Two Processes for Recognition Memory in Children of Early School Age: An Event-related Potential Study

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Abstract

■ We examined the ERP correlates of familiarity and recollection and their development in 8- to 10-year-old children and a control group of young adults. Capitalizing on the different temporal dynamics of familiarity and recollection, we tested recognition memory in both groups with a speeded and nonspeeded response condition. Consistent with the view that familiarity is available earlier than recollection and by this more relevant for speeded recognition judgments, adults and children showed an early frontal old/new effect, the putative ERP correlate of familiarity in the speeded response condition. No parietal old/new effect, the putative ERP correlate of recollection was obtained in the speeded condition in neither group. Conversely, in the nonspeeded condition, both groups showed the parietal old/new effect, and a frontal effect was additionally observed for adults. In light of the generally lower memory accuracy of the children, these data suggested that children use a weaker and less matured version of the same explicit memory network used by adults in which familiarity and recollection differentially contribute to speeded and nonspeeded recognition memory judgments. ■

INTRODUCTION

The development of recognition memory can be characterized as a continuous process by which the ability to retain and retrieve information improves from infancy over childhood to adolescence. In fact, item recognition memory, that is, the ability to judge an item as having been encountered before, undergoes a strong developmental change and variables known to affect adult's recognition memory also affect memory performance in infancy and in childhood (Cycowicz, Friedman, & Snodgrass, 2001; Cycowicz, Friedman, Snodgrass, & Duff, 2001; Dirks & Neisser, 1977). However, in addition to the examination of developmental changes in recognition memory as revealed by overt behavior, an important endeavor is to disentangle the processes underlying recognition memory performance and their developmental trajectories. From a dual-process point of view, it has been argued that two qualitatively distinct processes, familiarity and recollection, contribute to recognition memory (Yonelinas, 2002). Familiarity is a fast-acting process by which the strength of a memory representation is assessed without the retrieval of qualitative details about the event. Conversely, recollection refers to the retrieval of detailed information from a prior episode including its spatial and temporal context. The present study examines the development of recollection and familiarity by means of ERPs.

Despite the large number of studies that examined the developmental trajectories of recognition memory or other explicit memories (Cycowicz, Friedman, & Snodgrass, 2001; Cycowicz, Friedman, Snodgrass, Duff, et al., 2001; Holland Joyner & Kurtz-Costes, 1997; Parkin, 1997), so far only little is known about the development of familiarity and recollection. There is some evidence for the view that recollection shows more developmental change than familiarity. For example, item recognition memory tasks that can be performed on the basis of familiarity and recollection traditionally show less age differences, whereas recall tasks that primarily rely on recollection show strong improvements during childhood (Cycowicz, Friedman, & Snodgrass, 2001; Cycowicz, Friedman, Snodgrass, Duff, et al., 2001). Children also show poorer performance and more developmental changes on source memory tasks that require a judgment as to the context in which an item was previously presented (e.g., the voice in which a word was spoken). In contrast to item memory tasks, familiarity is not diagnostic for correct recognition judgments in the latter tasks (Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005; Lindsay, Johnson, & Kwon, 1991).

Only very few studies have examined the development of recollection and familiarity from a dual-process point of view (Ghetti & Angelini, 2008; Ofen et al., 2007; Billingsley, Smith, & McAndrews, 2002; Anooshian, 1999). One approach is to use the remember–know (R/K) procedure (Tulving, 1985), in which participants—upon presentation of a retrieval cue—have to evaluate their memory states and to indicate whether they recollect qualitative details from a prior study episode (R-response) or merely have a feeling of familiarity with a stimulus (K-response). Using this method, Billingsley et al. (2002) found an age-related

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increase in R-responses but not in K-responses between early school age and adulthood. Similarly, using a picture recognition memory task, Ofen et al. (2007) found an overall improvement of recognition memory accuracy from childhood to adolescence (ages 8–24 years) and a positive correlation between age and memory performance for R-responses but not for K-responses. However, the R/K paradigm has been criticized for its reliance on subjective reports of familiarity and recollection and, with respect to developmental or clinical studies, for the presumably large interindividual variability in interpreting the difference between remembering and knowing (Strack & Förster, 1995).

In an effort to overcome these limitations, Ghetti and Angelini (2008) recently employed receiver operating characteristic (ROC) curves to examine the development of familiarity and recollection. ROCs are functions that relate hit rates to false alarm rates while participants make recognition judgments at different levels of confidence (Yonelinas, 2002). Notably, ROCs allow to derive estimates for familiarity and recollection on the basis of dual-process models. Examining children and adolescents between 6 and 18 years of age, Ghetti and Angelini (2008) found an age-related improvement for recollection from childhood to adolescence after a semantic but not after a perceptual encoding task, whereas familiarity increased only between 6 and 8 years irrespective of encoding condition. These results indicate that familiarity is stable at around 8 years.

These studies shed light on familiarity and recollection and their development. They suggest that age differences in recognition memory primarily reflect age-related improvements in recollection from childhood through adolescence to adulthood, whereas familiarity shows early developmental changes but only small age-related changes after the age of 8 years. However, there are some methodological limitations in the aforementioned studies that need some consideration. First, studies employing the R/K procedure or studies including confidence judgments require participants to elaborate or to introspect their memory states and this form of meta-memory may be affected by age (Roebers, 2002; Holland Joyner & Kurtz-Costes, 1997). For example, in the aforementioned studies by Ofen et al. (2007) and Billingsley et al. (2002), it was not directly tested whether children and adults follow the R/K instruction in the same way and how these subjective reports are related to objective measures of familiarity and recollection. In fact, it has been argued that children in early school age cannot yet differentiate between different mental states, like knowing, believing, or remembering and by this would not be able to experience familiarity different from other mental states (Perner & Ruffman, 1995). By this, any age-related differences in familiarity and recollection may potentially reflect age-related differences in the ability to follow instructions and/or to assess memory states. Second, the ability to give confidence ratings that differ reliably among memory states, as required in ROC studies, may differ across age. Third, deriving estimates for familiarity and recollection from ROC curves presupposes that the model assumptions hold to the same extend across the age groups, that is, a criterion that is seldomly tested in ROC studies (Ghetti & Angelini, 2008). By this, age comparisons of ROC curves and derived recollection and familiarity estimates can produce misleading results.

In the present study, we used ERPs to examine the age-related changes in familiarity and recollection. ERPs reflect changes in scalp-recorded electrophysiological brain activity and provide an excellent temporal resolution to monitor functionally relevant brain processes. The amplitudes, latencies, and topographical distribution of ERP components can be used as markers for cognitive processes. Although currently controversial (Paller, Voss, & Boehm, 2007; Rugg & Curran, 2007), there is substantial evidence that in adults, recollection and familiarity are associated with qualitatively different ERP correlates (Mecklinger & Jäger, 2009; Rugg & Curran, 2007; Friedman & Johnson, 2000). The putative ERP correlate of familiarity is the midfrontal old/new effect, that is, more positive going waveforms for previously studied than unstudied items that are most pronounced between 300 and 500 msec at frontal electrode sides. By contrast, recollection is associated with a slightly delayed ERP effect, that is, more positive going waveforms for studied than nonstudied items between 400 and 600 msec at parietal recording sites, termed the parietal old/new effect (for a review of the empirical findings supporting this proposal, see Rugg & Curran, 2007; Friedman & Johnson, 2000; Mecklinger, 2000). By this, ERP components provide reliable measures of familiarity and recollection and, unlike the aforementioned approaches, do not depend on subjective reports of memory states.

ERP studies on recognition memory with children suggest that the parietal old/new effect, the putative ERP correlate of recollection can be reliably recorded at early school age (Czernochowski, Mecklinger, & Johansson, 2009; van Strien, Glimmerveen, Martens, & de Bruin, 2009; Czernochowski et al., 2005; Marshall, Drummey, Fox, & Newcombe, 2002; Hepworth, Rovet, & Taylor, 2001). For example, Czernochowski et al. (2005) used a study-test recognition memory paradigm in which line drawings of objects were used as retrieval cues for previously studied real-world photographs and spoken words. A parietal old/new effect was present for 6- to 8- and 10- to 12-year-old children, irrespective of target category, albeit at a slightly longer latency and with larger amplitude as compared with young adults. A similar parietal old/new effect was obtained with words and faces as test stimuli for 11- to 14-year-old children (Hepworth et al., 2001) and in 10-year-olds with pictures as retrieval cues (Cycowicz, Friedman, & Duff, 2003). This suggests that recollection is available for recognition judgments at early school age.

With respect to the midfrontal old/new effect, the putative ERP correlate of familiarity, the picture is less consistent. In the aforementioned study by Czernochowski et al. (2005), no midfrontal old/new effect was obtained for neither group of children. The absence of a midfrontal old/new effect in the latter study has been attributed to a specific retrieval and decision strategy employed by the children. Both children groups set a very conservative response criterion and only responded “old” when in a highly certain state, a decision strategy that may have attenuated any contribution of familiarity to recognition judgments for previously studied items (Azimian-Faridani & Wilding, 2006). Using a continuous recognition memory paradigm in which old/new decisions were required for continuously presented pictures of everyday objects, Czernochowski et al. (2009) even found an old/new difference at frontal recording sites in the opposite direction for 10- to 12-year-old children, that is, the ERPs were more positive going for new than for old items. This effect may result from component overlap with the Nc, a frontally focused negative component frequently reported in infant and children ERP studies that presumably reflect the allocation of attention to novel and unexpected events (de Haan, Johnson, & Halit, 2003). A similar attentional mechanism may also account for the results of Hepworth et al. (2001), who also found an old/new difference in the opposite direction in 11- to 14-year-olds at frontal recording sites. van Strien et al. (2009) found a midlatency old/new effect (labeled the N400 old/new effect) to be smaller over parietal regions for 8- to 9- as compared with 11- to 12-year-old children, which according to the authors reflects a less matured semantic memory system in the younger children group. Another reason for not finding a correlate for familiarity in children may be that these studies may have lacked an adequate operational definition of familiarity (see below) or may have been limited by the use of preexperimentally highly familiar items (Hepworth et al., 2001) for which ERP correlates of familiarity are not consistently found (Stenberg, Hellman, Johansson, & Rosén, 2009).

Taken together, the ERP studies outlined above suggest that ERP correlates of recollection in children of early school age have a similar morphology to that seen in adults and by this recollection is available for recognition memory at this age. An open issue is under which circumstances ERP correlates of familiarity can be reliably recorded and if so whether they show different developmental changes as the ERP correlates of recollection.

Two major goals were pursued in this experiment. First, we investigated whether a midfrontal old/new effect, the putative ERP correlate of familiarity, can be recorded from children at early school age and from an adult control group under experimental conditions that encourage familiarity-based remembering and attenuate recollection. Second, we explored whether the ERP correlates of familiarity and recollection show similar developmental differences. By this, we searched for converging evidence regarding measures of the two subprocesses of recognition memory and their developmental trajectories.

In our operational definitions of familiarity and recollection, we focused on the temporal dynamics of familiarity and recollection. On the basis of previous studies that showed that familiarity is available earlier than recollection (Hintzman & Caulton, 1997; Hintzman & Curran, 1994), we tested recognition memory in children and adults with a response deadline procedure, in which recognition decisions were required very quickly. A number of studies have shown that under speeded response conditions, that is, when participants have to give a recognition memory decision within 800 msec, recollection is diminished and tends to be at chance level while familiarity-based memory is still above chance (Boldini, Russo, & Avons, 2004; Hintzman & Caulton, 1997). As familiarity is fostered under speeded response conditions, we expected the ERP correlate of familiarity to be present and the correlate of recollection to be diminished when speeded recognition judgments have to be given.

On the basis of the aforementioned studies on the development of familiarity and recollection, the following predictions were made. If recognition memory performance depends more on familiarity than on recollection in a speeded response condition, performance for adults should be lower than that in a nonspeeded condition. Also there should be a midfrontal old/new effect but no parietal effect. If familiarity is available at early school age, as suggested by the findings of Ghetti and Angelini (2008), we predicted children of early school age to show the same performance and ERP pattern as the adult control group under a speeded condition because familiarity is fostered in this condition.

As in a nonspeeded condition recognition depends on both recollection and familiarity, recognition memory performance should be higher than that in a speeded condition and the ERP correlates of familiarity and recollection should be present for adults. For children, we predicted a parietal old/new effect. However, on the basis of the mixed pattern of results regarding the ERP correlate of familiarity in standard item recognition tasks, no specific predictions were made regarding the frontal old/new effect for children in this condition.

METHODS

Participants

Twenty-six children and 26 young adults participated in the study. Five adults and eight children had to be excluded from further analyses due to a too low number of artifact-free ERP trials that resulted of a combination of low performance levels and excessive movement artifacts. One adult was excluded because of technical problems during recording. The age and sex distributions within each group were as follows: 8- to 10-year-old children (mean age = 9.12 ± 0.90; 9 girls, one left-handed) and 19- to 27-year-old young adults (mean age = 22.05 ± 2.52; 10 women, all right-handed). All participants were native German speakers and reported themselves to be in good health. The children were recruited from schools in Saarbrücken and in the immediate vicinity. Young adults were undergraduate students at Saarland University, who either received course credit or were paid for their participation (€8.00/hr). Informed consent was obtained from adult participants and parents of all children. In addition, children signed assent forms.

Stimuli

The experimental stimuli were selected from a colored version of the Snodgrass and Vanderwart line drawings (Rossion & Pourtois, 2004). In total, 240 colored line drawings of common objects and animals were selected that were divided into two blocks of 120 items each. Of the 120 pictures in a block, 60 were randomly assigned to the study phase, whereas the remaining 60 were assigned as new items to the test phase. The order of pictures within a block was randomized separately for each participant. The assignment of pictures to old/new status and experimental block was balanced across subjects. For the practice lists, we used additional 30 pictures from a database from Becker, Kipp, and Mecklinger (2009).

Procedure

Participants were seated in a comfortable chair throughout the experiment. The stimuli were presented in central vision on a computer monitor. The whole session lasted approximately 2 1/2 hr, including setting up the EEG cap. The experiment consisted of two study-test cycles, one for the speeded and one for the nonspeeded condition. As we assumed that it would be more difficult to change from nonspeeded to speeded response requirements than vice versa and to control for interindividual variability in changing the response procedure, the study-test cycle for the speeded condition was always performed first.

Each cycle included a study phase, a retention interval, and a test phase. In both cycles, participants responded by using two buttons, one for each hand, with response hands counterbalanced across participants. Participants were given a practice block with 10 study and 20 test trials (speeded test block) or 5 study and 10 test trials (nonspeeded test block) before each study-test cycle. Generally, the subjects performed the practice blocks once, but occasionally the practice block preceding the first study-test cycle had to be repeated to ensure that the subjects understood the task instructions. In both study phases, the subjects viewed 60 pictures that were presented consecutively and were instructed to memorize the picture and to make an indoor/outdoor judgment by pressing a corresponding key. Each picture was presented for 1000 msec, preceded by a fixation cross (400 msec). After a fixed intertrial interval of 1400 msec, the next fixation cross appeared. Relative to two age-matched norm samples, the range of percent correct indoor/outdoor judgments was 0.48 to 0.90 for adults and 0.34 to 0.85 for children. By this, task performance in the study phases was highly similar for both groups.[1]

There was a retention interval of 1 min between the study and the test phase. During this retention interval, the subjects had to perform an easy arithmetic task. The children had to count backward in steps of two from a given number between 18 and 20. The adults had to count backward in steps of seven from a number between 400 and 600.

In each of the two test phases, the subjects viewed a total of 120 pictures (50% old) and were instructed to make old/new recognition decisions. A test trial began with a fixation cross (500 msec), which was followed by the critical picture presented for either 750 msec (adults) or 1050 msec (children). In the speeded condition, subjects were instructed to give their old–new responses during picture presentation (maximal response time = 750 and 1050 msec for adults and children, respectively). Different response deadlines were used for children and adults to account for the generally slower processing speed of children (Picton & Taylor, 2007). In fact, a pilot study revealed that under nonspeeded conditions, recognition judgments for the stimulus materials used in this study took about 300 msec longer for children than for adults. If the response was given after the presentation of the picture, subjects were informed about their time-out response by means of a brief sound, and the trial was discarded from analysis. If a response was given in time, a feedback stimulus (smiley or frown face) was presented indicating whether the correct or incorrect response had been given. In the nonspeeded condition, subjects were given unlimited time to respond. Immediately after the response, the feedback stimulus was presented. The intertrial interval was 2000 msec in both test blocks. Subjects were given a break every 15 trials in both test blocks. To ensure that the children had understood the procedure, they were asked to explain the instruction to the experimenter in their own words before each block and were corrected if necessary.

EEG Recording

EEG was recorded continuously with a sampling rate of 250 Hz with 27 Ag/AgCl electrodes from 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, and O2. The left mastoid served as an on-line reference, and all EEG electrodes were rereferenced off-line to the algebraic mean of both mastoids. The vertical EOG was recorded bipolar from additional electrodes placed on the supraorbital and infraorbital ridges of the right eye. Horizontal EOG was recorded bipolar from electrodes placed on the outer canthi of the two eyes. Electrode impedance was kept below 5 kΩ. EEG and EOG were recorded continuously and were A–D converted with 16-bit resolution at a sampling rate of 250 Hz. Off-line data processing involved low-pass filtering at 30 Hz and high-pass filtering at 0.2 Hz. Before averaging, each recording epoch was manually scanned for artifacts. Trials containing eye movement artifacts were corrected off-line using a modified version of the Gratton, Coles, and Donchin (1983) regression procedure. Trials were epoched and baseline corrected off-line with a 200-msec prestimulus period. The duration of the poststimulus period was 900 msec for the speeded and 1200 msec for the nonspeeded condition.

For each group, ERPs were averaged to correctly recognized old (hits) and new items (correct rejections; CRs) for both response conditions. For adults, the mean trial numbers (range) in the speeded test block were 38 (24–52) for hits and 38 (23–55) for CRs. The corresponding numbers for the nonspeeded test block were 43 (34–51) and 43 (33–53), respectively. For the children, the mean trial numbers (range) in the speeded test block were 27 (17–40) for hits and 27 (17–45) for CRs. In the nonspeeded test block, the corresponding numbers were 28 (18–37) and 28 (20–42), respectively. Post hoc *t* tests for independent samples indicate that children contributed fewer trials than young adults, 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.

Data Analyses

SPSS 17.0 statistical package was used for all analyses. Memory accuracy was analyzed by means of the discrimination index (Pr), that is, hit rates minus false alarm rates (Snodgrass & Corwin, 1988). In the speeded test block, all trials with time-out responses or in which no response was given were discarded from analysis. Also, in both response conditions, trials with response times faster than 200 msec were discarded. Response bias (Br) was calculated according to Snodgrass and Corwin (1988) as Br = false alarms / (1 − Pr).

For statistical analysis of the ERP data, nine electrodes over left, midline, and right frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal regions (P3, Pz, P4) were used. These recording sites were selected as they cover scalp regions on the anterior–posterior and the laterality dimension at which old/new effects can be reliable recorded. To quantify the midfrontal and parietal old/new effects, mean amplitude measures were calculated in early (300–450 msec for children and 250–400 msec for adults) and late (600–750 msec for children and 500–650 msec for adults) time windows in both response conditions. The selection of these time windows was based on visual inspection of the waveforms. They were adapted to capture the effects of interest where it was largest in each age group.

ANOVAs with the factors Item Type (hits, CRs), Anterior–Posterior (frontal, central, parietal), Laterality (left, midline, right), Response Condition (speeded vs. nonspeeded), and Group (children, adults) were conducted separately for each time window. Interactions involving the Group, the Response Condition, or the Item Type factor were then followed-up in separate group- and response-condition-specific ANOVAs. Whenever appropriate, the Greenhouse–Geisser correction for nonsphericity (Greenhouse & Geisser, 1959) was used. Corrected *p* values are reported along with uncorrected degrees of freedom. Treatment magnitudes (η_p^2) (Tabachnick & Fidell, 2007) were calculated to allow an assessment of effect sizes across electrode sites. For reasons of simplicity, only effects involving the factors Item Type, Group, or Response Condition are reported.

RESULTS

Behavioral Data

Memory accuracy, response bias, and response times for both groups and response conditions are illustrated in Table 1. Memory performance was high in both groups, and the mean number of time-out responses in the speeded condition was highly similar across groups (0.45, range = 0–3, and 1.1, range = 0–3, for adults and children, respectively). An ANOVA with the factors Group and Response Condition performed for the discrimination index Pr revealed main effects of Group, $F(1, 36) = 14.40, p < .010$, and Response Condition, $F(1, 36) = 72.19, p < .001$, indicating that memory accuracy was higher for adults than for children and also for the nonspeeded than the speeded response condition. For response bias, the two-way ANOVA

Table 1. Mean RTs in Milliseconds for Correctly Recognized Old and New Pictures, Proportions of Hits and Correct Rejections (CRs), Discrimination Index (Pr), and Response Bias (Br) for Each Group in the Speeded and Nonspeeded Condition

	Children	*Adults*
RT Speeded		
Hits	740 (14)	568 (7)
CRs	747 (10)	565 (5)
RT Nonspeeded		
Hits	1276 (104)	905 (42)
CRs	1265 (72)	971 (49)
Proportion Hits		
Speeded	0.71 (0.03)	0.79 (0.02)
Nonspeeded	0.82 (0.03)	0.92 (0.01)
Proportion CRs		
Speeded	0.78 (0.03)	0.84 (0.02)
Nonspeeded	0.87 (0.02)	0.92 (0.01)
Performance Estimate (Pr)		
Speeded	0.49 (0.04)	0.63 (0.03)
Nonspeeded	0.68 (0.04)	0.84 (0.02)
Bias Estimate (Br)		
Speeded	0.44 (0.03)	0.44 (0.03)
Nonspeeded	0.39 (0.04)	0.45 (0.05)

The standard errors of the means are given in parentheses.

did not reveal significant results (F values < 1), indicating that both groups used a similar response criterion that also was not modulated by the response conditions.

For mean response times, an ANOVA with the factors Group, Item Type (hits, CRs), and Response Condition revealed reliable effects of Group, $F(1, 36) = 29.86, p < .001$, and Response Condition, $F(1, 36) = 96.49, p < .001$. As expected, adults responded faster than children, and both groups took more time for responding in the nonspeeded than in the speeded condition.

Taken together, in showing higher memory accuracy for adults than for children, the present results are consistent with prior reports of age differences in item recognition memory tasks (Ghetti & Angelini, 2008; Czernochowski et al., 2005; Naus & Ornstein, 1977). They also show that the response condition manipulation was successful and comparable across groups, that is, both groups responded slower and more accurate in the nonspeeded than that in the speeded response condition.

ERP Data

The grand mean ERP waveforms, separately for each group and response condition at three midline electrodes, are presented in Figure 1. Figure 2 shows the scalp topographies of the mean amplitude measures for early and late ERP effects in each group and response condition.

In the speeded condition, both groups show an early old/new effect between 250 and 450 msec with a midfrontal distribution for adults and a left frontal scalp distribution for children.[2] This effect has its maximum slightly earlier in adults than that in children. In the late time windows (500–650 and 600–750 msec for adults and children, respectively), no parietal old/new effect was obtained for adults, albeit for children a late effect, characterized by a larger positivity for old than new pictures seemed to emerge at parietal recording sites. In the nonspeeded condition, adults show a topographically widespread early old/new effect, followed by a late old/new effect with a centro-parietal maximum. Conversely, for children, only a parietal old/new effect was obtained that started at around 400 msec but reached its maximum at around 700 msec at parietal recording sites. These observations were confirmed by a series of statistical analyses.[3]

Early Time Window (Children, 300–450 msec; Adults, 250–400 msec)

For the early time window, the ANOVA with the factors Group, Item Type, Anterior/Posterior, Laterality, and

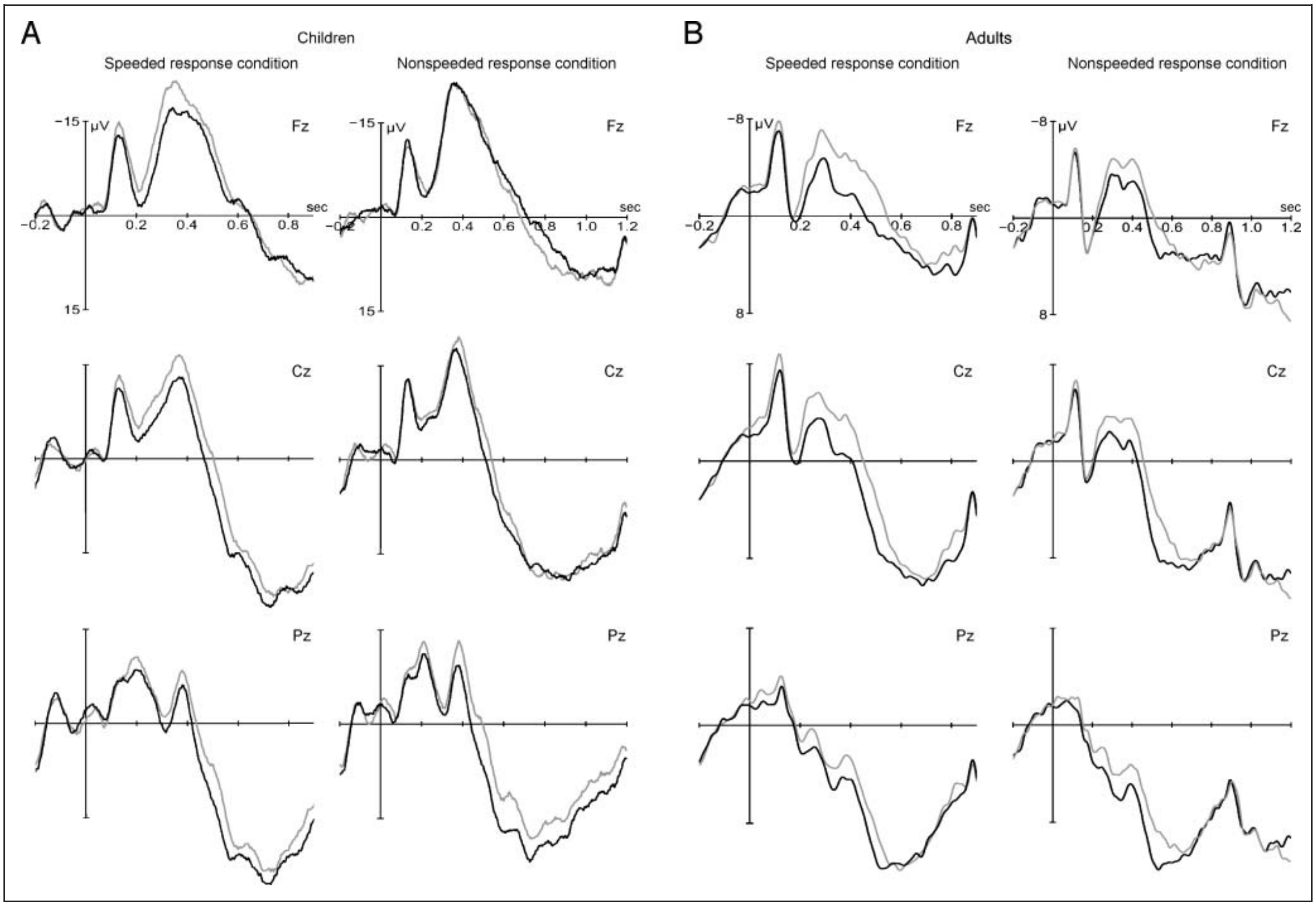
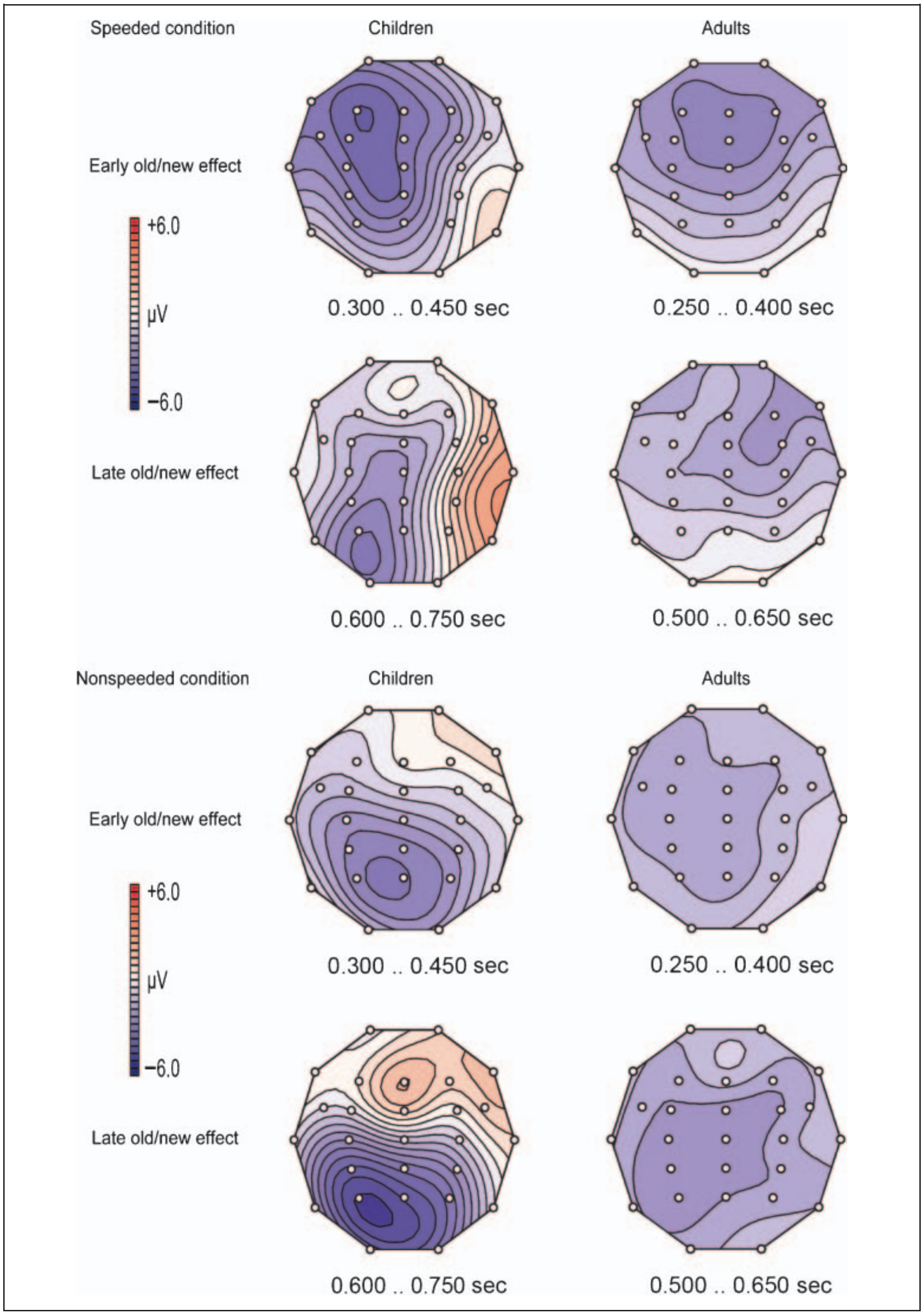


Figure 1. Grand mean ERPs elicited during the item memory task in the speeded and nonspeeded response condition for children (A) and adults (B). Correct rejections of new items are depicted in gray lines, and hits are depicted in black lines. Note the different amplitude scaling in both groups.

Figure 2. Scalp topographies of the early and late old/new effects (new minus old) for children and adults in the speeded and nonspeeded condition.



Response Condition revealed main effects of Item Type, $F(1, 36) = 33.39$, $p < .001$, and Group, $F(1, 36) = 83.62$, $p < .001$. In addition, interactions among Response Condition and Group, $F(1, 36) = 9.03$, $p < .010$, among Item Type, Anterior/Posterior, and Response Condition, $F(2, 72) = 5.74$, $p < .020$, and among Response Condition, Group, Anterior/Posterior, and Laterality, $F(4, 144) = 3.19$, $p < .020$, were obtained. These interactions indicate that the early old/new (Item Type) effect differed as a function of group in both the response conditions and the recording sites. They were followed-up in response condition and group-specific analyses.

In the speeded condition, for adults, an ANOVA with the factors Item Type, Anterior/Posterior, and Laterality revealed an effect of Item Type, $F(1, 19) = 17.19$, $p < .010$, and an interaction of Item Type and Anterior/Posterior, $F(2, 38) = 7.10$, $p < .020$. The interaction reflects the fact that the early old/new effect, although significant at frontal, central, and parietal electrodes, was larger at frontal ($\eta_p^2 = .471$) and central ($\eta_p^2 = .464$) than at parietal electrodes

($\eta_p^2 = .328$). For children, there also was an effect of Item Type, $F(1, 17) = 8.87$, $p < .010$, that was embedded in a marginally significant Item Type × Laterality interaction, $F(2, 34) = 3.69$, $p = .061$. Follow-up analyses revealed that the old/new effect was stronger at midline electrodes ($\eta_p^2 = .410$) compared with left-sided ($\eta_p^2 = .339$) and right-sided electrodes ($\eta_p^2 = .110$).

In the nonspeeded condition, for adults, the three-way ANOVA revealed an effect of Item Type, $F(1, 19) = 8.44$, $p < .010$, and a three-way interaction between Item Type, Anterior/Posterior, and Laterality, $F(4, 76) = 3.79$, $p < .030$. The interaction reflects the fact that the early old/new effect, although significant at all nine electrodes, was largest at F4 ($\eta_p^2 = 0.313$) and Pz ($\eta_p^2 = 0.343$). For children, there was neither an effect of item type nor any interactions involving this factor (p values $> .150$).

To summarize, consistent with our prediction, the ERP effects in the early time window in the speeded condition were highly similar for children and adults, in that both groups showed an early frontally focused old/new effect, the ERP correlate of familiarity. In the nonspeeded condition, the ERP pattern in the early time interval differed as a function of group. For adults, a broadly distributed, albeit right-frontally focused early old/new effect, indexing familiarity, was obtained. Conversely, for children, no early ERP differences between old and new items were found. This latter result is consistent with other studies that did not find midfrontal old/new effects for children in standard item recognition memory tasks (Shamdeen et al., 2008; Hepworth et al., 2001).

Late Time Window (Children, 600–750 msec; Adults, 500–650 msec)

In the late time window, the initial five-way ANOVA revealed main effects of Item Type, $F(1, 36) = 12.03$, $p < .010$, and Response Condition, $F(1, 36) = 27.80$, $p < .001$, that were embedded in interactions among Response Condition and Group, $F(1, 36) = 17.11$, $p < .001$, Item Type, Anterior/Posterior, and Group, $F(2, 72) = 3.89$, $p < .030$, and Item Type, Anterior/Posterior, Response Condition, and Group, $F(2, 72) = 3.56$, $p < .040$. These interactions suggest that for the late time window, the item type (old/new) effects were modulated by response condition, group, and recording sites, and follow-up analyses were performed to further elucidate these interactions.

Consistent with our prediction that recollection does not contribute to recognition memory when the response deadline is shortened, in the speeded condition for adults there was neither an effect of Item Type nor any interaction involving the Item Type factor (p values $> .06$). For children, there was a marginal significant interaction of Item Type, Anterior/Posterior, and Laterality, $F(4, 68) = 2.92$, $p = .062$. Follow-up analyses revealed that the old versus new differences did not reach the significance at any electrode site (p values $> .17$).

In the nonspeeded condition, for adults, there was a main effect of Item Type, $F(1, 19) = 13.86$, $p < .010$. Effect size analyses performed for frontal, central, and parietal recording sites revealed that the old/new effect was stronger at parietal ($\eta_p^2 = .484$) than at central ($\eta_p^2 = .399$) and frontal ($\eta_p^2 = .296$) recording sites. For children, an Item Type × Anterior/Posterior interaction, $F(2, 34) = 8.89$, $p < .010$, was found. Further analyses revealed an old/new effect at parietal, $F(1, 17) = 12.89$, $p < .010$, $\eta_p^2 = .431$, but not at central ($p = .243$) or frontal sites ($p = .428$).

To summarize, as predicted, no ERP correlate of recollection was found for adults when recognition decisions were given with a response deadline. For children, a marginally significant triple interaction was found, but the differences between old and new responses did not reach significance at neither recording site in the late time interval. Also, consistent with our predictions, without response deadline both groups show a parietally accentuated old/new effect, the correlate of recollective processing.

Topographic profile analyses. For adults in the nonspeeded condition early and late old/new effects, the putative correlates of familiarity and recollection were obtained. A topographic profile analysis was performed to assess if different neurocognitive systems support the putative ERP correlates of familiarity and recollection. If the scalp distributions of both effects differ after the data have been rescaled to remove overall amplitude differences across conditions, it can be inferred that qualitatively different neural systems and by this different cognitive processes (Wilding, 2006; McCarthy & Wood, 1985) are engaged in the early and late time windows. We analyzed the rescaled new minus old difference waveforms in the early and late time window using the whole electrode montage of 27 electrodes. The ANOVA with factors Time Window (250–400 vs. 500–650 msec) and Electrode (27) revealed a marginally significant Electrodes × Time Window interaction, $F(26, 494) = 1.43$, $p < .079$. This result tentatively verifies the distinct topographies of both effects and supports the view that differential cognitive processes underlie the putative ERP correlates of familiarity and recollection.

DISCUSSION

There were two goals in this study. First, we set out to examine whether a midfrontal old/new effect, the putative ERP correlate of familiarity, can be recorded from children at early school age and from an adult control group under a speeded response condition that encouraged familiarity-based remembering and diminished recollective processing. Second, we explored whether the ERP correlates of familiarity and recollection show similar developmental changes.

Eight- to 10-year-old children and adults performed a picture recognition memory task in a speeded and a nonspeeded condition. Group-specific response deadlines were used to account for the generally slower processing speed of school age children (de Ribaupierre, 2002). Response times were faster and memory accuracy lower in the speeded condition for both groups. Consistent with other item recognition memory studies, memory performance was higher for adults than for children (Czernochowski et al., 2005; Cycowicz, Friedman, & Snodgrass, 2001; Cycowicz, Friedman, Snodgrass, Duff, et al., 2001). Notably, as apparent from Table 1, memory accuracy (Pr) in the speeded condition relative to the nonspeeded condition was lowered to 72% and 75% in the children and adult group, respectively, suggesting that the effects of the response deadline manipulation were highly comparable across groups on the behavioral level. Also, in light of the fact that there were no differential effects of response conditions on setting the decision criterion (response bias), we feel safe to conclude that no differential decision strategies were used in both response conditions. We rather assume that participants in both groups based their recognition judgments in the speeded condition on familiarity and attenuated recollection based remembering.

Support for this view comes from a recent study with a patient with a circumscribed lesion to the left anterior temporal lobe (Bowles et al., 2007). Consistent with the view that anterior temporal lobe structures are critically involved in familiarity processing, she showed a consistent pattern of impaired familiarity and preserved recollection across a variety of tasks. Most notably, as one would expect if a speeded response condition fosters familiarity-based remembering, she was strongly affected in making recognition judgments under a short response deadline but showed normal performance with a slower deadline.

ERP Data

The analysis of the ERP data revealed a variety of results relevant for the understanding of the processes contributing to recognition memory and their developmental trajectories. First, adults and children showed an early old/new effect in the speeded response condition. On the basis of its high resemblance with the midfrontal old/new effect reported in other studies (Rugg & Curran, 2007; Jäger, Mecklinger, & Kipp, 2006; Opitz & Cornell, 2006), we take this effect as the ERP correlate of familiarity. By showing that the midfrontal old/new effect is reliably found with a generally agreed on and empirically well-supported operational definition of familiarity, we provide further evidence for the functional significance of this effect and converging evidence for the dual-process view of recognition memory. Notably, the observation that the midfrontal old/new effect was present for 8- to 10-year-old children and highly similar in its temporal and topographic characteristics to the corresponding effect in adults suggests that familiarity is available for recognition judgments at early school age under specific circumstances. This is consistent with other studies using the R/K procedure (Billingsley et al., 2002) or ROC analyses (Ghetti & Angelini, 2008), which showed that there is only small age-related change in familiarity after the age of 8 years and that familiarity is immune to development after that age.

Why was a familiarity correlate for children found in the present study but not in former ERP studies? A variety of previous children studies did not explicitly address the question of whether ERP old/new effects were independently sensitive to familiarity and recollection (Marshall et al., 2002; Hepworth et al., 2001) or may have used operational definitions that did not capitalize on the different temporal dynamics of familiarity and recollection and by this were not sensitive enough to dissociate familiarity and recollection as for example the variant of the process dissociation procedure employed by Czernochowski et al. (2005) or the source memory task used by Cycowicz et al. (2003). In a similar vein, van Strien et al. (2009) used highly familiar words that were shown six times in a continuous recognition task so that because of a combination of high presentation rate and high lexical frequency of the words, familiarity may not have been diagnostic for the children's recognition judgments (Stenberg et al., 2009).

The view that recollection plays a negligible role when recognition judgments are given with a fast response deadline (Boldini, Russo, Punia, & Avons, 2007; Boldini et al., 2004) is supported by our findings for the late time interval. For adults, no parietal old/new effect was obtained, suggesting that the influence of recollection was minimized by the fast response deadline. For children, there also was no difference between old and new items in the late time interval. However, an old/new difference with a maximum at Cz emerged, when the same time interval (500–650 msec) as for the adults was used for the quantification of the children's late effect.[3] This suggests that this effect is subtle, restricted to a small time interval and not reliable when the time window was adapted to adequately capture the late effects in the children ERPs (i.e., 600–750 msec). Notably, the scalp topography of this late effect between 500 and 650 msec was different from the early effect in the speeded condition and the late parietal effect in the nonspeeded condition, indicating that it reflects neither delayed familiarity processing nor recollective processing. Notably, other studies have identified ERP differences between old and new items at posterior sites in this time range with implicit memory (Groh-Bordin, Zimmer, & Mecklinger, 2005; Nessler, Mecklinger, & Penney, 2005; Rugg et al., 1998). However, given the transient and subtle character of this effect and the observation that it was statistically not reliable when group-specific time windows were used for its quantifications, we refrain from drawing firm conclusions on the functional significance of this effect. Further empirical data are required to disentangle the processing mechanisms reflected in these late and subtle old/new differences in children.

Although the early ERP signatures were highly similar for both groups in the speeded condition, group differences emerged in the nonspeeded condition. The adult group showed a midfrontal old/new effect followed by a widely distributed but parietally focused late old/new effect, an

ERP pattern that is frequently found in standard item recognition memory task with young adults (for a review, see Johansson, Mecklinger, & Treese, 2004; Friedman & Johnson, 2000). As in addition the topographic profile analysis provides tentative support for qualitative differences in the scalp topography of both effects, we take this pattern of results to reflect that both processes, familiarity and recollection, play a role when making recognition judgments with or without low temporal constraints. For children, there was no midfrontal old/new effect, replicating former studies that did not find this effect when nonsensitive operational definitions of familiarity were applied. Rather, the children group showed a clear parietally focused late old/new effect. This effect replicates a variety of earlier ERP studies, which showed that the ERP correlate of recollection can reliably be recorded starting at early school age (Friedman, de Chastelaine, Nessler, & Malcom, 2010; van Strien et al., 2009; de Chastelaine, Friedman, & Cycowicz, 2007; Czernochowski et al., 2005; Cycowicz et al., 2003; Hepworth et al., 2001) and implies that recollection is fully developed by the age of 8 years.

Taken together, these results emphasize the functional distinction between familiarity and recollection and shed light on their developmental trajectories using a method that is not reliant on metamemory or the ability to follow instructions to introspect about memories. The results suggest that although adult's recognition memory was much improved as compared with the children group, irrespective of response condition, the differential contribution of familiarity in the speeded condition and recollection in the nonspeeded condition is highly similar across groups. This suggests that children at that age use a weaker and less matured version of the same explicit memory network used by adults.

A shortcoming of the present approach is that in contrast to mathematical estimates of familiarity and recollection, the size of ERP effects does not allow to directly quantify the magnitude with which each process contributes to recognition memory. In fact, ERP amplitudes tend to be much higher in children than that in adults, indicating that other factors than those related to memory development, as for example brain size, volume conductivity, or myelinization, influence the size of ERP components and effects (Picton & Taylor, 2007). Elucidating the developmental trajectories of familiarity and recollection by means of ERP correlates and a better understanding of the relation between the various measures of familiarity and recollection remain important endeavors for further research.

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Notes

1. To examine whether performance in the indoor/outdoor judgment task was comparable across groups, we performed an additional analysis, in which the range of correct judgments relative to an age-matched norm sample ($n = 10$) was calculated only for those objects with high across-rater agreement in the norm samples of both age groups (e.g., traffic light, cake). For these items with high interrater agreement, the percentage of correct judgments were 0.79% and 0.86% for children and adults, respectively, and by this, well above chance and not significantly different from each other. In this analysis, the ranges of the percentage of correct judgments were 0.49–0.97% for adults and 0.58–0.93% for children. This means that for those items that can unambiguously be classified as indoor or outdoor in the respective group, there is no across-group difference in the percent correct judgments. By this, we feel safe to conclude that both groups encoded the stimuli in a highly similar way.
2. It appears that there were also earlier old/new differences at around 100 msec present in both age groups in the speeded condition. However, these effects were not reliable in neither group when old/new differences were analyzed with mean amplitude measures between 100 and 250 msec.
3. An additional statistical analysis was performed using the same time windows for the quantification of the early (300 to 450 msec) and late (500 to 650 msec) effects in both groups. These time windows were comparable with other developmental ERP studies (Czernochowski et al., 2005; Cycowicz et al., 2003). All effects and the pairwise comparisons from the initial analysis were replicated. The only difference between both analyses was that the Item Type × Anterior/Posterior × Laterality interaction for the late time interval for the children group in the speeded condition reached significance ($p < .010$), as did the Item Type effect at Cz ($p < .050$) in the follow-up analysis. An additional topographic profile analysis on rescaled old/new differences revealed that this weak late effect (500–650 msec) in the speeded condition differed in topography from the early (300 to 450 msec) effect in the speeded condition ($p < .020$) and from the late effect in the nonspeeded condition ($p < .010$).

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