items, i.e. an acontextual form of memory. Instead, the recollection of detailed contextual information is necessary to distinguish between the study contexts (see Yonelinas, 2002, for a review of the distinction between

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familiarity and recollection-based recognition memory). These two subprocesses of recognition memory can be distinguished by distinct ERP modulations that vary in latency after stimulus presentation and topography. In young adults, correctly identified old items in general elicit more positive-going waveforms than correctly identified new items (see Mecklinger, 2000, Friedman & Johnson, 2000). An early old/new effect is observed at mid-frontal electrode sites between 300 and 500 ms and is believed to reflect familiarity (e.g. Curran, 2000; Nessler, Mecklinger & Penney, 2001; Mecklinger, 2006). The putative ERP correlate of recollection is observed between 400 and 800 ms at (left) parietal electrode sites (e.g. Wilding & Rugg, 1996; Wilding, 2000). For episodic memory retrieval in healthy young adults, the recruitment of PFC structures is crucial, in particular in source memory tasks when the PFC is needed to specify retrieval cues, to guide the search for item-context attribute conjunctions and to monitor and evaluate the outcome of the retrieval process (see Ranganath, 2004; Dobbins, Simons & Schacter, 2004; Simons & Spiers, 2003). The PFC structures recruited by young adults continue to mature in children well into adolescence (Sowell, Thompson, Tessner & Toga, 2001), hence it is particularly interesting to examine to which extent children are able to recall the source of item information.

The ERP correlates of recognition memory have been validated in a variety of studies on young adults with various materials and source specifying features (e.g. Johnson & Friedman, 2000, for a review). However, only very few studies so far have examined item and source memory and their ERP correlates in children. While behavioral evidence for familiarity is inferred indirectly based largely on the fact that children are typically prone to source errors, ERP analyses can assess the neuronal correlates of familiarity and recollection as a function of behavioral performance. For instance, Cycowicz, Friedman and Duff (2003) examined memory for line drawings and their associated color in young adults, 9–10-year-old children and 12–13-year-old adolescents. Despite longer latencies and generally larger amplitudes in children and adolescents, in all groups a centroparietal old/new effect was observed for items with accurate source memory between 415 and 615 ms (Cycowicz, Friedman & Duff, 2003). Consistent with these findings, Czernochowski, Mecklinger, Johansson and Brinkmann (2005) found parietal old/new effects associated with accurate source memory in two groups of children between the ages of 6–8 and 10–12 years. Relative to young adults, ERP latencies and amplitudes were larger for children, especially for the younger group (Czernochowski, Mecklinger, Johansson & Brinkmann, 2005). Considerable behavioral improvements in source memory accuracy notwithstanding, the time course and parietal topography of the observed old/new effects in those two studies suggest that children as young as 6–8 years show evidence of recollection-based recognition judgements (Czernochowski *et al.*, 2005;

Cycowicz *et al.*, 2003). The continuous improvement of source memory performance during the course of childhood is closely related to the ongoing brain maturation, which continues until late adolescence for the PFC (e.g. Casey, Giedd & Thomas, 2002; Casey, Tottenham, Liston & Durston, 2005; Sowell *et al.*, 2001). However, it remains an open question by what age recollection can be employed *strategically*, since strategic modulations of recollection have so far only been reported for young adults. For instance, without explicit instructions to retrieve information about non-targets, sometimes these items are recalled along with their context attributes in the service of source memory performance, particularly when target source memory is low ('recall to reject'; Clark, 1992; Fraser, Bridson & Wilding, 2007; Herron & Rugg, 2003; Wilding, Fraser & Herron, 2005). While episodic recollection appears to be functional early on, successful source memory requires additional control processes guiding and monitoring the search for relevant source-specifying attributes provided by the PFC (e.g. Simons & Spiers, 2003; Dobbins, Simons & Schacter, 2004).

Unlike the ERP correlate of recollection, to the best of our knowledge the mid-frontal old/new effect has not yet been demonstrated in children. Czernochowski and colleagues (2005) reported that neither group of children showed evidence of frontal old/new effects for any item type, whereas in young adults early frontal old/new effects were found for all item repetitions in this paradigm (see Czernochowski *et al.*, 2005).

The search for familiarity signals in children is complicated by findings from the infant literature suggesting that attention allocated to old items enhances a large frontal negative deflection (Nc) for old items in infants (e.g. de Haan, Johnson & Halit, 2003; Bauer, Wiebe, Carver, Lukowski, Haight, Waters & Nelson, 2006). This negative deflection is present at birth and maximal over fronto-central electrodes. Over the course of the first year of life, its peak latency decreases from 1000–1200 ms to 400–500 ms, whereas its peak amplitude increases during this time and decreases in the third year of life (see de Haan, 2007). Developmental changes in the relative size of the Nc for familiar or novel stimuli towards the end of the first year of life are attributed to the distribution of processing resources devoted to each type of stimulus (see Bauer *et al.*, 2006). In addition to general age effects between infants and adults, such as large differences in morphology, timing and topography, the polarity of the Nc (i.e. more negative-going waveforms for attended items) is in sharp contrast to the mid-frontal old/new ERP effects in adults, where familiarity-based recognition memory is associated with a positive ERP difference between old and new items.

A pronounced frontal negativity irrespective of an item's old/new status is typically observed in school-aged children (Cycowicz *et al.*, 2003; Czernochowski *et al.*, 2005). So far, it remains open whether this frontal

negativity in children is predominantly a consequence of morphological changes in brain development, e.g. the ongoing fiber myelination particularly in frontal areas of the brain (see Casey *et al.*, 2000; 2005), or reflects a similar functional process as the Nc in infancy. Therefore, one important step in the search for an ERP correlate of familiarity in children is to examine the potential functional role of the frontal negativity. The ERP correlate of familiarity in children in previous studies could have been masked by another ERP component with temporal and spatial characteristics similar to the mid-frontal old/new effect, but with opposite polarity, for instance the Nc. Alternatively, it is conceivable that familiarity in children relies to a lesser extent on conceptual information than in adults (Curran & Dien, 2003; Mecklinger, 2006; Nessler, Mecklinger & Penney, 2005), and rather depends on the amount of matching perceptual features between the first and second occurrence of events. To test this latter account, the present study used perceptually rich visual stimuli (colored line drawings of objects) and source was specified without a change in perceptual features by using temporal order as the relevant source defining feature.

#### *Aims and predictions*

The ability to use the temporal context of an item's last presentation as the source-specifying feature was compared between children and adults in two runs of a continuous recognition paradigm in which items were presented twice per run (presentation P1 and P2 in run A, P3 and P4 in run B). The task was to indicate repetitions *within* the current experimental run (i.e. second and fourth overall presentations – P2 and P4) and disregard item repetitions across experimental runs (i.e. the third overall presentation, P3). We had three major predictions:

First, we expected children's performance to be lower compared with adults' as evident in both fewer correct responses and longer reaction times. These performance differences should be most pronounced when the demands for control processes are higher, i.e. children should commit more false alarms to the critical repetitions of items studied in a previous experimental run (P3 or non-targets).

Second, with respect to the subprocesses of recognition memory, we expected familiarity to be sufficient to distinguish between new and repeated items (i.e. item memory) in the first, but not in the second experimental run. In adults, the use of familiarity should be evident in an early ERP old/new effect observed for any repeated item irrespective of target status. It is currently open whether this effect is also present in children following perceptually identical item repetitions. In contrast, in the second experimental run an item's temporal context needs to be retrieved as part of an integrated episodic representation. Correct target recognition in this run requires recollection. If the ERP correlate of recollection,

i.e. the parietal old/new effect, is indeed similar in both age groups, the effect should be obtained for correct target recognitions in this run, irrespective of age group. Depending on strategic modulations guiding the extent to which additional information is included in the memory search, this later old/new effect might also be observed for non-targets (P3). The retrieval of non-targets may be strategically used to avoid false alarms to these items ('recall to reject') and by this promote overall memory performance.

Finally, items that have been encoded in the first and in the second run should have a stronger memory trace than those presented only once. This memory strength effect (i.e. differences between hits in run A and in run B) has been consistently found for the ERP correlate of recollection (e.g. Van Strien, Hagenbeek, Stam, Rombouts & Barkhof, 2005). By contrast, it has been suggested that familiarity-based recognition is not further modulated by repeated encoding (e.g. Nessler, Friedman, Johnson & Bersick, 2007). Thus, we expected the memory strength effect to be restricted to the ERP correlate of recollection.

## **Methods**

### *Participants*

16 children (mean age 11.5 years, range 10–12.5 years) and 18 young adults (mean age 24 years, range 19–29 years) participated in this study. Six additional participants had to be excluded due to excessive artifacts following technical problems during recording ( $n = 2$ , one adult) or excessive movement artifacts ( $n = 4$ , one adult). All participants were right handed and reported to be in good health and free of neurological or psychiatric diseases. Both children and their parents were thoroughly informed about the EEG procedure. Participants (or the children's parents) provided informed consent and received €7.50/ hour in payment for their participation.

### *Stimuli and procedure*

The stimuli were selected from a colored version of the Snodgrass and Vanderwart line drawings (Rossion & Pourtois, 2004). In total, 150 items of everyday objects and animals were selected, 30 of which were used as practice items.

Participants were seated in a comfortable chair throughout the experiment. The whole session lasted approximately 2 hours, including setting up the EEG cap. In both runs, participants responded using two buttons, one for each hand. In the first part, the experimental task was to indicate first presentations by pressing one button and item repetitions by pressing the alternative button, with response hands counterbalanced across participants. Each stimulus was presented for

1000 ms and was preceded by a fixation cross (300 ms) and a black screen baseline period (200 ms). Before the next trial began after a fixed inter-trial interval of 1000 ms, a feedback stimulus (smiley face) indicated whether the correct response had been given.

Thus, in the first part 60 items were presented (P1) and repeated with a lag of 10 to 15 intervening items (P2). Thirty additional foil items (Foil A1) were included to enable the lag manipulations for the targets (see also Figure 1, top). In order to maintain equal probabilities of old and new items, these stimuli were also repeated at variable lags (Foil A2), but these foils did not enter subsequent analyses.

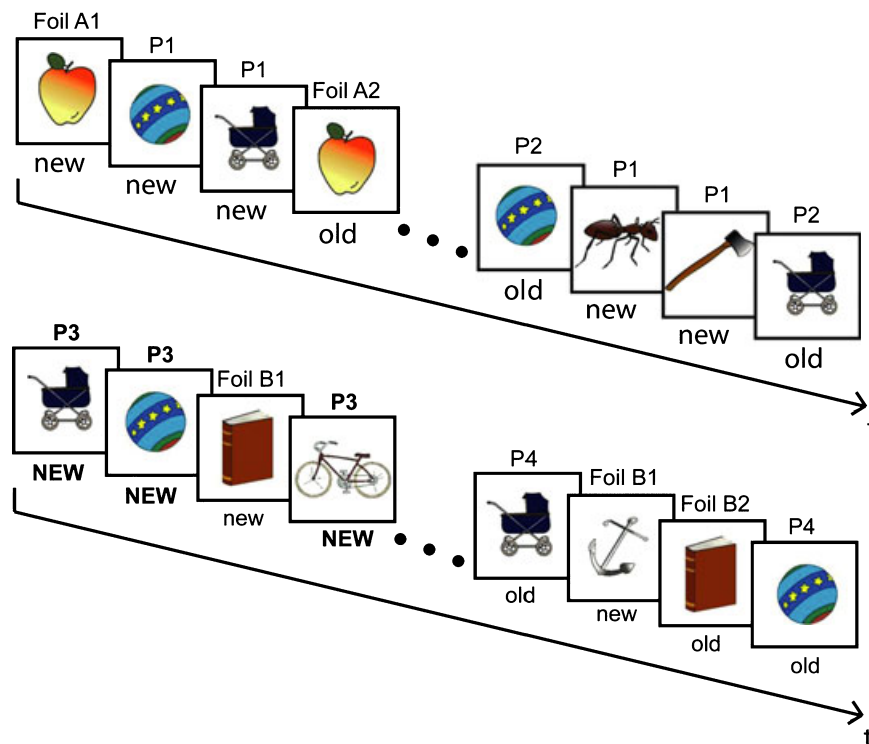
After a 10-minute break, in the second part participants were informed that some items from the first part were going to be repeated again along with new items. As illustrated in Figure 1, in run B the task was to respond 'old' selectively to repetitions occurring within the same block (i.e. P4), whereas the third presentation of a stimulus (P3) had to be rejected as a non-target. The 60 items previously studied in run A were presented again (P3) in a pseudo-randomized order with the same repetition lags. Thirty additional items were included (Foil B1) and repeated at variable lags (Foil B2). Those entirely new items in run B (Foils B1) were used for the behavioral analyses (i.e.  $Pr\_B\_new = P4 \text{ hits} - \text{Foil B1}$

false alarms and  $Br\_B = \text{Foil B1 false alarms} / (1 - Pr\_B\_new)$ ), whereas their repetitions (Foils B2) served only to counterbalance old and new responses and did not enter the statistical analyses. To summarize, the 60 items from part A were presented two more times in part B, once as non-targets (P3) and once as targets (P4), along with 30 entirely new foil items (Foils B1) and their repetitions (Foils B2).

To ensure that participants would understand the procedure, a practice phase was run before the experiment started. In addition, children were asked to explain the instructions to the experimenter in their own words before each block and were corrected if necessary.

#### EEG recordings

EEG was recorded continuously 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 500 Hz. The right mastoid served as an online reference and all EEG electrodes were re-referenced offline to the algebraic mean of both mastoids. Electrooculogram (EOG) was recorded with additional electrodes located above and below the right eye and



**Figure 1** Illustration of the continuous recognition procedure. In run A (top), 60 items were presented (P1) and repeated with a lag of 10–15 intervening items (P2). Additional foil items (Foil A1 and Foil A2) were included to enable the lag manipulation and to counterbalance correct old and new responses (illustrated here below each picture). These items were not further analyzed. In run B (bottom), items presented previously in run A (P3) were shown along with new items (Foil B1). Participants were instructed to ignore across-run repetitions (P3 or non-targets) and to indicate only repetitions within run B (P4). Correct non-target rejections are illustrated in bold letters, i.e. **NEW**. Foil item repetitions (Foil B2) were included to counterbalance correct old and new responses and were not further analyzed. Note that colored stimuli were used during the Experiment.



outside the outer canthi of the eyes. Electrode impedance was kept below 5 k $\Omega$ . Both EEG and EOG were A-D converted with 16-bit resolution. The EEG data were bandpass filtered offline (0.5 to 20 Hz). The duration of the epochs was 1200 ms, including a 200 ms prestimulus interval that was used for baseline correction. Prior to averaging, each epoch was manually scanned for eye movements and other artifacts. Ocular artifacts were corrected using a linear regression approach (cf. Gratton, Coles & Donchin, 1983), whereas trials containing muscular and technical artefacts were excluded from further analyses.

For each group, in run A ERP averages were formed for correct rejections of new items (P1) and for correctly identified repetitions (P2). The mean trial numbers (range) were 29 (20–36) and 30 (18–46) for adults and 26 (17–35) and 30 (18–42) for children, respectively. In run B, ERP averages were formed for correct rejections of non-targets (P3) and for correctly identified target repetitions (P4). The mean trial numbers were 31 (22–36) and 35 (24–49) for adults and 28 (18–43) and 28 (13–40) for children, respectively. Post-hoc independent samples *t*-tests for each condition indicate that children contributed fewer trials than young adults merely for the condition P4 [ $t(32) = 2.63$ ;  $p < .05$ ], but the mean number of trials for each condition was large enough to provide a sufficiently high signal to noise ratio for the analysis of the ERP effects of interest in both age groups.

While the proportion of correct ‘old’ and ‘new’ responses was equal in both parts, in part B the overall probability for new items (Foil B1) was relatively low (30 new vs. 150 repeated items, i.e. 17%). Thus, ERPs to correctly rejected new items in run B (Foil B1) might have been confounded by their low probability of occurrence, therefore these items were used only for behavioral analyses and not considered in the ERP analyses.

### Data analyses

Memory accuracy was analyzed by means of corrected recognition scores (Pr), i.e. by subtracting the proportion of false alarms to *new* items from the proportion of hits (i.e.  $Pr_A = P2 \text{ hits} - P1 \text{ false alarms}$  and  $Pr_{B\_new} = P4 \text{ hits} - \text{Foil B1 false alarms}$ ). In order to quantify controlled episodic retrieval performance, a separate recognition score was formed by subtracting the proportion of false alarms to non targets (P3 false alarms) from the proportion of hits in run B (i.e.  $Pr_{B\_non-target} = P4 \text{ hits} - P3 \text{ false alarms}$ ). Response bias was defined as Br (Snodgrass & Corwin, 1988), with  $Br_A = P1 \text{ false alarms} / (1 - Pr_A)$  and  $Br_B = \text{Foil B1 false alarms} / (1 - Pr_{B\_new})$ . In order to compare the age groups, between-group ANOVAs were used. To compare reaction times for targets, non-targets and new items, a two-factor mixed ANOVA with the within-subject factor Response and the between-subjects factor Group was performed.

For statistical analysis of the ERP data, the following eight electrodes were selected to cover anterior-frontal and centro parietal regions of the scalp over both hemispheres: bilateral anterior-frontal (FP1, FP2), frontal (F3, F4), central (C3, C4) and parietal (P3, P4). Initial ANOVAs were conducted with the factors Condition, Anterior-Posterior (AP, anterior-frontal vs. frontal vs. central vs. parietal) and Laterality (left vs. right). All ERP analyses were conducted on average amplitudes within the time windows specified below. Where appropriate, the Greenhouse-Geisser correction for non-sphericity was used. Corrected *p*-values are reported along with uncorrected degrees of freedom. All ERP effects were first evaluated for group differences using ANOVAs with the between-subjects factor Group. Interactions involving the Group factor were then followed up in separate group-specific ANOVA designs.

The factor Condition was specified according to two central analyses: In the first ANOVA, it comprised correct rejections of new items (P1), hits in run A (P2) and hits in run B (P4). This design allowed us to examine differences between old and new items in run A (old/new effect A), as well as effects of memory strength following repeated encoding (i.e. hits in run A vs. hits in run B). Old/new effects and memory strength effects were evaluated in two time windows to obtain separate estimates of familiarity-based recognition (adults: 300–450 ms, children: 350–500 ms) and recollection (adults: 450–600 ms, children: 550–700 ms). The selection of these time windows was based on previous developmental ERP studies using comparable stimulus material (Cycowicz *et al.*, 2003; Czernochowski *et al.*, 2005), and takes into account the differential processing speed and related timing differences of ERP components in adults and children (see Marshall *et al.*, 2002, for a comparable approach).

In order to examine the ERP correlates of controlled episodic retrieval, a second ANOVA contrasted the ERPs elicited by correct rejections of non-targets (P3) and correct rejections of first presentations (P1). Visual inspection of the waveforms suggested the use of a later time window for the late parietal effect (reflecting recollection) for this analysis (between 600 and 750 ms for adults and between 650 and 800 ms in children). The early time windows were the same as in the aforementioned analysis.

## Results

### Memory performance

An ANOVA with the factors Group (adults, children) and Condition (Pr<sub>A</sub>, Pr<sub>B\_new</sub>, Pr<sub>B\_non-target</sub>) revealed reliable main effects of Group [ $F(1, 32) = 27.15$ ,  $p < .0001$ ] and Condition [ $F(2, 64) = 10.42$ ,  $p < .0001$ ] as well as an interaction of Group by Condition [ $F(2, 64) = 4.52$ ,  $p < .05$ ]. Memory accuracy was higher

for adults than for children in run A [ $Pr\_A$ :  $F(1, 32) = 9.77, p < .01$ ], and in run B [ $Pr\_B\_new$ :  $F(1, 32) = 25.48, p < .0001$ ], and especially pronounced for correct rejections of non-targets [ $Pr\_B\_non-target$ :  $F(1, 32) = 32.73, p < .0001$ ]. The Group by Condition interaction reflects the fact that in run B children's performance was significantly lower when rejecting non-targets relative to rejecting new items [ $F(1, 15) = 20.11, p < .01$ ], whereas for adults this performance decrement was only marginally significant ( $p = .08$ ). Within the group of children, older children were better able to avoid false alarms to non-target items ( $r = .52, p < .05$ ), while no correlations were found for the other performance measures (all  $ps > .19$ ), suggesting ongoing development beyond 10 years of age specifically for the ability to avoid false alarms to non-target items. No corresponding correlations were found for adults ( $p > .29$ ).

With respect to response bias (Br), an ANOVA with the factors Group (adults, children) and Run (A vs. B) indicated that the age groups did not differ from each other [ $F(1, 32) < 1$ ], but a main effect of Run indicated that the criterion to respond 'old' was stricter in the second run [ $F(1, 32) = 31.90, p < .0001$ ] with no reliable interaction between Run and Group [ $F(1, 32) < 1$ ]. An overview of the behavioral data can be found in Table 1.

#### Reaction times for hits and correct rejections

An ANOVA with the factors Group (adults, children) and Condition (P1, P2, P3, P4, Foil B1) revealed reliable

**Table 1** Overview of performance data

	Children	Adults
Performance estimates		
Pr_A	0.73 (0.04)	0.87 (0.02)
Pr_B_new	0.72 (0.03)	0.89 (0.01)
Pr_B_non-targets	0.62 (0.04)	0.85 (0.02)
Bias estimates		
Br_A	0.44 (0.03)	0.40 (0.04)
Br_B	0.21 (0.04)	0.20 (0.05)
Proportion correct rejections		
New_A (P1)	0.86 (0.02)	0.94 (0.01)
New_B (Foil B1)	0.92 (0.02)	0.97 (0.01)
Non-targets (P3)	0.81 (0.03)	0.93 (0.01)
Proportion hits		
A (P2)	0.85 (0.02)	0.92 (0.01)
B (P4)	0.80 (0.02)	0.92 (0.01)
Reaction Times correct rejections		
New_A (P1)	754 (17)	644 (18)
New_B (Foil B1)	736 (20)	590 (16)
Non-targets (P3)	812 (23)	661 (19)
Reaction Times hits		
A (P2)	798 (16)	667 (19)
B (P4)	784 (23)	636 (18)

*Note:* Mean performance accuracy and response bias for both age groups. Accuracy was calculated separately for part A ( $Pr\_A = P2$  hits - P1 false alarms) and B. In part B the accuracy was further subdivided and calculated with respect to number of false alarms to new items ( $Pr\_B\_new = P4$  hits - Foil B1 false alarms) as well as to non-targets ( $Pr\_B\_non-target = P4$  hits - P3 false alarms). Response bias was calculated as  $Br\_A = P1$  false alarms / (1 -  $Pr\_A$ ) and  $Br\_B =$  Foil B1 false alarms / (1 -  $Pr\_B\_new$ ). Proportion of correct responses and reaction times (ms) is given for correct rejections to new items and targets in runs A and B and for non-targets in run B. The standard errors of the mean are given in parentheses.

main effects of Group [ $F(1, 32) = 30.34, p < .0001$ ] and Condition [ $F(4, 128) = 32.57, p < .0001$ ] as well as a reliable interaction [ $F(4, 128) = 2.72, p < .05$ ]. Post-hoc tests, performed to follow up the latter interaction, revealed faster hit responses for adults in parts A and B ( $p < .0001$ ). Comparing correct rejections to new items in runs A and B for each group separately revealed that adults were reliably faster in run B than in run A ( $p < .0001, 54$  ms), while this appeared only as a trend for children ( $p = .052, 18$  ms). A comparison of correct rejections of new items and of non-targets in run B revealed no reliable differences for adults ( $p > .17, 17$  ms), but a reliable slowing (58 ms) for non-target rejections for children ( $p < .0001$ ).

Taken together, children showed the expected performance difficulties in controlled episodic retrieval, i.e. they showed a markedly reduced  $Pr\_B\_non-target$  score and prolonged response times to non-targets.

#### ERP results

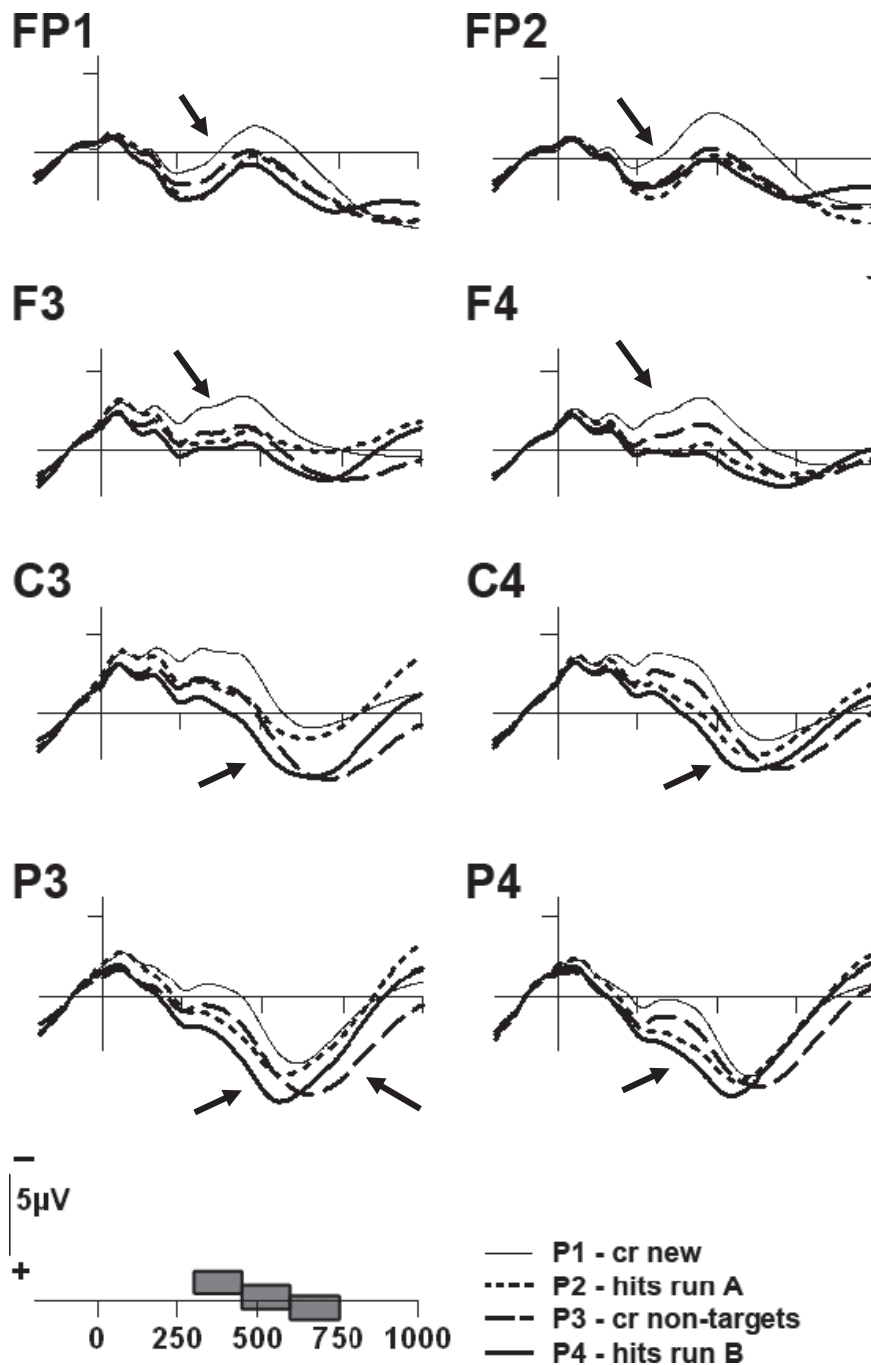
The ERP waveforms for adults are depicted in Figure 2. Starting around 250 ms, more positive-going waveforms for all repeated item presentations (P2-P4) relative to correct rejections of new items (P1) were observed. This early effect of repetition was visible across electrode sites, but most pronounced at frontal recordings. At posterior electrode sites, hits in both runs (P2 and P4) were more positive-going than correct rejections. This effect was more pronounced for hits in run B (P4). For non-targets (P3), a similar positive peak at posterior electrode sites was observed about 150 ms later than for hits in run B.

Figure 3 shows the corresponding ERP waveforms for children. A large and broadly distributed negative component was observed at anterior-frontal, frontal, and central recording sites. Unlike in the ERP data of the adults, at anterior frontal recording sites more negative-going waveforms were observed for all repeated item presentations (P2-P4) relative to first item presentations (P1). This effect was visible around 300 ms and extended for approximately 200 ms. At posterior sites, hits in both runs (P2 and P4) elicited more positive-going waveforms than correct rejections. Correct rejections of non-targets (P3) elicited a positive peak that was delayed by about 100 ms relative to the positivity to hits (P2 and P4), albeit much smaller in magnitude and restricted to left (centro-) parietal recording sites. Table 2 provides a summary of the results for each time window and contrast in adults and children.

#### Old/new effects and effects of memory strength

##### Early time window

The initial ANOVA with the factors Group, Condition (P1, P2, P4), AP (anterior-frontal vs. frontal vs. central vs. parietal) and Laterality (left vs. right) revealed a main effect of Condition [ $F(2, 64) = 5.93, p < .01, \epsilon = .972$ ] as

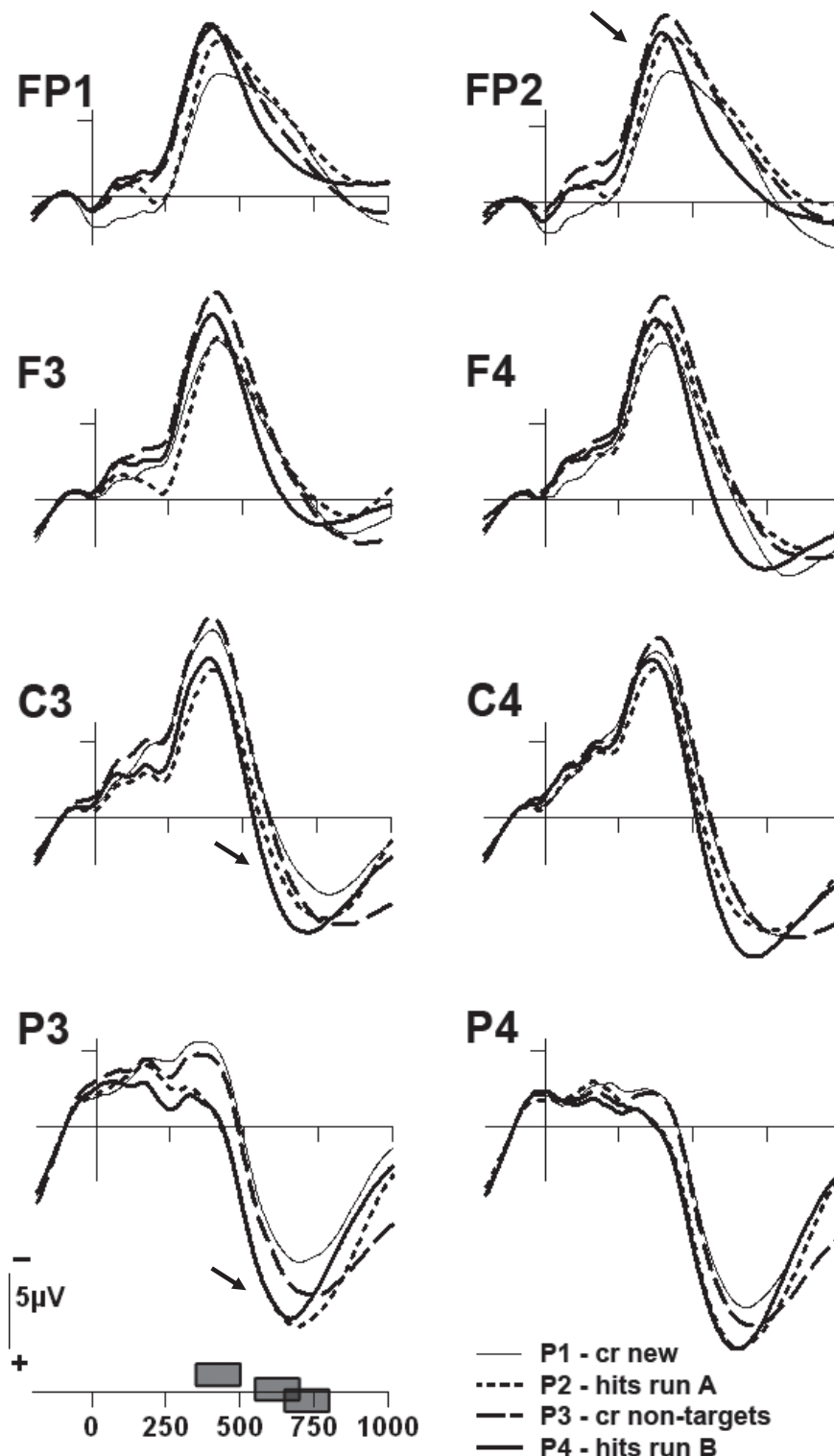


**Figure 2** ERP waveforms for adults at eight selected electrode sites that were included in the analyses. Correct rejections of new items in run A (P1) are depicted in thin solid lines, hits in run A (P2) in dotted lines. In run B, correct rejections of non-targets (P3) are depicted in dashed lines and hits (P4) in solid lines. ERPs were evaluated between 300 and 450 ms, 450 and 600 ms and 600 and 750 ms. Arrows at frontopolar and frontal electrode sites point to the early old/new effect, those at centroparietal sites illustrate the later old/new effect. The non-target old/new effect between 600 and 750 ms is illustrated at P3.

well as interactions of the factors Group, Condition and AP [ $F(6, 192) = 6.43, p < .01, \epsilon = .373$ ] and Group, Condition and Laterality [ $F(2, 64) = 4.11, p < .05, \epsilon = .906$ ]. The latter interactions suggest that Condition effects differ across age groups and recording sites. Follow-up analyses were performed separately for each age group: For adults, an ANOVA with the factors Condition, AP and Laterality revealed a main effect of

Condition [300–450 ms:  $F(2, 34) = 13.43, p < .0001, \epsilon = .838$ ]. For the contrast between P1 and P2 (old/new effect run A), a difference was seen across electrode sites [ $F(1, 17) = 14.62, p < .01$ ], whereas no effect of memory strength (P2 vs. P4) was obtained [ $F(1, 17) = 1.14, p > .30$ ].

For children, interactions of Condition and Laterality [ $F(2, 45) = 3.50, p < .05, \epsilon = .588$ ] and of Condition and



**Figure 3** ERP waveforms for children. Correct rejections of new items in run A (P1) are depicted in thin solid lines, hits in run A (P2) in dotted lines. In run B, correct rejections of non-targets (P3) are depicted in dashed lines and hits (P4) in solid lines. ERPs were evaluated between 350 and 500 ms, 550 and 700 ms and 650 and 800 ms. Note the same scaling for children and adult waveforms to illustrate between-group differences in amplitudes. Arrows at frontopolar and frontal electrode sites point to the reversed polarity early old/new effect superimposed on a large negativity, those at (left) centroparietal sites illustrate the later old/new effect.

AP [ $F(6, 90) = 8.27, p < .01, \epsilon = .333$ ] were obtained. The old/new analysis in run A (P1 vs. P2) revealed an interaction of Condition and Laterality [ $F(1, 15) = 5.29, p < .05$ ]. Follow-up ANOVAs performed to elucidate this

interaction revealed that the waveforms elicited by correct rejections of new items were more negative at left compared to right posterior electrode sites [ $F(1, 15) = 6.28, p < .05$ ], see also Figure 3. Moreover, an



**Table 2** Summary of the results for the ERP contrasts in adults and children.

Group	Time window	Old/new A (P1 vs. P2)	Strength (P2 vs. P4)	Non-target (P1 vs. P3)
Adults	300 – 450 ms	C	<i>ns</i>	C C × AP × LAT
	450 – 600 ms	C	C	(—)
	600 – 750 ms	(—)	(—)	C C × AP × LAT
Children	350 – 500 ms	C × LAT C × AP	C × LAT	C C × AP
	550 – 700 ms	C C × AP	C	(—)
	650 – 800 ms	(—)	(—)	<i>ns</i>

Note. C = Condition, AP = Anterior-Posterior, LAT = Laterality, *ns* = non-significant, (—) = time window not analyzed for the contrast.

interaction of Condition and AP [ $F(3, 45) = 24.56$ ,  $p < .01$ ,  $\epsilon = .527$ ] was obtained. This interaction reflects the fact that P1 elicited more positive-going waveforms than P2 at anterior-frontal sites [ $F(1, 15) = 4.73$ ,  $p < .05$ ], whereas the reverse pattern (P2 > P1) was found at central [ $F(1, 15) = 6.71$ ,  $p < .05$ ] and parietal electrodes [ $F(1, 15) = 20.53$ ,  $p < .0001$ ]. For the contrast between P2 and P4 (effect of memory strength), an interaction of Condition and Laterality was obtained [ $F(1, 15) = 5.09$ ,  $p < .05$ ], suggesting that hits in run B (P4) tended to be more negative than hits in run A (P2) for the left hemisphere, and the reverse pattern was seen over the right hemisphere. However, these follow-up analyses remained non-significant [ $F < 1$ ].<sup>1</sup>

Taken together, for adults the early old/new effects were broadly distributed across the scalp, as evident in the absence of Condition × Electrode site interactions. Notably, no reliable differences between P2 and P4 were evident in this time window. For children the observed old/new effects were topographically more focused to certain electrode sites, as evident in the interactions of Laterality or AP with the factor Condition. Reliable differences were seen for hits at (centro-) parietal electrodes. In addition to these positive-going old/new differences, at frontopolar electrode sites hits in run A were associated with more negative waveforms than new items.

#### Late time window

The initial ANOVA with the factors Group, Condition (P1, P2, P4), AP (anterior-frontal vs. frontal vs. central vs. parietal) and Laterality (left vs. right) for the second

<sup>1</sup> Visual inspection of Figure 2 suggests that the ERPs for children at anterior frontal recordings differed between condition in early time intervals. However, between 150 and 250 ms at FP1 and FP2 there were neither reliable main effects of condition nor interaction of condition by electrode for P1 and P2 (both  $p$ -values > .19), P1 and P3 (both  $p$ -values > .07) or P2 and P4 (both  $p$ -values > .14).

time window revealed a main effect of Condition [ $F(2, 64) = 23.31$ ,  $p < .0001$ ,  $\epsilon = .838$ ] as well as an interaction of the factors Group, Condition and AP [ $F(6, 192) = 3.28$ ,  $p < .05$ ,  $\epsilon = .445$ ].

Again, the interaction involving the Group factor was followed up by group-specific ANOVAs. For adults, a main effect of Condition [ $F(2, 34) = 13.35$ ,  $p < .0001$ ,  $\epsilon = .744$ ] was found. A difference across electrode sites was obtained for the contrast between P1 and P2 (old/new effect run A) [ $F(1, 17) = 10.09$ ,  $p < .01$ ] as well as for memory strength (P2 vs. P4) [ $F(1, 17) = 7.55$ ,  $p < .05$ ].

For children, a main effect of Condition [ $F(2, 30) = 10.71$ ,  $p < .0001$ ,  $\epsilon = .897$ ] and a reliable interaction of Condition and AP [ $F(6, 90) = 3.15$ ,  $p < .01$ ,  $\epsilon = .397$ ] were found. The old/new analysis in run A (P1 vs. P2) revealed an interaction of Condition and AP [ $F(3, 45) = 7.16$ ,  $p < .0001$ ,  $\epsilon = .490$ ], reflecting more positive-going waveforms for P2 relative to P1 at parietal electrode sites [ $F(1, 15) = 13.56$ ,  $p < .01$ ]. A main effect of Condition [ $F(1, 15) = 13.09$ ,  $p < .01$ ] without reliable interactions was found when comparing P2 and P4, indicating a topographically wide spread memory strength effect for children.

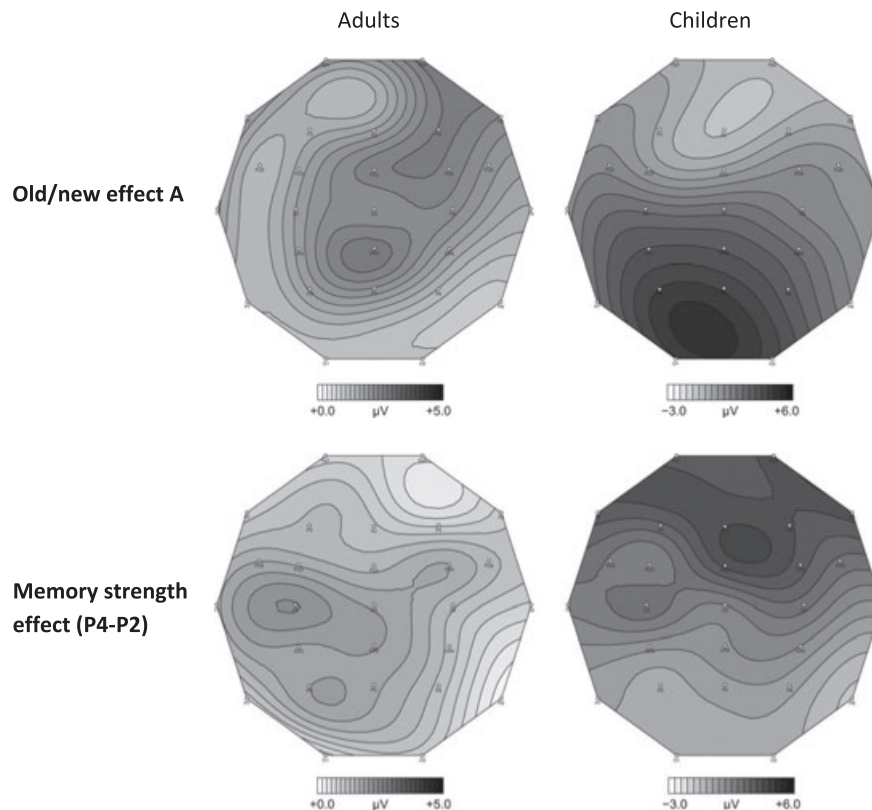
To summarize, in the second time window old/new effects were again broadly distributed across the scalp for adults, as evident in the absence of Condition × Electrode site interactions. In addition, a memory strength effect was obtained in this late time window. For children, old/new differences in run A were restricted to parietal electrodes, whereas the effect of memory strength, similar to the adults, was seen across all electrodes.

The topographies of the old/new effect in run A (i.e. P2-P1) and the memory strength effect (i.e. P4-P2) in the second time window for both age groups are illustrated in Figure 4. For adults, both effects were broadly distributed across the scalp, consistent with the main effects of Condition without reliable interactions for both analyses. For children, a maximum over left parietal electrode sites was observed for the old/new effect in run A, whereas the memory strength effect was also widespread across the scalp.

#### Effects of controlled episodic retrieval

##### Early time window

In order to examine the ERP correlates of controlled episodic retrieval, we compared correct rejections of non-targets (P3) with correct rejections of new items (P1). These analyses included the factors Group, Condition (P1, P3), AP (anterior-frontal vs. frontal vs. central vs. parietal), and Laterality (left vs. right). The ANOVA revealed interactions of the factors Group and Condition [ $F(1, 32) = 12.03$ ,  $p < .01$ ] and Group, AP and Condition [ $F(3, 96) = 4.50$ ,  $p < .05$ ,  $\epsilon = .472$ ]. This again indicates that the Condition effects vary across age groups and recording sites. Follow-up analyses,



**Figure 4** Overview of the topographies in adults (left, between 450 and 600 ms) and children (right, between 550 and 700 ms). Top: Old/new effect in run A (i.e. P2-P1), bottom: Memory strength effect (P4-P2). Note the different scaling for the age groups to illustrate amplitude differences between the conditions rather than between groups.

performed separately for each age group, revealed an effect of Condition [ $F(1, 17) = 6.36, p < .05$ ] as well as a three-way interaction between Condition, AP, and laterality [ $F(3, 51) = 3.90, p < .05, \epsilon = .785$ ] for adults. Further analyses revealed reliable non-target effects for anterior-frontal [ $F(1, 17) = 3.90, p < .05$ ], frontal [ $F(1, 17) = 7.32, p < .05$ ], and central electrode sites [ $F(1, 17) = 5.73, p < .05$ ]. In all instances, non-targets elicited more positive waveforms than new items.

For children, an effect of Condition [ $F(1, 15) = 5.62, p < .05$ ] and an interaction between Condition and AP [ $F(3, 45) = 4.00, p < .05, \epsilon = .461$ ] were found. Follow-up analyses revealed that non-targets were reliably more negative-going than new items at anterior frontal [ $F(1, 15) = 4.78, p < .05$ ] as well as frontal sites [ $F(1, 15) = 10.88, p < .01$ ].

To summarize, for both groups reliable differences between non-targets and new items were found at frontal recording sites in the early time interval. More positive-going waveforms for non-targets were obtained for adults, whereas more negative-going waveforms were found for non-targets relative to new items for children.

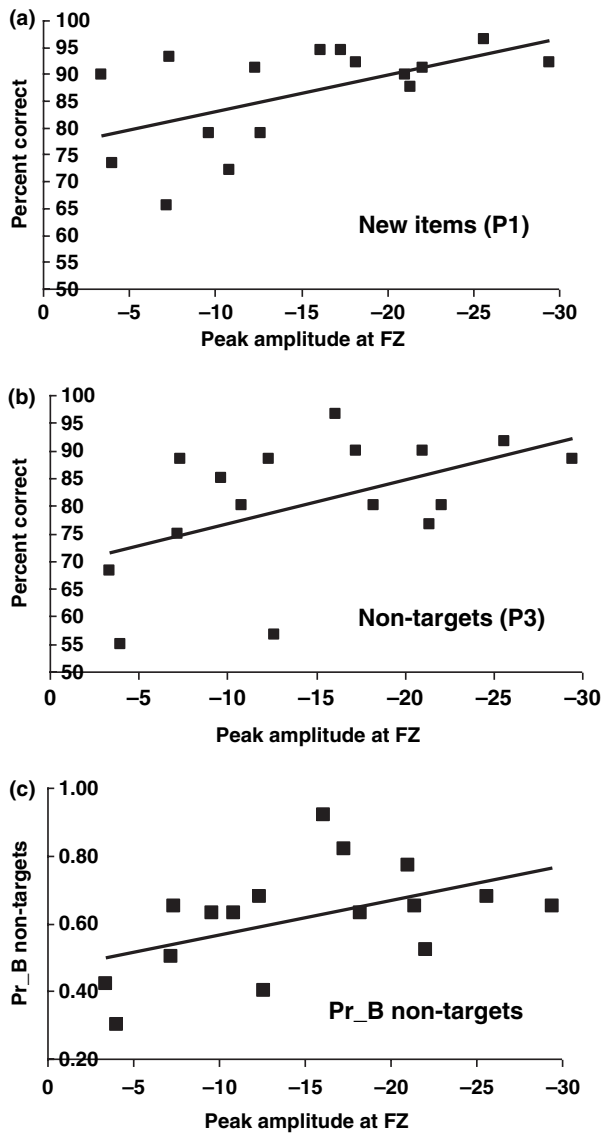
#### Late time window

For the late time window, the initial ANOVA with the between-subjects factor Group revealed a main effect of

Condition [ $F(1, 32) = 4.28, p < .05$ ] with no reliable interactions involving the Group factor (all  $ps > .28$ ). Since the behavioral analyses suggest that adults and children differ in the type of processing engaged for non-target retrieval, we predicted that the ERP non-target effects should also differ across groups. Group-specific ANOVAs were conducted in this late time interval to test this prediction.

For adults, a main effect of Condition [ $F(1, 17) = 6.14, p < .05$ ] as well as a three-way interaction between Condition, AP, and Laterality [ $F(3, 51) = 3.15, p < .05, \epsilon = .727$ ] were found. Follow-up analyses revealed reliable effects of Condition at frontal [ $F(1, 17) = 4.44, p = .05$ ], central [ $F(1, 17) = 5.70, p < .05$ ], and parietal sites [ $F(1, 17) = 4.36, p = .05$ ]. In addition, an interaction between Condition and Laterality indicated that the effect was larger for the left than right hemisphere over central [ $F(1, 17) = 6.70, p < .05$ ] and parietal sites [ $F(1, 17) = 6.98, p < .01$ ]. Notably, for children no reliable effects involving the Condition factor were obtained in the late time interval [ $Fs < 1$ ].

To summarize, behavioral differences in non-target retrieval between the two groups were paralleled by group differences in the ERP correlates of controlled episodic retrieval in this late time interval. For adults, differences between non-targets and new items were obtained at more posterior (left) electrode sites.



**Figure 5 (a–c):** Relationship between the frontal negativity and task performance for children (a: percent correctly rejected new items in run A (P1), b: percent correctly rejected non-targets in run B (P3), c: Pr\_B non-targets). For children, the frontal negativity was correlated with the ability to correctly reject new items in run A (P1) and non-targets (P3) in run B (% correct non-targets, Pr\_B\_non-targets), whereas for adults no corresponding correlations were obtained.

Consistent with prior studies, these effects took the form of more positive-going waveforms for non-targets. No differences between non-targets and new items were obtained for the group of children, suggesting that children engaged in strategic non-target retrieval to a lesser extent than adults.

#### Frontal negativity to new items

Based on visual inspection of the opposite polarity of frontal old/new effects and also confirmed by the statistical analyses with the between-subjects factor group, the most pronounced differences between

children's and adults' ERPs were observed at frontal and antero-frontal electrode sites in the early time interval. Consistent with previous ERP studies with children (e.g. Cycowicz *et al.*, 2003; Czernochowski *et al.*, 2005), a large negative peak elicited in all conditions was evident for children. Notably, in the present study it was attenuated for correct rejections of new items (P1) relative to repeated item presentations (P2 and P4). To further examine the functional significance of this attenuated negativity observed across conditions, a series of correlation analyses were performed for the peak amplitude of this negativity elicited by correct rejections of new items. For these analyses, we selected the electrode FZ, where the negativity was most pronounced, and a time window between 350 and 450 ms.

As illustrated in Figure 5, for children there was a negative correlation between the peak amplitude elicited by correct rejections in run A (P1) and correct rejection performance with these items ( $r = -.56$ ,  $p < .05$ ). Interestingly, this frontal negativity also correlated with performance in run B. That is, the larger the negativity to new items in run A, the better able participants were to correctly reject these items when they reoccurred as non-targets in run B (P3) ( $r = -.51$ ,  $p < .05$ ). An analogous negative correlation was revealed between the frontal negativity and the behavioral index of controlled episodic retrieval performance, Pr\_B\_nontarget, ( $r = -.49$ ,  $p = .05$ ). In adults, no corresponding correlations were found (all  $p$ -values  $> .68$ ). When using age as a covariate in the correlations between peak amplitude and performance measures (i.e. partial correlations), for adults still no reliable correlations emerged (all  $ps > .59$ ), suggesting that adults and children use distinct neuronal networks for successful task performance. When including age as a covariate in the group of children, the correlations were reduced in magnitude, presumably a statistical (side) effect due to the very low age range in the children's group. However, the correlation with the proportion of correctly identified new items was still robust when controlling for age ( $r = -.53$ ,  $p < .05$ ), while the associations with correctly identified non-targets ( $r = -.47$ ) and Pr\_B\_nontarget ( $r = -.44$ ) were still marginally significant ( $ps < .10$ ). Hence, the correlations between peak amplitude at FZ and performance cannot be accounted for by chronological age which is only a very crude and indirect indicator of brain maturation and myelination, thus supporting a functional interpretation.

#### Discussion

In the present investigation, we used a continuous recognition paradigm to compare memory retrieval of item information (run A) and of associations between items and the temporal context in which they appeared (run B). The pattern of performance in children was

consistent with the results of previous studies examining memory for item–context associations in children by means of an exclusion task (Czernochowski *et al.*, 2005, Cycowicz *et al.*, 2003). Children had longer RTs and lower performance relative to adults. Specifically, elevated false alarm rates and prolonged response times to non-targets were observed in children, but not in adults. This result is consistent with the view that children show a selective attenuation of memory performance in a condition requiring controlled episodic retrieval, i.e. the retrieval of non-targets in order to classify these items as new ('recall-to-reject'; Clark, 1992).

#### *ERP effects in adults*

In adults, topographically widespread old/new effects were observed at all electrode sites. This contrasts with old/new effects usually found in study-test paradigm (see Friedman & Johnson, 2000, for a review). It is conceivable that the requirement for simultaneous encoding and retrieval in continuous recognition memory tasks calls for a higher level of connectivity between specialized brain areas relative to the retrieval demands in the test phase of study-test paradigms in which old/new effects are usually analyzed. These processing differences could account for the broadly distributed old/new effects in the present study. Consistent with our prediction, in the early time window, waveforms for old items irrespective of target status were more positive-going than those for new items across electrodes. Based on the assumption that ERP differences between old and new items in this early time interval reflect familiarity-based recognition (e.g. Curran, 2000; Mecklinger, 2000; Rugg & Curran, 2007), this pattern of results suggests that all types of old items including non-targets elicited a familiarity signal. By contrast, memory strength modulated only the later old/new effect, suggesting enhanced recollection for hits in run B (P4) relative to run A (P2). These observations are consistent with the view that after repeated encoding, the proportion of items that were recollected as well as the amount of contextual detail recollected for every item was enhanced, leading to a larger amplitude of the parietal old/new effect (Wilding, 2000; see also Van Strien *et al.*, 2005). Notably, no effect of memory strength was observed in the early time window. Due to the presence of non-targets in run B, it was no longer sufficient to rely on an assessment of familiarity as both target hits and non-targets were familiar. In order to dissociate non-targets and targets, controlled episodic retrieval was required, i.e. retrieving that an item was repeated in the wrong context and by this can be rejected ('recall to reject'; Clark, 1992; Fraser *et al.*, 2007; Wilding *et al.*, 2005). Consistent with this view, we found a reliable and delayed parietal old/new effect for non-targets for the adults.

#### *Parietal ERP effects in children*

Target old/new effects in children were apparent between 550 and 700 ms at posterior recording sites, consistent with previous studies (e.g. Marshall *et al.*, 2002; Cycowicz *et al.*, 2003; Czernochowski *et al.*, 2005). Using an interleaved study and test design as in the present study in contrast to more traditional recognition memory paradigms with study-test cycles did not appear to influence old/new effects at parietal electrodes. Characteristic for children's ERP data are overall large amplitudes, which are presumably related to ongoing maturation of the brain, including myelination (see Casey *et al.*, 2000, 2005) and skull thickness (see Lai *et al.*, 2005). Despite differences in the peak amplitudes, the relative differences between old and new items at parietal electrodes were similar for both age groups, i.e. old items were associated with more positive waveforms than new items. Also, the effects of memory strength, i.e. more positive-going waveforms for hits in run B (P4) than in run A (P2), were highly similar across age groups. Consistent with previous ERP studies of recognition memory in children of early school age (e.g. Marshall *et al.*, 2002; Czernochowski *et al.*, 2005), the differences between the conditions emerged somewhat later for children than adults. Taken together, the similarities in the relative differences between old and new items can be taken as evidence that the parietal old/new effect reflects recollection-based recognition in adults and children in this age range. While recollection is associated with hippocampal activation as observed in numerous fMRI studies (see Simons & Spiers, 2003), ERPs predominantly detect neural activity from cortical areas. Hence, the observed activity recorded from scalp electrodes presumably reflects projections from hippocampal and adjacent medial temporal lobe networks to association cortices. Based on these as well as previous findings (Marshall *et al.*, 2002; Czernochowski *et al.*, 2005) this neural network mediating recollection appears to mature relatively early, at least by middle childhood, consistent with recent evidence that even preschool children are able to correctly identify the source of information when given appropriate questions and short item lists (see Giles *et al.*, 2002). Thus, recollection or a precursor of recollection might be available very early on, and become more and more reliable with ongoing frontal lobe maturation. Currently, it still remains an open question why children are so error-prone. Behavioral and ERP studies concur that improvements in retrieval accuracy are largely due to improvements in recollection. These most likely are related to the delayed maturation of frontal control processes. In fact, children did not show any reliable parietal old/new effect for non-targets and showed a higher tendency to falsely accept those items as targets than adults. The absence of non-target old/new effects in children suggests that controlled episodic retrieval develops later during adolescence. Presumably, such



task-adaptive non-target recollection is depending on further maturation of the frontal lobes.

Taken together, the large left-lateralized centroparietal old/new effect in children is consistent with previous findings (e.g. Cychowicz *et al.*, 2003; Czernochowski *et al.*, 2005), suggesting that both item and source memory in children rely predominantly on recollection. Notably, this effect was seen selectively for targets. Very similar results were previously reported for an exclusion task where source was defined by the modality of study information (photos vs. spoken words; (see Czernochowski *et al.*, 2005), hence, the localization and latency of the ERP correlate for recollection in children does not appear to depend on the nature of the source-specifying attributes nor on the shorter amount of time between first and repeated item presentations in a continuous recognition paradigm. While recollection, as reflected in the parietal old/new effect, and the effects of memory strength appear comparable across the age groups studied here, a strategic modulation of recollection as seen in adults for non-target information was not consistently present in children.

#### *Frontal ERP effects in children*

Pronounced age group differences emerged at frontal and anterior-frontal recording sites: The early ERP old/new effect in children was apparent as modulation of a frontal negativity between 350 and 500 ms. In this time period, the waveforms for correctly identified new items (P1) differed reliably from those to non-targets (P3) and targets (P2) at anterior frontal electrode sites and from those for non-targets also at frontal electrode sites. However, in children this early old/new effect was reversed in polarity relative to adults, i.e. there were larger negative amplitudes for old than for new items. Developmental differences in the polarity of the early old/new effect could reflect the ongoing maturation of the frontal lobes (e.g. Casey *et al.*, 2000, 2005). As a reversed polarity frontal old/new effect was observed for both targets and non-targets, it is conceivable that this effect is a developmental precursor of the ERP correlate for familiarity. While the exact nature of this effect still needs to await further examination, it is worth noting that previous ERP studies of recognition memory using separate study and test blocks did not report any early frontal ERP modulations in children (Cychowicz *et al.*, 2003; Czernochowski *et al.*, 2005), suggesting that task characteristics may have contributed to these differences between studies. Specifically, in the continuous recognition paradigm employed here, there were no explicit encoding instructions and encoding and retrieval demands were interleaved within a trial. In this respect, the task used here somewhat resembles the paradigms commonly employed in infant research, in which infants watch sequences being presented repeatedly and memory is inferred from successful deferred imitation in the correct temporal order at a later point in time. Frontal

negativities with similar functional characteristics (Nc) have repeatedly been reported in infants using these paradigms (e.g. Bauer, Wiebe, Carver, Waters & Nelson, 2003; Lukowski, Wiebe, Haight, deBoer, Nelson & Bauer, 2005), peaking between 1000 and 1200 ms in newborns and around 500 ms in 1-year-olds (DeBoer, Scott & Nelson, 2005). The late maturation of frontal brain regions, in particular the ongoing myelination of fiber connections (see Casey *et al.*, 2000), could potentially contribute to the relatively similar morphology of the Nc in infants and frontal ERP modulations in older children.

From a functional point of view, the Nc has been taken to reflect the allocation of attention to novel or unexpected events. In ERP studies with young children and infants, the Nc component has been obtained for different stimulus materials such as faces and emotional pictures: Interestingly, a recent cross-sectional study revealed that children under the age of 24 months show a larger Nc for familiar (mother) faces, whereas 4-year-olds show the opposite pattern, i.e. larger Nc to stranger as compared to mother faces (Carver *et al.*, 2003). This has been taken to reflect that older children direct more attention to unfamiliar faces (de Haan *et al.*, 2003; de Haan, 2007; deBoer *et al.*, 2005). Even though the children in the present and the aforementioned studies differ in their age range, it is conceivable that the frontal negativity observed in the present study has a similar functional significance as the above-mentioned Nc in 4-year-olds: The children allocate more attention to novel pictures than to repeated pictures. The correlations between the frontal negativity and the performance measures are consistent with this view. Notably, the correlation pattern was also found for the performance measures in run B, in which familiarity does not suffice to discriminate target from non-targets. This suggests that the allocation of attention to novel pictures (as reflected in the frontal negativity) may boost children's memory encoding and may promote the formation of memory traces that give rise to recollection-based remembering. Such a mechanism would allow limited attentional resources to be optimally allocated to the formation of new memory traces (see Fernandez & Tendolkar, 2006) and promote rapid learning as observed in infancy and early childhood. A similar relationship between negativities elicited at the initial encoding and subsequent memory performance has been reported by Mangels, Picton and Craik (2001). However, it appears premature to draw any firm conclusions at this point, and further empirical work is required to examine the functional role of frontal ERP negativities in early childhood.

Why were these effects not observed for adults? In the absence of an explicit encoding task, children may use different ways of 'memorizing' than young adults. Consistent with the view that repetition renders an item more familiar, the adults show more positive ERP waveforms for all repeated items relative to new items at

frontal recording sites, whereas the opposite pattern was found for children. In light of these pronounced age differences in the early ERP effects, it is tempting to speculate that children may have relied more on the salience of novel items, thus by-passing familiarity-based remembering due to a not fully matured semantic memory system which does not allow fast and reliable recognition judgments. It is conceivable that this attentional mechanism enables infants as well as older children to acquire large amounts of new information very rapidly. Ensuring that attention is allocated to everything that is new and hence worth memorizing would be the ideal way of building a comprehensive semantic memory system. Under the assumption that such a strategy is particularly efficient in a continuous recognition memory task (as in the present study in run A), since only the more salient novel items need to be encoded, this view would also account for the observation that similar relations between novelty processing and memory performance have not been found in typical recognition memory tasks using study-test cycles with explicit encoding instructions for all items in the study phase.

## Conclusions and open issues

Remarkably similar ERP old/new effects and effects of memory strength were obtained for children and adults at parietal electrodes, suggesting that recollection-based remembering is comparable across the two age groups under investigation. As a parietal effect to non-targets was obtained in adults but not in children, our data suggest that this aspect of controlled episodic retrieval shows a delayed maturational development.

While the typical early old/new effect in the form of more positive waveforms for old relative to new items was observed for adults, in children a relative larger negativity of old vs. new items was observed at (anterior) frontal electrode sites. The peak amplitude of the waveforms contingent upon an item's first correct classification as new was correlated with task performance in runs A and B and may reflect the allocation of attentional resources to novel events. In a situation of not fully matured semantic memory, this attentional mechanism might support the formation of recollection-based memories, which are critical for task performance in run B, where targets and non-targets were equally familiar.

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