Cognitive Development 40 (2016) 82–100

Contents lists available at ScienceDirect

Cognitive Development

Task characteristics are critical for the use of familiarity: An ERP study on episodic memory development in middle childhood

André Haese*, Daniela Czernochowski

Faculty of Social Sciences, Department of Cognitive Science, Building 57, Room 566.1, University of Kaiserslautern,
Erwin-Schrödinger-Straße, 67663 Kaiserslautern, Germany

ARTICLE INFO

Article history:
Received 29 June 2015
Received in revised form 8 August 2016
Accepted 28 August 2016
Available online 5 September 2016

Keywords:
ERPs
Development
Middle childhood
Recognition memory
Memory retrieval

ABSTRACT

Children have often been assumed to rely on familiarity in episodic memory retrieval, based on low source memory performance. However, the frontal familiarity-related event-related potential (ERP) correlate is typically absent in children, in contrast to a prominent parietal old/new effect reflecting recollection. Here, we presented identical and perceptually changed pictures after incidental and intentional encoding to assess whether (a) identical perceptual item features or (b) a high memory performance promoted by intentional encoding would elicit an ERP correlate associated with familiarity in 7-year-olds ($N = 20$) and 10-year-olds ($N = 20$). Despite generally high memory performance we observed frontal old/new effects in older children only, selectively for perceptually identical items after intentional encoding. By contrast, parietal old/new effects were observed in both groups. Furthermore, late parietal old/new effects were much smaller for changed items, suggesting that older children employed additional recollective search processes to differentiate between identical and changed items.

1. Introduction

Imagine that you are searching for a misplaced key. What strategies might you employ to help you remember where you last saw it? You might choose to search in all the usual places such as the entrance to your home or inside your handbag. Imagine further that when you ask your child to help you in the search, they immediately remember that you left it on a shelf in the bathroom. Why did you fail in your search while your child succeeded? One possibility is that you and your daughter utilized different strategies to help in the memory search. For example, it is possible that you did not think about this possibility because you hardly ever take your keys into this room. In this case, you utilized previously held conceptual information in your memory search. Although this normally supports successful memory retrieval, your child's less conceptually guided search led to a quicker solution. This example illustrates that when children engage in memory retrieval, they likely use different strategies than adults – strategies that may sometimes even lead to a better outcome than the conceptual strategy of adults.

Although there has been a growing interest in episodic memory retrieval in children in recent years (e.g., Cycowicz, 2000), there are still inconsistencies in the literature. As detailed below, behavioral data suggest that children mainly rely

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* Corresponding author.
E-mail addresses: andre.haese@sowi.uni-kl.de (A. Haese), czernochowski@sowi.uni-kl.de (D. Czernochowski).

http://dx.doi.org/10.1016/j.cogdev.2016.08.008
0885-2014/

on familiarity (Cycowicz, 2000). By contrast, most event-related potential (ERP) studies found evidence for recollection but not for familiarity-based retrieval in children (Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005; Friedman, de Chastelaine, Nessler, & Malcolm, 2010). To reconcile these apparently contradicting findings, it is necessary to pay close attention to the methods used in the respective lines of research. For instance, the paradigms commonly used in adult ERP research might not be effective in eliciting familiarity-based retrieval in children, as the cognitive processes supporting familiarity might differ between children and adults. The aim of the present study was to address this open issue by using a new paradigm designed to promote familiarity-based retrieval in children.

In adults, the contribution to retrieval of two processes, familiarity and recollection, has been studied extensively (Yonelinas, 2002). When people base their memory judgment on their global feeling of having previously encountered an event, they have employed familiarity in their retrieval, when they engage in a controlled memory search that leads to the retrieval of contextual details, they have used recollection (Yonelinas, 2002). Recollection processes generally reflect more effortful and slower retrieval compared to familiarity-based processes, and further, result in higher response confidence. These two types of retrieval processes can be distinguished by multiple outcome measures like fast versus slow reaction times, the correct versus incorrect retrieval of contextual details, or introspective reports of “knowing” something is old versus “remembering” contextual details (Tulving, 1985; for a review, see Yonelinas, 2002).

Previous literature has indicated that recollection and familiarity processes follow different developmental trajectories and that there are age-related differences in children’s ability to recruit these two processes (Ghetti & Angelini, 2008). For example, several studies found that age-related differences are larger when source memory measures are used compared to when item memory is tested, suggesting a slower development of recollection compared to familiarity (Cycowicz, 2000; Cycowicz, Friedman, & Duff, 2003; Cycowicz, Friedman, Snodgrass, & Duff, 2001; Czernochowski et al., 2005; Gulya et al., 2002; for paradigms with preschool children, see also Riggins, Rollins, & Graham, 2013). Cycowicz, Friedman, Snodgrass, Duff (2001) investigated this by comparing the results of two different test phases. In the item recognition block, participants decided whether a black test picture was “old” or “new”. Thus, contextual information was not necessary for successful task execution. In the source recognition block, participants instead decided whether a picture was “old-red”, “old-green”, or “new”, so the old categories were further separated according to the contextual information. Accordingly, contextual information was essential for the task. Memory representations of children seemed to be less detailed as they exhibited more errors when it came to the retrieval of an item’s context than adults. This was taken as evidence that children rely on familiarity, not recollection, as it has been shown that successful retrieval via recollection allows the recognition of contextual information. Since then, more studies have been conducted, sketching a more complex pattern of behavioral results: While recollection appears to develop until adolescence, familiarity seems to have a different developmental trajectory. Based on confidence ratings, signal detection models of familiarity and recollection estimate a relatively stable use of familiarity between the ages of five and eleven years, whereas estimates of recollection double or even triple in the same age range (Ghetti & Angelini, 2008). Other studies report similar results with little or no developmental differences with respect to familiarity in children beyond five years of age (e.g., Billingsley, Smith, & McAndrews, 2002; Brainerd, Holliday, & Reyna, 2004; for an overview, see Rollins & Riggins, 2015). In a nutshell, behavioral evidence suggests that children rely on both familiarity and recollection. Based on errors in source memory paradigms, recollection appears to have a longer developmental trajectory than familiarity.

A very different pattern of results is shown in studies of familiarity and recollection using event-related potentials (ERPs). In adults, recollection and familiarity have been dissociated using the temporo-spatial characteristics of ERPs in numerous investigations (Curran, 2000; Friedman & Johnson, 2000; Rugg et al., 1998; for an overview, see Opitz & Cornell, 2006). In episodic memory paradigms, differences between ERPs of correctly recognized “old” and “new” items (old/new effects) are compared to describe memory-related effects in neurophysiological data. For adults, recollection has been associated with a parietal positivity for old versus new items between approximately 500 and 700 ms (e.g., Wilding, 2000). Similarly, a parietal ERP correlate of recollection was consistently observed in children (10-year-olds, Cycowicz et al., 2003; 12-year-olds, Czernochowski, Mecklinger, & Johansson, 2009; 8-year-olds and 11-year-olds, Czernochowski et al., 2005; 8-year-olds and 14-year-olds, Sprondel, Kipp, & Mecklinger, 2011). By contrast, familiarity has been associated with a frontal positivity for old versus new items in earlier time windows (e.g., Curran, 2000; for a review, see Rugg & Curran, 2007) in adults. Based on the behavioral findings cited above, a corresponding ERP correlate of familiarity should be expected in children as well. However, no such correlate was observed in children (e.g., Czernochowski et al., 2005). So if children rely on familiarity and if early frontal old/new effects reflect familiarity in adults, why have no studies reported a frontal positivity for children as well?

This has been a gap in the literature for several years, until Mecklinger, Brunnemann, and Kipp (2011) offered one potential explanation with a new paradigm. They asked participants to respond fast (response deadline: 750 ms for adults; 1050 ms for children aged 8–10), as familiarity-based retrieval is usually faster than recollection-based recognition (Yonelinas, 2002; but see also Besson et al., 2015; Montaldi & Mayes, 2010). As a result, the response deadline paradigm eliminated recollection as a viable route to memory retrieval, as reflected by the lack of parietal old/new effects in adults and children. Interestingly, when the ERP correlate of recollection was no longer present, a frontal old/new effect could be observed in children’s ERP averages, taken to reflect familiarity. This procedure has been successful in eliciting familiarity-based retrieval by eliminating the alternative route to retrieval. Note that this is one of the few developmental ERP studies in which participants were only required to distinguish between old and new items. Hence, all old items were presented with the same perceptual features during study and test. Maybe in previous ERP studies children relied on recollection because the paradigm promoted recollection-based retrieval processes due to the requirement to retrieve contextual details – rendering familiarity-related old/new effects less prominent. Still, during the same paradigms, ERP correlates of familiarity-based retrieval were observed in young adults, suggesting age differences in the factors promoting familiarity- versus recollection-based retrieval strategies. Alternatively, children might simply prefer recollection if feasible.

Previous studies focused on investigating episodic memory retrieval as a whole, but it seems that for the particular investigation of ERPs associated with familiarity the task has to be adapted. In this study, we addressed a few methodological factors, which might have interfered with the previous observation of this correlate in children (see also Czernochowski et al., 2005): (1) age differences in memory performance (2) response format, and (3) age-related differences in the employment of a perceptual or conceptual focus during study. In the following paragraphs, we explain each of these factors in more detail.

With respect to memory performance, children typically perform worse than adults in episodic memory tasks (e.g., Cycowicz, 2000; Czernochowski et al., 2005). Children sometimes produce a large number of false alarms (i.e., "old" responses to new items), so a potentially large portion of their "old" responses may be based on guessing whether an item was old or new. Accordingly, ERPs associated with hits (i.e., "old" response to an old item) may well reflect both successful memory retrieval and cases where children just guessed. If we assume that children in previous studies might have been more prone to guessing, this might have attenuated old/new effects reflecting both familiarity and recollection. In a previous study, Azimian-Faridani and Wilding (2006) argue that the ERP correlate of familiarity might be too small compared to the ERP correlate of recollection to index differences between critical conditions (see also Curran, 2004). So while guessing induced by a high task difficulty may mask the effect of both retrieval processes – familiarity and recollection –, it may well have a stronger masking effect on the less robust ERP correlate of familiarity. It should be highlighted that there are also paradigms in which children produced fewer false alarms than adults (Czernochowski et al., 2005; Paz-Alonso, Ghetti, Donohue, Goodman, & Bunge, 2008; Rollins & Riggins, 2013), which can be the result of a more cautious response tendency, or potentially age-related differences in prior semantic knowledge (for a review, see Brod, Werkle-Bergner, & Shing, 2013). In sum, guessing behavior is likely to differ between paradigms, and sometimes also between age groups. As it is difficult to estimate beforehand, it is best to minimize this potentially confounding factor by aiming to achieve a high memory performance across age groups. Thus, we propose that ERP correlates of familiarity and recollection need to be associated with similar and sufficiently high levels of memory accuracy in children and adults in order to validly compare retrieval processes between age groups. To ensure this, we used colorful pictures of familiar objects and animals as stimuli and kept instructions as well as response requirements as simple as possible.

With respect to response format, most ERP studies that investigated episodic memory in children specifically assessed source memory. Hence during study, items were presented with a contextual detail, e.g. a red or green outline color. At test a "neutral" format was used (for instance black outlines, e.g. Cycowicz et al., 2003) in either an inclusion or exclusion task. In an inclusion task, participants are asked to focus on whether or not items have been presented before – thus old items are judged to be "old" and successful task completion does not require access to contextual details (e.g., Cycowicz et al., 2003; item test; Czernochowski, Brinkmann, Mecklinger, & Johansson, 2004; Sprondel, Kipp, & Mecklinger, 2013, general test). In an exclusion task, retrieval of contextual details is necessary for a correct response – old items are only judged to be "old" when they belong to the target category (Cycowicz et al., 2003; source test; Czernochowski et al., 2005; Sprondel et al., 2013; specific test). Hence, non-target items are classified as either "old" or "new", according to task. Note that an exclusion task does not permit to differentiate between correctly rejected non-targets and those falsely identified as distractors (misses). Often inclusion and exclusion task requirements are changed several times between blocks of retrieval, adding additional demands with respect to response monitoring and the inhibition of an "old" response for a non-target item. Thus, we propose that introducing executive control demands during a memory retrieval task can underestimate children's source memory ability, as lower memory performance for non-targets might be due to underdeveloped executive control abilities rather than a memory deficit per se. In our paradigm we addressed this issue by offering three concurrent response options to our participants. Participants were asked whether an item was identical, changed, or new with respect to the study phase. This allowed us to compare ERP old/new effects separately for each item type. At the same time, this procedure does not introduce additional demands with respect to executive functions, which could distort our findings regarding memory judgments.

With respect to age differences in the spontaneous focus of attention, children and adults have been shown to focus on different aspects when viewing pictures of meaningful objects. While children process items on a perceptual level, adults tend to process items on a more conceptual level (Sloutsky & Fisher, 2004) unless perceptual details are task-relevant (Haese & Czernochowski, 2015). This might further contribute to age differences in the use of familiarity in previous investigations. In adults familiarity has been suggested to reflect a global study-test similarity, i.e. the overall "echo" of brain activitation in reponse to a previously studied stimulus (Hintzman, 2001). If children assess familiarity predominantly on a more perceptual level, consistent with their spontaneous focus of attention, they might require a perceptual overlap between study and test in order to assess an item's study-test similarity. This issue might be addressed by comparing items with a complete perceptual overlap and those with changed perceptual item features. We would like to highlight that the perceptual item features changed in the context of the present investigation were designed to avoid salience effects, and at the same time prevented participants from focusing on single item aspects in the second encoding phase. For effects on differential item changes, please refer to ERP studies conducted with adults (e.g., Ecker, Arend, Bergström, & Zimmer, 2009; Ecker & Zimmer, 2009; Ecker, Zimmer, & Groh-Bordin, 2007a,b; Ecker, Zimmer, Groh-Bordin, & Mecklinger, 2007; Tsivilis, Otten, & Rugg, 2001). One important caveat is that adults can flexibly adapt their focus of attention to relevant item features (Haese & Czernochowski, 2015). Thus, we propose that explicit instructions to attend certain features during encoding or systematic variations in the stimuli employed will often allow participants to anticipate which stimulus features are relevant for later retrieval. Hence, adults are likely to adapt their attentional focus after anticipating task demands, whereas children are less likely to employ such strategic modulations of selective attention to single item features. As a consequence, age differences in memory performance are expected to increase due to these strategic modulations. How can we make sure that the attentional focus does not gradually change towards processing of single item features (e.g. by verbalizing the color along with each object)? In our study, participants did not anticipate any retrieval demands before the first test phase, and could not predict which feature would be relevant for any given item during the second phase. Hence, we eliminated this potential confound that arises when adults, but not children, adapt their encoding strategies.

1.1. Summary and hypotheses

To summarize, we modified key aspects of the standard recognition paradigm to investigate familiarity-related old/new effects in children. Previous studies (Cycowicz et al., 2003; Czernochowski et al., 2005; Sprondel, Kipp, & Mecklinger, 2012; Sprondel et al., 2013) changed contextual details of items and asked participants in the test phase to remember the contexts from the previous study episode. Here, for half of the items, intrinsic item features (i.e., parts of the stimulus per se, Ecker et al., 2007a) were changed between study and test to evaluate the role of perceptual overlap for familiarity-based retrieval in children. We changed items on different dimensions (e.g., color, size, or specimen) to ensure that participants did not just focus on single object attributes. This way, participants could not predict which feature would be changed later. The concurrent encoding task encouraged participants to encode objects semantically during both phases of memory encoding. Furthermore, we used two study-test blocks. In the first run, participants were unaware of the subsequent memory retrieval phase (incidental encoding), whereas in the second run, they were asked to intentionally memorize the items while performing the same encoding task.

We designed a task that should be easy for children to ensure high memory performance across groups. Accordingly we expected few, if any, behavioral differences in memory performance. Furthermore, performance should be higher after intentional encoding than after incidental encoding, indicating memory representations that are easier to access as a result of the intent to remember. With respect to ERPs, the pattern of results should be more complex. The ERP correlate of recollection, a late parietal old/new effect, should be observable across all age groups, potentially with later peak latencies in younger children. Our hypotheses regarding the ERP correlate of familiarity in children were more exploratory in nature. In line with previous evidence, we did not expect an ERP correlate of familiarity for all old items. We evaluated whether frontal old/new effects can be observed in children when the test item is presented identically – similar to Mecklinger et al. (2011). In adults, familiarity and recollection have often been investigated in the time windows between 300 and 700 ms. There are only few ERP studies on episodic memory in children and some of those selected later time windows to evaluate ERP correlates of retrieval in children compared to adults. To account for this inconsistency between previous studies, we also evaluate later aspects of recollection, reflected in the time window beyond 700 ms.

2. Method

2.1. Participants

Twenty-five second-graders (three left-handed) and 24 fifth-graders (two left-handed), recruited in local communities and schools participated in our study. They received 20 EUR and a small present as compensation. Data from five second-graders and four fifth-graders could not be analyzed due to (a) an insufficient amount of artifact-free EEG trials (two second-graders), (b) low performance level (more than two standard deviations below each group mean; two second-graders and three fifth-graders), and (c) incomplete data (one second-grader, one fifth-grader). Thus, the final samples consisted of 20 second-graders (aged 7 – 8 years, mean 7;8 years, 8 girls) and 20 fifth-graders (aged 9 – 11 years; mean 10;6 years, 10 girls). According to parents' reports, none of the children suffered from neurological or psychiatric disorders. We compared these two groups of children to a group of undergraduate students who were assessed with the same paradigm (Haese & Czernochowski, 2015). These data on young adults are briefly resumed in Appendix A to reduce redundancy.

2.2. Material

We used pictures from the dataset of Rossion and Pourtois (2004), but only included items familiar to children in the second and fifth grade. For the test phase, we either changed perceptual features of each stimulus or paired two items that showed different exemplars of the same object. After modification, items could have changed in size, orientation, or color, or depict a different specimen of the object. Since perceptual changes were a key manipulation of this paradigm, we also made sure no similar objects were included, like images for "bee" and "fly". In our paradigm, items were changed on more than one feature dimension to prevent participants from predicting which particular feature dimension would be relevant in the subsequent test phase. Thus participants were required to encode items as a whole, and could not simply focus on a single item feature during encoding, e.g. "blue button". In addition, we selected cliparts from CorelDRAW Graphics Suite X4

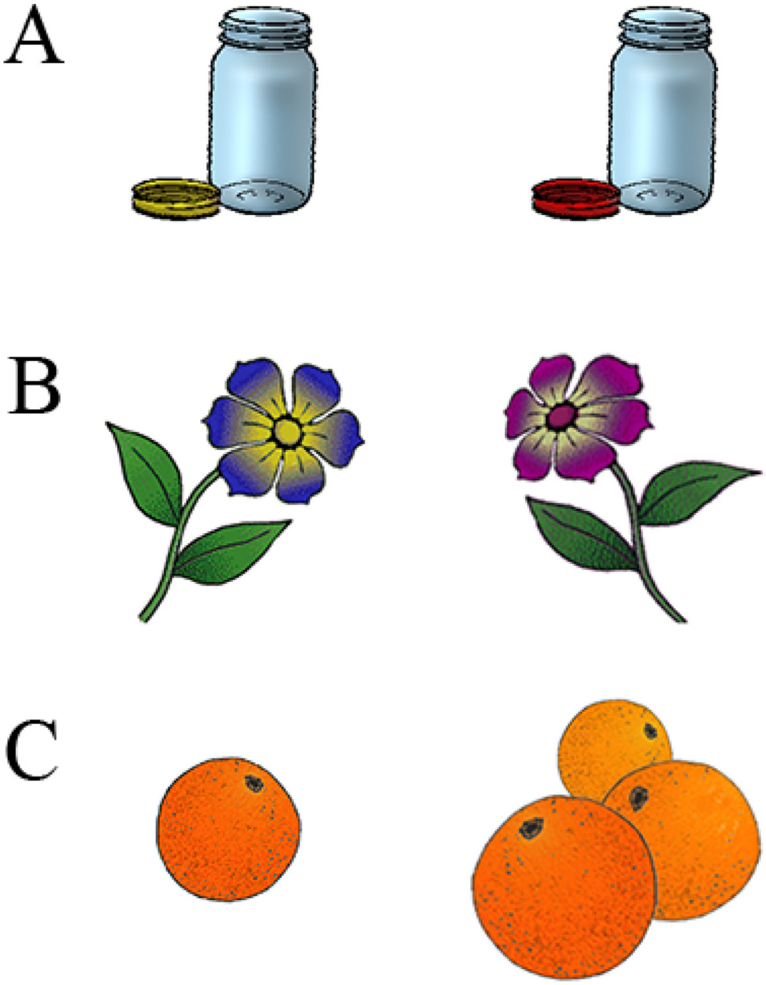

Fig. 1. Sample stimuli. Illustration of perceptual changes in the study (A: color; B: orientation and color; C: quantity and orientation).

which met the same criteria and were overall similar to the Rossion and Pourtois dataset (please refer to Fig. 1 for examples of stimulus modifications).

2.3. Procedure

The experiment was part of a multi-experiment session lasting approximately 2.5–3 h. On the day of EEG testing, participants completed two experiments in counterbalanced order (a task-switching paradigm, (Czernochowski, 2014); and the memory paradigm reported here; 1.5–2 h including breaks). The memory paradigm consisted of two blocks, incidental encoding and an unexpected recognition test, and intentional encoding and another recognition test. Throughout the study phase participants were asked to decide whether each item was more commonly found indoors or outdoors. In both test phases, we presented 120 items. Of these, 40 were novel distractors, 40 were identical repetitions of studied items, and 40 items were perceptually changed. Participants decided whether each item was “same”, “different”, or “new” (using index and middle finger of one hand for both “old” categories and the other index finger for responding “new”; the association of old and new categories to right and left hand were counterbalanced across participants). Immediately prior to each task, participants practiced both tasks with eight study items and 12 test items. During the intentional study phase, participants were instructed to memorize the images while still performing the indoors-outdoors categorization task. The intentional test phase was identical to the previous test phase, with one exception: We took 40 items that had been presented as identical items in the incidental phase and used these again. Of these, half were presented identically and half were replaced by changed exemplars. Thus, the test phase again consisted of 40 identical items (20 from the incidental phase), 40 changed items (20 from the intentional phase), and 40 new items. All responses were self-paced—if participants needed more than 5 s for a response, participants were encouraged to answer more spontaneously. During the breaks (two min between each study and test phase, five minutes between incidental and intentional study blocks) rehearsal was minimized by engaging

Table 1
Mean trial numbers for analyzed item types.

Response category	Younger children		Older children	
	Incidental encoding mean (range)	Intentional encoding mean (range)	Incidental encoding mean (range)	Intentional encoding mean (range)
Correct rejection	23.6 (7–35)	24.6 (12–32)	30.4 (14–36)	29.3 (14–37)
Feature hits identical	17.8 (7–26)	23.6 (14–36)	25.0 (15–39)	29.0 (18–38)
Feature hits changed	14.8 (7–28)	21.9 (12–30)	22.5 (11–31)	25.9 (8–34)

participants in conversation. All pictures were individually presented at the center of fixation (1000 ms), and were preceded by a fixation cross (1000 ms).

2.4. Behavioral analyses

To assess memory performance for the general old/new discrimination, we calculated Pr scores (Hit rate − False Alarm rate; cf. Snodgrass & Corwin, 1988). For this general index of memory performance, a participant response was categorized as hit when identical items were categorized as either identical or changed (and vice versa for changed items). Likewise, a participant response was categorized as false alarm when new items were categorized as identical or changed. To assess feature memory, we compared the proportion of correct feature identifications across groups (response "identical" to identical items relative to the number of old items categorized as "identical" or "changed" and vice versa). In addition, we analyzed reaction times. For all behavioral analyses, we computed mixed-model ANOVAs with the factors Age (younger children/older children/young adults), Item type (identical/changed/new), and Phase (incidental/intentional). All behavioral and ERP analyses were computed with SPSS 22 ($\alpha = 0.05$).

2.5. EEG recording and data preprocessing

We recorded EEG with active Ag/AgCl electrodes at 27 positions according to the extended 10–20 system: FP1, FP2, AF7, AF3, AFz, AF4, AF8, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, CP1, CP2, P7, P3, Pz, P4, P8, O1, O2 (reference FCz was restored after offline re-referencing to linked mastoids). Electrodes above and below the right eye and F9 and F10 measured EOG, we kept impedances below 25 kΩ (500 Hz sampling rate; A-D converted with 16 bit resolution; offline Butterworth band-pass filter of 0.1 Hz − 30 Hz, 24 dB/oct). We corrected ocular movements by applying an ICA-based correction (as implemented in the Vision Analyzer 2.0.3; BrainProducts GmbH, Gilching, Germany) and used a semi-automatic procedure to detect artifacts like muscular activity. The automatic algorithm detected trials meeting at least one of the following criteria: (1) gradient of the EEG amplitude exceeded 20 μV/ms at any electrode site, (2) within 200 ms, the voltage increased or decreased more than 75 μV, or (3) for 100 ms, activity fell below 0.5 μV. The spherical spline interpolation of Perrin, Pernier, Bertrand, and Echallier (1989) was applied to interpolate electrodes (up to 3 per participant) that could not be corrected otherwise. To investigate effects of successful memory retrieval, we analyzed correct responses in each test phase. Epochs lasted from −100 ms prior to stimulus onset until 3000 ms (the first 100 ms served as baseline). We compared feature hits for both same items ("same" responses to identical items) and different items ("different" responses to changed items) to correct rejections (planned contrasts). We excluded exceedingly slow responses (> 4000 ms in children) from ERP analyses (approximately 5% of all trials). Mean trial numbers and ranges for each condition are given in Table 1.

2.6. ERP analyses

Here, we compared ERP differences during memory retrieval after both incidental and intentional encoding. Visual inspection of the waveforms suggested only small laterality effects in children, but ERP effects were clearly more posterior in children than in adults (see Appendix A). Hence, we averaged across midline and lateral electrode sites to increase statistical power and computed mixed-model ANOVAs with the factors Anterior-Posterior (Frontal vs. Central vs. Parietal vs. Occipital) and Item Type (Feature Hits Identical vs. Feature Hits Changed vs. Correct rejections) on four regions of interest — F' (F3, Fz, F4), C' (C3, Cz, C4), P' (P3, Pz, P4), O' (O1, O2). In Appendix A, the same analyses were calculated for adults to allow for a direct comparison. Reliable effects of Item Type were followed up with planned contrasts (identical vs. Correct Rejection and changed vs. Correct Rejection). We evaluated the time windows 300–500 ms and 500–700 ms, corresponding to familiarity and recollection old/new effects, respectively. In order to examine later aspects of retrieval, we also evaluated old/new effects in the time window 700–1000 ms. Throughout the paper, old/new effects specify differences between old items and new items (for both identical and changed items). For a more extensive comparison the anterior-posterior distribution of effects (familiarity and recollection are associated with more frontal and parietal effects, respectively), we performed subsidiary analyses at frontal, central, parietal, and occipital electrode sites. For the sake of brevity, we only report effects related to the factor Item Type.

To prevent response bias for any of the three response categories, one third of all items presented during the test phases were new. As performance in the intentional test was expected to increase relative to the incidental test, these distractors

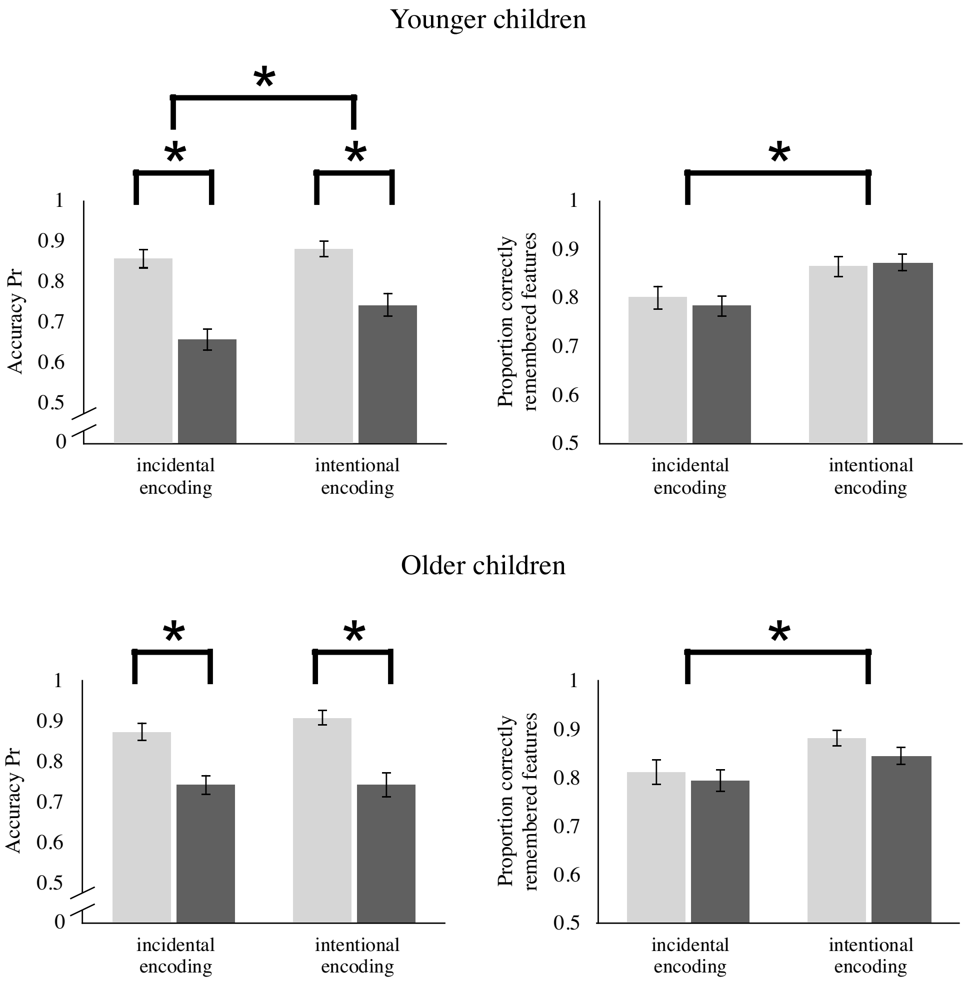

Fig. 2. Memory performance for general old/new (left) and specific identical/changed (right) discrimination. Behavioral recognition probability after incidental and intentional encoding for identical (light gray) and changed (dark gray) exemplars. Item recognition was higher for identical items, feature recognition was higher after intentional encoding, but behavioral findings were largely comparable for both age groups. Pr values of 0 and feature recognition scores of 0.5 reflect guessing. Error bars represent standard errors of the mean, asterisks indicate significant post-hoc comparisons.

may be particularly salient in the second test phase. In line with previous research on oddball effects (Cycowicz & Friedman, 2007; Czernochowski et al., 2009; Wetzel, Widmann, Berti, & Schroger, 2006), we observed more positive amplitudes for ERP averages of new items after intentional, compared to incidental, encoding in the time window between 300 and 700 ms in older children and adults, $F(1,19) = 7.63$, $p < 0.05$, $\eta_p^2 = 0.29$ and $F(1,17) = 15.04$, $p < 0.01$, $\eta_p^2 = 0.47$, respectively. As this saliency-related positivity for new items and the recollection-related positivity for old items share spatio-temporal characteristics, this overlap is likely to considerably attenuate recollection-related old/new effects investigated here. To avoid a potential confound of salience in the ERP waveforms, we used correct rejections from the incidental phase for all ERP analyses (for a similar approach, see Czernochowski et al., 2009; Haese & Czernochowski, 2015). Greenhouse-Geisser correction (Jennings & Wood, 1976) was applied where necessary. Uncorrected degrees of freedom are reported along with ε-values and with corrected p-values for these instances.

3. Results

3.1. Memory performance

We found better old/new discrimination after intentional encoding, $F(1,55) = 13.48$, $p < 0.001$, $\eta_p^2 = 0.20$, and for identical items, $F(1,55) = 189.30$, $p < 0.001$, $\eta_p^2 = 0.78$. For the more specific feature discrimination, we found that performance was better both after intentional encoding, $F(1,55) = 81.29$, $p < 0.001$, $\eta_p^2 = 0.60$, and for identical items, $F(1,55) = 8.20$, $p = 0.006$, $\eta_p^2 = 0.13$ (see Fig. 2). General old/new discrimination only tended to differ across age groups ($p = 0.090$), and there was no age difference in feature discrimination ($p = 0.989$). However, an interaction Age X Item Type indicated differences in

Table 2
Mean reaction times and intra-individual coefficients of variations for analyzed item types.

Response category	Younger children		Older children		Young adults	
	Incidental mean (ICV) [SD]	Intentional mean (ICV) [SD]	Incidental mean (ICV) [SD]	Intentional mean (ICV) [SD]	Incidental mean (ICV) [SD]	Intentional mean (ICV) [SD]
Correct Rejection (item type new, response "new")	1657 ms (0.41) [675]	1611 ms (0.41) [649]	1441 ms (0.38) [545]	1431 ms (0.39) [558]	1190 ms (0.32) [384]	1265 ms (0.30) [383]
Feature Hits identical (item type identical, response "same")	1776 ms (0.39) [678]	1672 ms (0.39) [656]	1531 ms (0.31) [481]	1469 ms (0.37) [552]	1138 ms (0.29) [338]	1130 ms (0.30) [338]
Feature Hits changed (item type changed, response "different")	1983 ms (0.34) [665]	1849 ms (0.33) [614]	1743 ms (0.31) [551]	1596 ms (0.32) [517]	1403 ms (0.26) [369]	1345 ms (0.29) [395]

feature memory performance, $F(2,55) = 3.34$, $p = 0.043$, $\eta_p^2 = 0.11$. Both groups of children showed similar feature recognition performance for identical and changed items (both $ps > 0.31$), whereas adults correctly identified more identical than changed items, $F(1,17) = 18.39$, $p < 0.001$, $\eta_p^2 = 0.52$.

3.2. Reaction times

Across all age groups (see Table 2), reaction times were faster in the second (intentional) test phase, $F(1,55) = 12.20$, $p < 0.001$, $\eta_p^2 = 0.18$, and for both identical and new (relative to changed) items, $F(2110) = 48.77$, $p < 0.001$, $\eta_p^2 = 0.47$, qualified by an interaction of these two factors, $F(2,110) = 6.04$, $p = 0.003$, $\eta_p^2 = 0.10$. With respect to age, we found that young adults were faster than both younger and older children and at the same time, older children were faster than younger children, $F(1,55) = 55.32$, $p < 0.001$, $\eta_p^2 = 0.67$, qualified by interactions with Phase, $F(2,55) = 3.39$, $p = 0.041$, $\eta_p^2 = 0.11$, and Item type, $F(4,110) = 2.80$, $p = 0.029$, $\eta_p^2 = 0.09$. Follow-up analyses revealed that only the two groups of children (younger children: $p < 0.05$; older children: $p < 0.01$), but not adults ($p = 0.91$) responded generally faster after the second intentional encoding. While changed items generally led to longer reaction times than identical and new items, this difference was larger for both groups of children (younger children: $\eta_p^2 = 0.60$; older children: $\eta_p^2 = 0.61$) than for adults ($\eta_p^2 = 0.53$).

The employment of two rather than one retrieval processes should be associated with more heterogeneity in reaction times. Thus, we also calculated the intra-individual coefficient of variation (ICV, defined as standard deviation divided by mean; for a similar approach, see Stuss, Murphy, Binns, & Alexander, 2003) and computed the mixed-model ANOVA used on reaction time data with these ICV values. Both groups of children exhibited more variable reaction times than young adults, $F(1,55) = 17.19$, $p < 0.001$, $\eta_p^2 = 0.39$; also, identical and new items were associated with a larger variability than changed items, $F(2110) = 20.00$, $p < 0.001$, $\eta_p^2 = 0.27$. As illustrated in Table 2, ICVs in younger children and adults are descriptively comparable, and variability only tended to differ between incidental and intentional encoding ($p = 0.088$). By contrast, ICVs of older children selectively increased after intentional encoding for identical – but not changed or new – items, $t(19) = 2.95$, $p < 0.01$. In sum, all age groups responded faster to new and identical items relative to changed items. While children were generally faster after intentional encoding, adults were only faster for new items. Furthermore, reaction times of children were more variable than reaction times of adults; generally, changed items caused more variability in reaction times than identical or new items. We found no reliable difference of response variability between test phases after incidental or intentional encoding (Fig. 3).

3.3. ERP old/new effects

In the following analyses, ERP averages for identical and changed items reflect feature hits (i.e., identical items correctly remembered as identical and changed items correctly remembered as changed). Correct rejections were items correctly rejected after incidental encoding. Throughout the analyses, feature hits will be referred to as old items, correct rejections as new ones. An insufficient number of artifact-free trials prevented a direct comparison between items presented once or three times after intentional encoding. As there was no main effect indicating a difference between both conditions, we collapsed across these item types to increase the amount of trials. Consistent with prior findings, overall ERP amplitudes differed between age groups (for a review, see Picton & Taylor, 2007), but throughout all age groups, old/new effects emerged at about 250 ms. In adults, a widespread positivity for old items was observed (see Appendix A). To reduce redundancy, please refer to Tables 3 and 4 for an overview of statistical effects. Some participants provided less than 10 trials for one (younger children, N = 3; older children, N = 1) or three conditions (younger children, N = 1). We ran an additional analysis to check for differences in the pattern of results but the results were virtually unchanged. At the end of each ERP result section we will briefly summarize the specific differences in the result pattern of the full sample compared to the sample with at least 10 trials per condition.

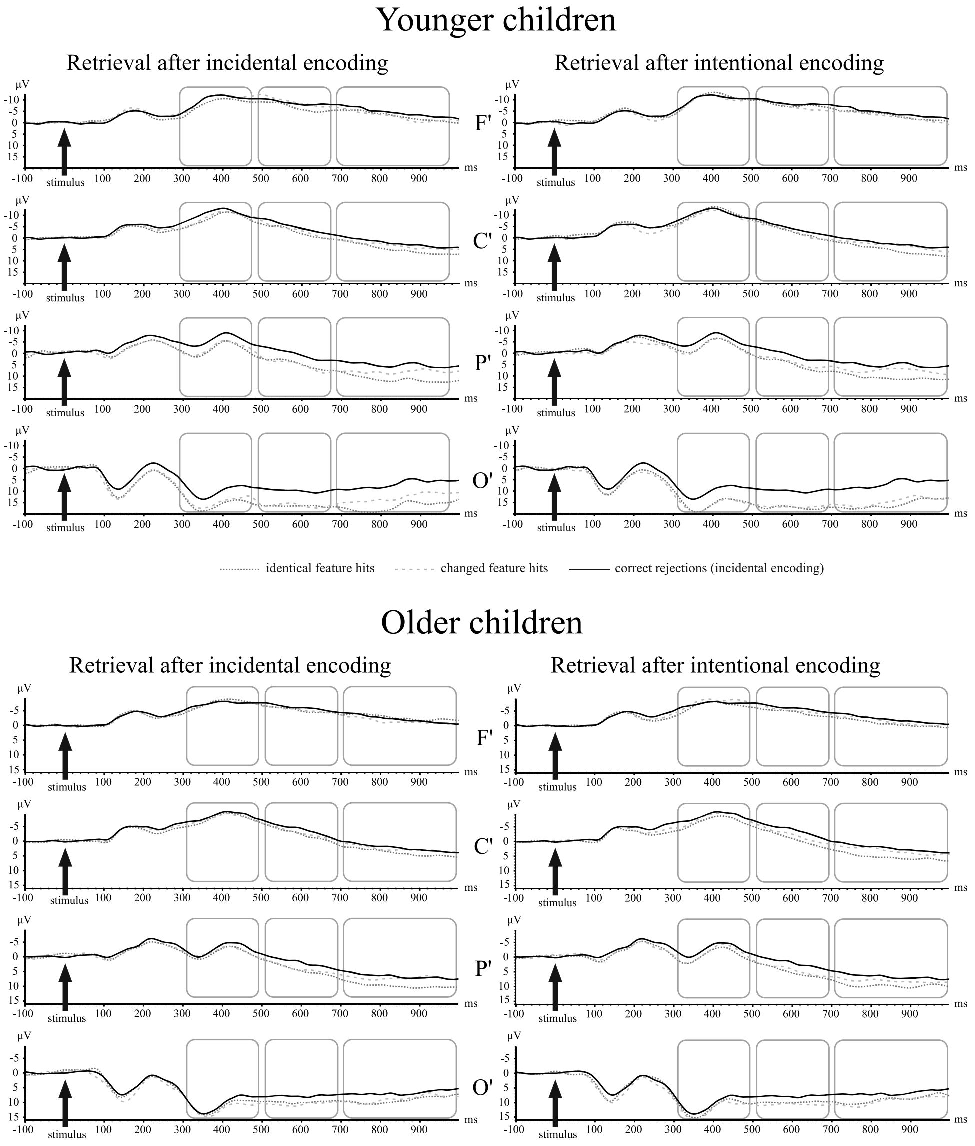

Fig. 3. ERP old/new effects following incidental and intentional encoding. ERP waveforms after incidental (left) and intentional (right) encoding reflecting identical (dotted) and changed (dashed) feature hits in comparison to correct rejections (after incidental encoding; black line). Note the difference in scaling for both groups of children and, in particular, the much larger old/new differences at parietal and occipital electrode sites.

3.3.1. *First time window (300–500 ms; see Table 3)*

In younger children, both identical and changed items were associated with more positive amplitudes than new items after both incidental and intentional encoding, largest at parietal and occipital electrode sites. In older children, only identical items (i.e., not changed items) were associated with more positive amplitudes than new items, and only after intentional encoding (largest at central, but also extending to frontal electrode sites). We conducted a follow-up analysis to confirm this finding in an ANOVA with the factors Phase (incidental/intentional) and Item type (identical/changed) for this group. At frontal electrode sites, we observed a reliable interaction of both factors, $F(1,19) = 4.92$, $p < 0.05$, $\eta_p^2 = 0.21$. For comparison, in young adults both identical and changed items were associated with more positive amplitudes than new items across electrode sites, after incidental and intentional encoding (largest at frontal and central electrode sites). When we limited the analyses to participants with at least 10 trials per condition, an additional effect for changed items emerged in the overall ANOVA for older children after intentional encoding. However, this overall effect was no longer reliable in any of the subsidiary analyses, hence we do not believe it adds substantially to our data.

3.3.2. *Second time window (500–700 ms; see Table 3)*

In younger children, both identical and changed items were associated with more positive amplitudes than new items after both incidental and intentional encoding (largest at parietal and occipital electrode sites). In older children, both

Table 3
Overview of ERP results for the familiarity- (300–500 ms) and recollection-related (500–700) old/new effects.

effect (df_1,df_2)	300–500 ms						500–700 ms					
	incidental			intentional			incidental			intentional		
	ε	*F*	η^2_p	ε	*F*	η^2_p	ε	*F*	η^2_p	ε	*F*	η^2_p
Younger children												
Item type (2,38)		6.85**	0.27		9.31***	0.33		10.73***	0.36		13.03***	0.41
identical vs. CR (1,19)		9.11**	0.32		6.33*	0.25		14.74**	0.44		15.41***	0.44
changed vs. CR (1,19)		8.78**	0.32		22.51***	0.54		15.81***	0.45		17.22***	0.48
Item type X AP (6,114)	–			0.38	6.67**	0.26	0.40	3.29*	0.15	0.35	5.60**	0.23
F’ (2,38)	–			–			–			–		
identical vs. CR (1,19)	–			–			–			–		
changed vs. CR (1,19)	–			–			–			–		
C’ (2,38)	–			–			–			–		
identical vs. CR (1,19)	–			–			–			–		
changed vs. CR (1,19)	–			–			–			–		
P’ (2,38)		6.56**	0.26		5.22**	0.22		9.38***	0.33		6.44**	0.25
identical vs. CR (1,19)		9.32**	0.33		4.60*	0.20		12.78**	0.40		9.24**	0.33
changed vs. CR (1,19)		10.38**	0.35		9.49**	0.33		15.38***	0.45		5.97*	0.24
O’ (2,38)		6.71**	0.26		6.71**	0.26		9.05***	0.32		9.05***	0.32
identical vs. CR (1,19)		8.98**	0.32		8.98**	0.32		12.53**	0.40		12.53**	0.40
changed vs. CR (1,19)		8.47**	0.31		8.47**	0.31		10.04**	0.35		10.04**	0.35
Older children												
Item type (2,38)	–				3.87*	0.17		7.08**	0.27		12.51***	0.40
identical vs. CR (1,19)	–				7.39*	0.28		15.72***	0.45		24.87***	0.57
changed vs. CR (1,19)	–			–				7.87*	0.29		12.57**	0.40
Item type X AP (6,114)	–			–			–			–		
F’ (2,38)	–				3.70*	0.16	–				4.00*	0.17
identical vs. CR (1,19)	–			–			–				6.58*	0.26
changed vs. CR (1,19)	–			–			–			–		
C’ (2,38)	–				4.49*	0.19	–				9.80***	0.34
identical vs. CR (1,19)	–				12.62**	0.40	–				18.03***	0.49
changed vs. CR (1,19)	–			–			–				6.09*	0.24
P’ (2,38)	–			–				5.90**	0.24		8.25**	0.30
identical vs. CR (1,19)	–			–				11.50**	0.38		15.72***	0.45
changed vs. CR (1,19)	–			–				6.12*	0.24		9.59**	0.34
O’ (2,38)	–			–				6.58**	0.26		6.58**	0.26
identical vs. CR (1,19)	–			–				8.36**	0.31		8.34**	0.31
changed vs. CR (1,19)	–			–				9.12**	0.32		9.12**	0.32
Group effects												
AP X Group (3,114)	–			–			–			–		
Item Type X Group (2,76)		3.53*	0.09	–				4.84*	0.11		5.86**	0.13
AP X Item Type X Group (6,228)	–				3.70*	0.09	–				3.61*	0.09

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, CR = Correct Rejection.

identical and changed items were associated with more positive amplitudes than new items, after both incidental and after intentional encoding (largest at parietal and occipital electrode sites). After intentional encoding, old/new effects were found across all electrode sites (with the exception of frontal electrode sites for changed items). Note that in young adults, both identical and changed items were associated with more positive amplitudes than new items across electrode sites after incidental and intentional encoding. When we limited the analyses to participants with at least 10 trials per condition, changed items no longer elicited a reliable parietal old/new effect after intentional encoding; most likely, this was due to the smaller magnitude of this old/new effect in the reduced sample.

3.3.3. *Third time window (700–1000 ms; see Table 4)*

In younger children, both identical and changed items were associated with more positive amplitudes than new items, after both incidental and intentional encoding (largest at parietal and occipital electrode sites). Note that at the four levels of the factor Anterior-Posterior electrode location, changed items elicited old/new effects only at parieto-occipital (incidental encoding) and at occipital electrode sites (intentional encoding). In older children, both identical and changed items were associated with more positive amplitudes than new items after intentional encoding; after incidental encoding, only identical (but not changed) items elicited reliably more positive amplitudes than new items. Similar to younger children, the old/new effects had different distributions across the electrodes. While identical items elicited old/new effects across several electrode sites (incidental encoding: central, parietal, & occipital; intentional encoding: central & parietal), changed items only elicited old/new effects at parietal electrodes and only after intentional encoding. For comparison, in young adults identical and changed items were associated with more positive amplitudes than new items after both incidental and intentional encoding.

Table 4
Overview of ERP results for the later time window (700–1000 ms).

effect (df_1,df_2)	Younger children						Older children					
	incidental			intentional			incidental			intentional		
	ε	F	η^2_p	ε	F	η^2_p	ε	F	η^2_p	ε	F	η^2_p
Item type (2,38)		14.81***	0.44		13.69***	0.42		5.27**	0.22		9.48***	0.33
identical vs. CR (1,19)		19.96***	0.51		22.14***	0.54		12.62**	0.40		17.26***	0.48
changed vs. CR (1,19)		11.89**	0.39		10.73**	0.36		–			9.29**	0.33
Item type X AP (6114)	0.47	4.73**	0.20	0.36	7.32**	0.28	0.40	4.00*	0.17		–	
F' (2,38)		–			–			–			–	
identical vs. CR (1,19)		–			–			–			–	
changed vs. CR (1,19)		–			–			–			–	
C' (2,38)		–			6.06**	0.24		3.63*	0.16		12.89***	0.40
identical vs. CR (1,19)		–			11.50**	0.38		5.69*	0.23		33.46***	0.64
changed vs. CR (1,19)		–			–			–			–	
P' (2,38)		13.34***	0.41		8.94***	0.32		7.25**	0.28		5.93**	0.24
identical vs. CR (1,19)		26.45***	0.58		16.33***	0.46		13.51**	0.42		10.63**	0.36
changed vs. CR (1,19)		5.40*	0.22		–			–			5.06*	0.21
O' (2,38)		14.07***	0.43		14.07***	0.43	0.76	3.87*	0.17	0.76	3.87*	0.17
identical vs. CR (1,19)		22.22***	0.54		22.22***	0.54		14.91**	0.44		14.91**	0.44
changed vs. CR (1,19)		7.90*	0.29		7.90*	0.29		–			–	
Group effects												
AP X Group (3114)		–			4.21*	0.10						
Item Type X Group (2,76)		5.05*	0.12		–							
AP X Item Type X Group (6228)		–			3.72*	0.09						

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, CR = Correct Rejection.

These effects were only observed at central (incidental encoding) and centro-parietal (intentional encoding) electrode sites. Limiting the analyses to participants with at least 10 trials per condition led to the same pattern of results.

4. Discussion

Although familiarity and recollection have been investigated thoroughly in young adults, it still remains open how children engage in memory retrieval. While behavioral studies suggested a contribution of both familiarity and recollection, nearly all ERP studies so far only reported observing an ERP correlate associated with recollection. We argued that this might have been due to certain task characteristics in the few ERP studies conducted with children. Here, we developed a paradigm with adapted characteristics to test this notion.

4.1. Summary

This study focused on the role of familiarity for children in episodic retrieval paradigms. Most previous ERP studies reported only parietal old/new ERP effects suggesting children relied on recollection, whereas behavioral results instead indicated that children might rely mainly on familiarity. We assume that the paradigm used might play a key role in the observation of frontal, familiarity-related, old/new effects, so we developed a task that was relatively easy for children in order to achieve a memory performance that was comparable to adults. Hence, EEG averages of correctly recognized old items reflected a comparable level of successful memory retrieval across all age groups. In addition, all participants responded to whether an item was perceptually identical, perceptually changed, or new at the same time. This ensured that the corresponding ERP response did not vary based on the onset of the ERP correlates and was, therefore, comparable across conditions. This approach is preferable to complex inclusion and exclusion paradigms, which might have contributed to age differences in memory performance and in ERP correlates of recognition memory. Further, we used separate incidental and intentional encoding tasks to determine the nature of familiarity-related ERP responses after both types of encoding. Prior research has shown that the ERP correlate of familiarity is observed in adults after incidental and intentional encoding (Curran, 2000; Groh-Bordin, Zimmer, & Ecker, 2006; Groh-Bordin, Zimmer, & Mecklinger, 2005; Haese & Czernochowski, 2015). By contrast, so far only one study observed a putative ERP correlate of familiarity in children (Mecklinger et al., 2011). In the following paragraphs, we discuss the behavioral and ERP findings in turn and then highlight differences in the topographical distribution of old/new effects and the role of brain maturation in memory retrieval.

4.2. Behavioral findings

Across age groups, the paradigm elicited a high memory performance. Hence, only small age differences in item memory performance were observed, thus eliminating the potential problem of guessing tendencies and low memory performance for interpreting age differences in ERPs. Both younger and older children exhibited better item memory performance for identical

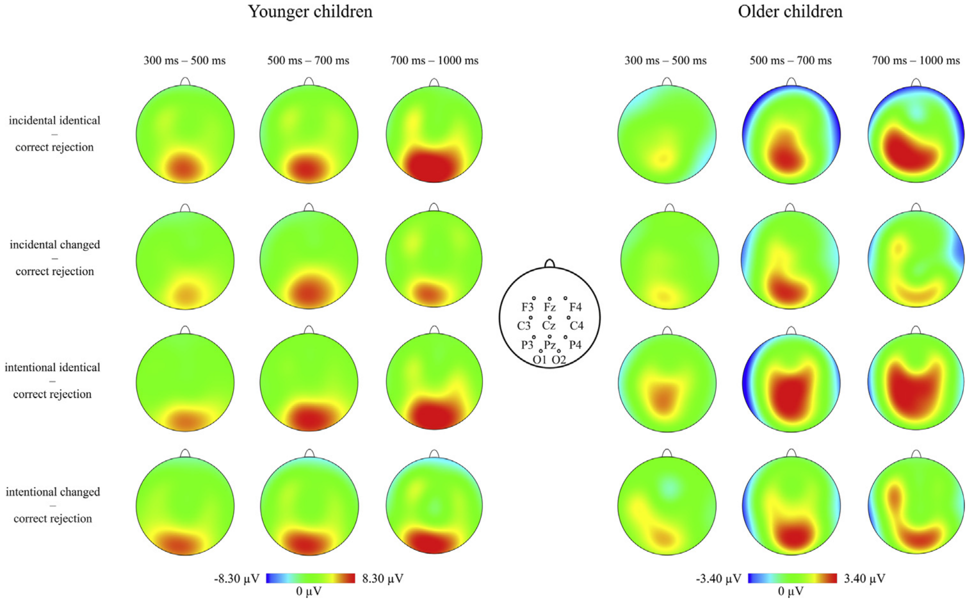

Fig. 4. Left: Topographies of old/new effects in younger children. These topographies show the spatial distribution of old/new effects – i.e. correct old responses minus correct rejections (after incidental encoding) – in younger children in the analyzed time windows. Effects are predominantly observed at parieto-occipital electrode sites. Right: Topographies of old/new effects in older children. Effects are largest at centro-parietal electrode sites and, after intentional encoding, further extend to frontal electrode sites for identical items.

than for changed items, but older children did not benefit further from the instruction to intentionally encode the pictures. The pattern of results was slightly different for feature recognition performance. Here, both groups of children exhibited higher performance after intentional encoding compared to incidental encoding, irrespective of perceptual changes. It should be mentioned that our paradigm does not allow for more detailed insights as to how participants achieved feature hits. It is entirely possible that they had access to a detailed memory trace, which allowed them to directly evaluate the perceptual study-test similarity of each item. Alternatively, it is also possible that they relied on a “recall-to-reject” strategy (recalling the exact study episode in order to distinguish identical from changed exemplars) at least for some items. The processes contributing to this response category cannot be further separated on an individual basis in our design, and need to be further evaluated in future investigations. Reaction time analyses revealed a general age-related reduction in reaction times (replicating previous studies; e.g., Sprondel et al., 2011), and across all age groups slower response times for changed compared to identical items. After intentional encoding, both groups of children responded faster, indicating more efficient processing. We discuss these behavioral effects in the context of the ERP findings below.

4.3. ERP findings

With respect to the ERP correlates of recognition memory in the time windows 300–500 ms and 500–700 ms, we found that younger children exhibited parieto-occipital old/new effects during both time windows. Interestingly, similar topographies (Fig. 4, left) suggest that they relied on the same cognitive processes during both retrieval phases, although the higher behavioral performance after intentional encoding demonstrates that they followed the instruction and encoded items more efficiently. While the topography of these effects (a parietal positivity for old items) closely resembles the ERP correlate of recollection, the strikingly early onset is inconsistent with this interpretation. Considering the similar reaction times in both groups of children, it is unlikely that the ERP correlate of recollection has a much earlier onset in younger children compared to older children or adults. Instead, it seems more plausible to assume that younger children relied on additional resources to retrieve details from memory. Their behavioral memory performance was relatively high despite the lack of or less efficient employment of familiarity. In previous memory studies, early parietal old/new differences have been observed, presumably reflecting processes supporting recollection. For instance, Sprondel et al. (2011) suggest that the variety of perceptual features that participants might attend to serve as cues for the subsequent recollective process. Alternatively, this early parietal positivity has been associated with higher-order visual processing and implicit memory processes (Evans & Federmeier, 2005; Friedman et al., 2010; Van Strien, Glimmerveen, Martens, & De Bruin, 2009). Similarly, results from a prospective memory paradigm suggest that in young adults, an early positivity (largest at Cz) reflects increased attention to specific (task-relevant) stimulus aspects (Czernochowski, Horn, & Bayen, 2012). Taken together, we argue that the early parietal positivity observed for old items in younger children could be interpreted as an early attentional modulation towards perceptual features for the discrimination between identical and changed items, which in turn supports recollective search.

Further evidence supporting this interpretation can be found by comparing adults and children with respect to their pattern of memory performance between the first and second run. For adults, feature memory performance was higher after intentional than after incidental encoding. It is likely that they shifted from a conceptual focus after incidental encoding to a more perceptual focus of attention towards item features (Haese & Czernochowski, 2015). By contrast, we observed no reliable difference of younger children's feature memory performance between incidental and intentional encoding, indicating a more perceptual approach to the task (as has been found previously in children, see Sloutsky & Fisher, 2004). Accordingly, we conclude that children did not shift their attention to perceptual features strategically, because their spontaneous approach was already sufficient. Instead, they relied on the same attentional processes in both phases. The notion of an early attentional modulation in children is in line with the review of Cabeza, Ciaramelli, and Moscovitch (2012), who compared several theoretical accounts for an activation in the ventral parietal cortex in adults. They concluded that fMRI activity in the parietal cortex is associated with a high level of bottom-up attention, either by external cues – attention is captured by a salient item – or by internal cues, when attention is captured by salient *cognitive states* (e.g. highly confident responses). In addition, Ofen and Shing (2013) suggested that for memory retrieval, children rely on rudimentary forms of perceptual, semantic, and episodic systems. Thus, they would additionally require the support of the posterior and perirhinal cortex in order to complete these tasks, which in turn might result in the parietal positivity for old items we observed. In contrast to this earlier parietal old/new effect, the later parietal old/new effect is most likely attributable to recollection, consistent with prior findings (e.g., Czernochowski et al., 2004; Czernochowski et al., 2005; Sprondel et al., 2011; Van Strien et al., 2009).

Older children exhibited a more complex pattern of results. After incidental encoding, there were no old/new effects in the early time window, suggesting that older children did not rely on familiarity to evaluate the old/new status of an item. After intentional encoding, however, they exhibited a frontal old/new effect (comparable to Mecklinger et al., 2011), but only during retrieval of identical items. In the later time window, we observed old/new effects for both item types at (centro-)parieto-occipital electrode sites, reflecting recollection, consistent with prior findings (e.g., Czernochowski et al., 2004; Czernochowski et al., 2005; Czernochowski et al., 2009; Friedman et al., 2010; Mecklinger et al., 2011; Van Strien et al., 2009). After intentional encoding, we observed a frontal positivity for old items that was only reliable for identical items, most likely the continuation of the familiarity-related effects in the previous time window (Fig. 4, right). While it seems plausible to assume that more experience with the task should be associated with a more consistent use of retrieval strategies, inspection of older children's ICVs (see Table 2) revealed that only identical items elicited larger ICVs after intentional encoding. Hence, this selectively larger variability supports the conclusion that older children engaged in additional processes after intentional encoding. In combination with the observation of a familiarity-related old/new effect in ERP averages for this condition only, this higher variability suggests that at least some children attempted to employ new strategies after intentional encoding for identical items, for instance evaluating the item's perceptual study-test similarity (i.e., perceptual familiarity). It should be noted that familiarity reflects a cascade of sub-processes (Tsivilis et al., 2001), which is not fully understood in adults either (Zimmer & Ecker, 2010). For instance, while earlier aspects of familiarity can lead to a fast old/new decision, there is evidence suggesting that some processes attributed to familiarity may continue, parallel to the slower recollection. If recollection is not successful, participants might then again rely on the (still ongoing) familiarity-related retrieval, resulting in familiarity-related, yet slower old/new judgments (for evidence suggesting that early and later familiarity-related processes can be separated, see Besson et al., 2015; Montaldi & Mayes, 2010).

Why do children change their strategy after intentional encoding, as evident in the ICVs and ERP pattern? A change in strategy may either be due to intentional encoding per se, or alternatively, due to the practice with retrieving items in the previous retrieval phase. As the order of incidental and intentional encoding cannot be counterbalanced – after a memory retrieval task, participants are likely to encode items irrespective of the actual task – the current paradigm does not allow to distinguish between these two possibilities. An alternative account that might explain the change between the incidental and intentional encoding is that during intentional encoding condition, one third of old items were presented again (i.e., four times in total; the fourth presentation was either identical or changed: A-A-A–A or A-A-A-B). Behaviorally, items presented three times were more likely to be recognized than items presented once, but ERPs for both item categories were indistinguishable. Although this suggests that both conditions did not differ reliably, this particular research question needs to be addressed by a paradigm specifically tailored for this question. So far, it remains open whether the identical repetition of a subset of stimuli also contributed to the old/new effects observed in older children in the present paradigm.

Taken together, our study provides evidence that not only a response deadline (Mecklinger et al., 2011), but also other task characteristics and perceptual attributes determine whether an ERP correlate of familiarity can be observed in children during middle childhood (i.e., aged 8–10, Mecklinger et al., 2011; aged 9–11, this study). Note that in both studies items that elicited familiarity-based retrieval in children were identical item repetitions with a complete perceptual overlap between study and test. Thus, perceptual overlap might be a considered a necessary, but not sufficient, pre-requisite for familiarity-based retrieval, as it was neither observed without a response deadline nor for the incidental encoding condition in the present investigation. This is in line with previous research suggesting that children at the age of eight years match perceptual stimulus aspects to memory contents at adult level (Sprondel et al., 2011) and that familiarity develops between the ages of six and eight years (Ghetti & Angelini, 2008). Moreover, older children have been reported to make less phonological and more semantic intrusion errors than younger children, indicating a development from a more perceptual (bottom-up) to a more conceptual (top-down) processing (5-year-olds and 8-year-olds, Dewhurst & Robinson, 2004; 8-to-11-year-olds, Maril et al., 2011; see also Sloutsky & Fisher, 2004 for pre-school children).

In the later time window (700–1000 ms), we observed a continuation of the ERP correlate of recollection from the previous time window for both groups of children. In adults, a late posterior negativity (LPN; Johansson & Mecklinger, 2003), associated with response inhibition and recollective search for perceptual features (Johansson & Mecklinger, 2003), overlapped with this positive old/new effect, as indicated by the lack of reliable old/new effects in this epoch (Haese & Czernochowski, 2015). We found no LPN of comparable extent in children, but in this time window identical and changed items were associated with different topographies (see Fig. 4), particularly in older children. Interestingly, we observed that changed – but not identical – items elicited no late old/new effects after incidental encoding in older children, which might be regarded as a related phenomenon (i.e., a negativity diminishing the positivity reflecting recollection). Similar to the adults' LPN, it could reflect the additional recollection of source-specifying features under conditions of uncertainty (Johansson & Mecklinger, 2003). By contrast, after intentional encoding reliable ERP old/new effects were observed for changed items (although smaller than for identical ones). Notably, the pattern of behavioral data supports this tentative interpretation. If older children employ additional source-specifying recollective search processes for changed items, this should be evident in reaction times – and indeed, they exhibited longer reaction times for changed than for identical items. For younger children, a similar pattern of results suggests a related mechanism. Reaction times to changed items were longer than for identical items and the old/new effects in this time window for changed items are smaller. By contrast, old/new effects were of comparable magnitude in the earlier, recollection-related, time window. However, our paradigm does not allow to further disentangle the cognitive processes underlying this phenomenon, and further studies are needed to replicate this effect. Assessing the developmental trajectory of the LPN might enhance our understanding of the associated cognitive processes across the life-span, as the LPN and its underlying processes are not entirely understood in adults, either (Johansson & Mecklinger, 2003). As the LPN has been shown to be larger for uncertain responses, one approach would be to assess metacognitive judgments associated with responses. A recent study suggested that children have the necessary metacognitive skills to evaluate and verbalize their confidence in learning (Destan, Hembacher, Ghetti, & Roebers, 2014), so it would be promising to investigate ERPs associated with different levels of response confidence. If children exhibit a higher confidence in their own judgment as a result of additional (source-specifying) retrieval, this metacognitive evaluation might be reflected in a similar negativity in the time window following the ERP correlate of recollection as in adults.

4.4. The role of brain maturation and open issues

When comparing the topographies in our age groups (Fig. 5), the distribution of old/new effects is very different. Younger children exhibited a positivity for old items selectively at parietal and occipital electrode sites, whereas adults show a much more widespread positivity. Interestingly, older children exhibited old/new effects that were not as widespread as in adults, but still extended further to central and frontal electrode sites than effects in younger children, reflecting the discussed neurological maturation continuing into adolescence (e.g., Casey, Giedd, & Thomas, 2000; Ghetti & Bunge, 2012). Crucially, the prefrontal cortex allows for a more coordinated memory retrieval. For instance, it might be an important support for determining whether an item is considered as "old" – for instance for the discrimination between pre-experimental and induced familiarity of any memory paradigm (Bridger, Bader, & Mecklinger, 2014; Ghetti & Angelini, 2008).

In developmental investigations, it should be noted that the neural architecture of children (e.g., their hippocampus) is not just a smaller version of the functional architecture of the mature nervous system in adults. For instance, in the study by Ghetti, DeMaster, Yonelinas, Bunge, 2010, activity in the mediotemporal cortex predicted subsequent item recognition, but not subsequent context recognition (i.e., the recognition of an item's color). By contrast, in adolescents and adults, activation in the hippocampus and posterior parahippocampal gyrus predicted successful color recognition, but not general item recognition. This suggests that during adolescence, the brain acquires additional capacities (i.e. a maturing prefrontal cortex) that can be utilized to support memory tasks – as evident in an age-related increase of the functional connectivity between the mediotemporal cortex and the dorsolateral prefrontal cortex (Ofen, Chai, Schuil, Whitfield-Gabrieli, & Gabrieli, 2012). It is conceivable that these additional processing resources allow the brain to specialize the existing regions employed in these tasks. In a similar vein, the memory representations of semantic and episodic memory seem to overlap in children, but no longer in adults (Ofen & Shing, 2013). According to Ofen and Shing, episodic and semantic memory systems might not be as specialized in children as in adults – children rely on rudimentary forms of perceptual, semantic, and episodic memory systems instead. Hence, younger brains are likely to compensate for the immaturity of the frontal lobe by recruiting other cortical areas than adults. Related findings have been found in memory studies with infant monkeys (Bachevalier & Mishkin, 1984) and in response inhibition paradigms conducted with children (e.g., Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002).

4.5. Conclusion

The focus of the present study was to assess ERP correlates of familiarity-based retrieval in children, which has previously only been reported by a single study using a response-deadline to eliminate the alternative route to episodic memory retrieval (Mecklinger et al., 2011). While no ERP correlates of familiarity-based retrieval were observed in younger children, older children relied on familiarity under certain conditions only. Replicating and extending previous work, we observed ERP correlates of familiarity for identical item presentations after intentional encoding in older children. By contrast, no reliable old/new ERP effects were observed for changed items and after incidental encoding in any group, likely reflecting a larger

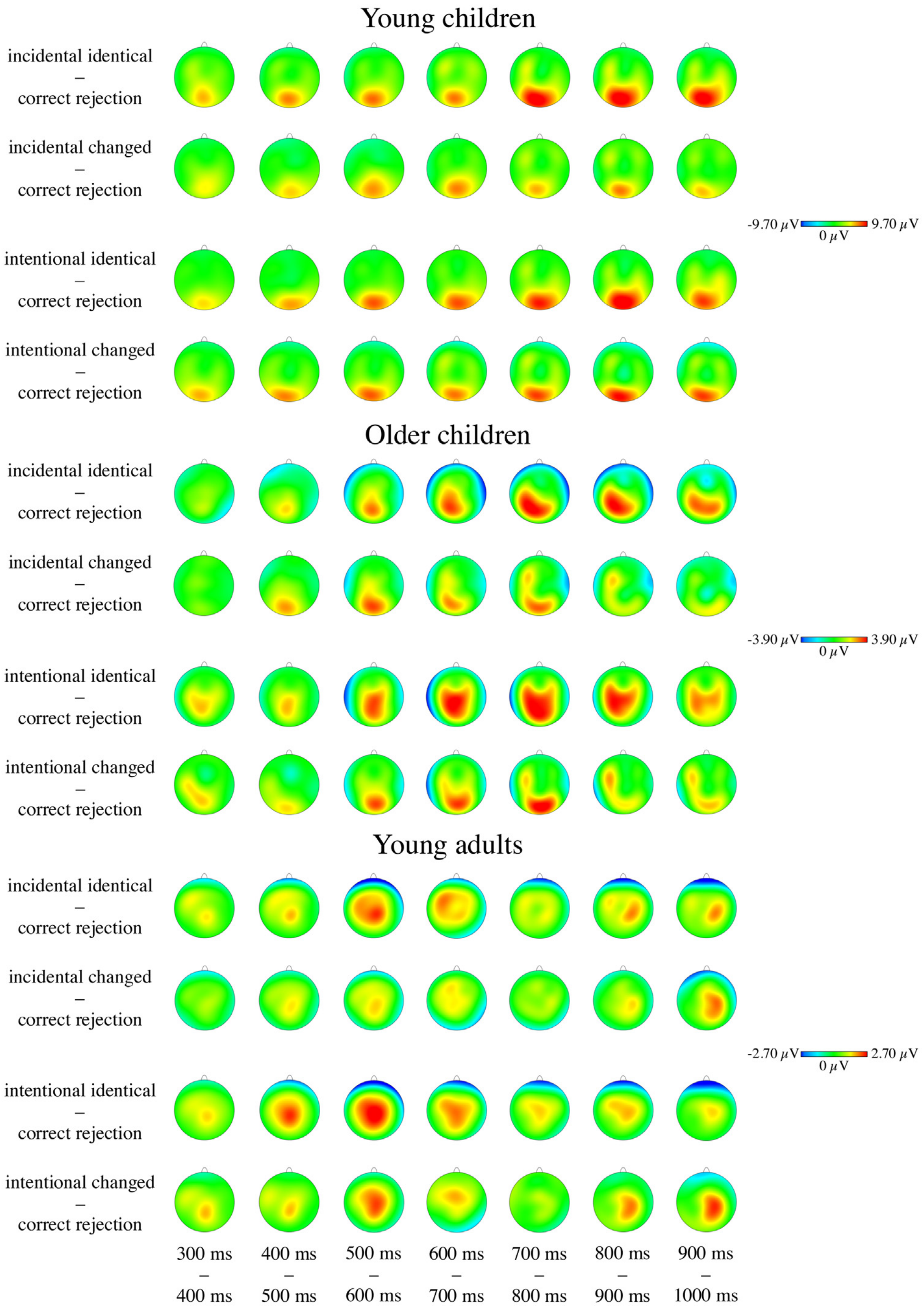

Fig. 5. Topographical time course of old/new effects across age groups. This figure depicts the topography of old/new effects during the analyzed time windows (in time segments of 100 ms each) in the three age groups investigated; note the scale differences across age groups. In younger children, parieto-occipital effects are predominantly observed in all conditions, whereas in older children effects are largest at centro-parietal elecrode sites. In comparison, adults show a widespread activation for old items that is, generally, much more frontal than in both groups of children.

heterogeneity in processing. It is possible that some older children mainly rely on recollection, like younger children, whereas others already evaluate an item's familiarity, like adults. Analyzing this heterogeneity in future studies might provide an answer why children seem to rely on familiarity only under some task characteristics.

In our paradigm, children and adults exhibited comparable memory performance in spite of differences in the underlying ERP correlates, presumably due to differences in brain maturation. Comparing topographies of ERP old/new effects, it is evident that successful episodic memory retrieval is associated with different neural computations in each age group during the same task. It is conceivable that children are able to compensate for a less fine-tuned memory system (c.f. DeMaster, Pathman, & Ghetti, 2013) by recruiting additional processes like an early attentional modulation towards item features in younger children and later source-specifying retrieval in older children.

Acknowledgments

We thank Julia Saße and Steffen Herff for assistance with data collection, and Sofia Kermas and Julia Saße for modifying stimuli to use as changed exemplars. Additionally, we would like to thank the editor and two anonymous reviewers for helpful comments on a previous version of this manuscript. This project was funded by the German Research Foundation. It had no involvement in the design, data collection, analysis or interpretation of data; furthermore it was not involved in the writing or submission of this article.

Appendix A.

Brief overview of adults' effects (see Tables A1 and A2)

Adults exhibited better old/new memory performance for identical items and after intentional encoding. Feature recognition also was better for identical items and after intentional encoding, with an additional improvement of feature recognition

Table A1
Overview of ERP results in adults.

effect (df_1,df_2)	incidental			intentional		
	ε	*F*	$\eta^2{}_p$	ε	*F*	$\eta^2{}_p$
300–500 ms						
Item type (2,34)		7.49^{**}	0.31		11.54^{***}	0.40
identical vs. CR (1,17)		11.84^{**}	0.41		16.53^{***}	0.49
changed vs. CR (1,17)		14.77^{**}	0.47		12.25^{**}	0.42
Item type X AP (6102)		–			–	
F' (2,34)		6.81^{**}	0.29		6.12^{**}	0.27
identical vs. CR (1,17)		11.40^{**}	0.40		10.34^{**}	0.38
changed vs. CR (1,17)		6.65^{*}	0.28		5.65^{*}	0.25
C' (2,34)		7.66^{**}	0.31		15.06^{***}	0.47
identical vs. CR (1,17)		13.41^{**}	0.44		22.23^{***}	0.57
changed vs. CR (1,17)		17.86^{***}	0.51		14.03^{**}	0.45
P' (2,34)		3.62^{*}	0.18		6.60^{**}	0.28
identical vs. CR (1,17)		5.98^{*}	0.26		10.31^{**}	0.38
changed vs. CR (1,17)		4.87^{*}	0.22		6.24^{*}	0.27
O' (2,34)		–			–	
identical vs. CR (1,17)		–			–	
changed vs. CR (1,17)		–			–	
500–700 ms						
Item type (2,34)		10.30^{***}	0.38		18.00^{***}	0.51
identical vs. CR (1,17)		13.49^{**}	0.44		29.29^{***}	0.63
changed vs. CR (1,17)		14.49^{**}	0.46		13.34^{**}	0.44
Item type X AP (6102)		–			–	
F' (2,34)	0.63	7.70^{**}	0.31		7.40^{**}	0.30
identical vs. CR (1,17)		8.41^{**}	0.33		7.99^{*}	0.32
changed vs. CR (1,17)		8.79^{**}	0.34		9.72^{**}	0.36
C' (2,34)		12.20^{***}	0.42		19.58^{***}	0.54
identical vs. CR (1,17)		16.21^{***}	0.49		26.00^{***}	0.61
changed vs. CR (1,17)		12.51^{**}	0.42		19.47^{***}	0.53
P' (2,34)		7.60^{**}	0.31		11.97^{***}	0.41
identical vs. CR (1,17)		10.75^{**}	0.39		24.51^{***}	0.59
changed vs. CR (1,17)		8.73^{**}	0.34		6.87^{*}	0.29
O' (2,34)		–			3.51^{*}	0.17
identical vs. CR (1,17)		–			4.48^{*}	0.21
changed vs. CR (1,17)		–			–	
700–1000 ms						
Item type (2,34)		3.74^{*}	0.18		5.73^{**}	0.25
identical vs. CR (1,17)		5.93^{*}	0.26		9.95^{**}	0.37
changed vs. CR (1,17)		–			7.68^{*}	0.31
Item type X AP (6102)		–			–	
F' (2,34)		–			–	
identical vs. CR (1,17)		–			–	

Table A1 (*Continued*)

effect (df_1,df_2)	incidental			intentional		
	ε	F	$\eta^2{}_p$	ε	F	$\eta^2{}_p$
changed vs. CR (1,17)		–			–	
C' (2,34)		4.41*	0.21		7.28**	0.30
identical vs. CR (1,17)		7.17*	0.30		12.51**	0.42
changed vs. CR (1,17)		4.76*	0.22		7.78*	0.31
P' (2,34)		–			4.38*	0.21
identical vs. CR (1,17)		–			7.18*	0.30
changed vs. CR (1,17)		–			5.70*	0.25
O' (2,34)		–			–	
identical vs. CR (1,17)		–			–	
changed vs. CR (1,17)		–			–	

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, CR = Correct Rejection.

Table A2
Young adults' mean trial numbers for analyzed item types.

Response category	Incidental encoding mean (range)	Intentional encoding mean (range)
Correct rejection	33.1 (26–39)	31.3 (22–37)
Feature hits identical	28.7 (21–40)	30.7 (23–37)
Feature hits changed	20.7 (12–31)	28.3 (18–36)

after intentional encoding for changed items only. With respect to reaction times, reaction times were longer to changed items than to identical and new items (just as for children), but after intentional encoding, they only became faster for new items, suggesting additional retrieval of perceptual details for both types of old items. Concerning the ERP correlates of familiarity and recollection, we observed old/new effects at frontal and parietal electrodes in their respective time windows, reflecting familiarity- and recollection-related memory retrieval. These effects were more widespread in adults than in both groups of children. With respect to later effects, we found old/new effects related to recollection (positivity for old items) to be largely diminished at parietal electrode sites due to an overlap with a late parietal negativity (for old items; associated with source-specifying retrieval of item features). This effect was neither affected by the encoding instruction or item type, so we can conclude that retrieval effort did not differ across these conditions.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cogdev.2016.08.008.

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