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Errorful and errorless learning in preschoolers: at what age does the errorful advantage appear?

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Abstract

Explicit memory has been tested extensively in young children. The results show that young children's explicit memory is weak and decays quickly but is in many ways similar to that of adults. However, most studies showed that young children's implicit memory is intact. This inconsistency has lead to a debate about the extent to which the memory of young children resembles that of healthy adults. When adults with impaired explicit memory and intact implicit memory are tested for semantic knowledge, they show better memory under errorless learning procedures. In contrast, healthy adults show better memory under errorful procedures. We tested these two procedures in 3- and 5-year-olds. 3-year-olds remembered less than 5-year-olds, but both groups showed similar errorful learning advantages, which persisted after 5 weeks. Our data show that while 3-year-old children's memory is weak, it is more similar to intact than to impaired explicit memory in adults.

Keywords: errorful learning; errorless learning; preschoolers

Word count: 4,403 words.

1. Introduction

Memory develops gradually during childhood. For example, Bauer et al. (2012) found that 4-year-olds remembered less than 6-year-olds, who in turn remembered less than 8-year-olds. Similar findings have been reported by Perner and Ruffman (1995) and many others (e.g., Pathman, Larkina, Burch & Bauer, 2013; Riggins, Blankenship, Mulligan, Rice, & Redcay, 2015).

It is not clear from what ages memories become permanent. Bauer, Leventon and Varga (2012) argued that children show at a very early age that they can remember events from the past. On the other hand, when adults report their first childhood memory, the average age at the time of their first memory is 3 or 4, and memories from before that age are rare, a phenomena called childhood (or infantile) amnesia. In addition, children have an accelerated rate of forgetting (3 and 4-year-olds more pronounced than 8-year-olds), especially in response to open ended questions (Bauer & Larkina, 2015). It seems that children at the age of 3 do remember past events but this memory contains less information (associations) and is more susceptible to forgetting.

Other populations which show less accurate memory include the elderly and patients with anterograde amnesia. When the memory of elderly and amnesic patients was tested, it was found that memory changes are not just in quantity, but also in quality. Hay and Jacoby (1999) found that whereas elderly people's recollection is impaired, their habit memory is intact. Others have found that explicit memory is more impaired in old age than is implicit memory (Anderson & Craik, 2000). Studies have shown that amnesic patients also have impaired explicit memory, but intact implicit memory (Corkin, 1965; Corkin, 2002).

The fact that younger children’s memory is less accurate does not address the question of whether the differences between adult memory and young children's memory are only in terms of quantity, or also of quality.

Many studies of explicit memory in younger children have focused on episodic memory (the ability to remember an event, the combination of what when and where). For instance, Bauer et al. (2012) found that four year old children's ability to remember where events took place was lower than the ability of 8 year old children. Similar findings have been reported for temporal order (Pathman, Larkina, Burch & Bauer, 2013) and activity associated with an item (Riggins, Blankenship, Mulligan, Rice, & Redcay, 2015). Moreover, it seems that while item memory develops gradually from age 4 to age 10, binding of memory [as shown by fact and source combination] shows accelerated development between the ages of five and seven (Riggins, 2014). Episodic memory, clearly, develops gradually over time.

While it is well established that episodic memory, which is part of explicit memory, develops gradually, most studies find that implicit memory is relatively stable during childhood. For example, Vöhringer et al. (2017) found that implicit memory is stable from 9 months of life to the age of 3 years. Similarly, Finn et al. (2016) tested explicit and implicit memory of 10 year olds and adults and found that children had poorer explicit memory and less working memory capacity than adults, but exhibited learning equivalent to adults on measures of implicit memory. Hayes and Hennessy (1996) found similar findings in 4, 5 and 10 year olds (but see Murphy, McKone & Slee, 2003).

Another aspect of memory, level of processing, shows discontinuity between young children and adults' memory. For example, although level of processing had similar effect for all ages on true memory (Kheirzadeh & Pakzadian, 2016), it had different effects on false memory: Wimmer and Howe (2010) showed that whereas deeper level of processing improved true memory in 4 and 7 year olds and also in adults, it reduced false memory for adults but *increased* false memory for the 7 year olds. As another example, most people remember better in recognition tasks than in free recall tasks. However, this difference is much more pronounced in amnesic (Isaac & Mayes, 1999) and aging people (Perlmutter, 1979). Perner and Ruffman (1995) tested the proportions of correct answers under free recall and recognition conditions in young children. They found that although 4-year-old children were worse than 6-year-old children in memory tasks, this effect was equal for free recall and cued recall. That is, young children did not show more pronounced imbalance between recognition and free recall as did older adults and amnesic patients. Similar results were also found by Cheke and Clayton (2015). Thus, it seems that young children have intact implicit memory and existent but less developed explicit memory.

Clearly, some aspects of children's memory are similar to that of adults, while other aspects are not. Aspects of memory change during childhood not only in quantity, but also in quality. It could also be asked if the memory of young children is more similar to that of healthy adults, or of impaired adults. One paradigm that shows an interesting difference between memory in amnesic and healthy adults is the errorful vs. errorless learning paradigm.

In 1995 Hamann and Squire tested semantic learning in amnesic patients and a control group. They used two procedures of learning: study-test (errorful) procedure and study only (errorless) procedure. In the errorful procedure, participants saw the first two words of a sentence and were asked to guess the last word (medicine cured ?????) in the study phase. All sentences were constructed so that the third word of the sentence was difficult to guess from the first two words. If the participant guessed incorrectly, the correct answer was given (hiccups). In contrast, in the errorless procedure, participants saw the whole sentence (medicine cured hiccups) in the study phase. The memory of the last word in each sentence was tested using cued recall, with the first two words of each sentence being the cue. Hamann and Squire found that whereas healthy participants showed better memory under the errorful procedure, amnesic patients showed better memory under the errorless procedure. [The errorful procedure benefit healthy adults may hold true for semantic learning, but not in lexical learning (Cyr and Anderson, 2014).]

There is a debate in the literature as to whether the errorless advantage in amnesic patients stems from implicit or residual explicit abilities. Tailby and Haslam (2003) used a more elaborate self-generation version of the errorless paradigm (they gave participants elaborate clues to the guessed words, e.g., I'm thinking of a five letter word beginning with BR and this word describes a food made of flour, liquid and yeast which is baked and then sliced to make sandwiches). They found that, as expected, severely and moderately memory impaired participants showed better memory under the errorless procedure than under an errorful procedure but they also found that the self-generation paradigm improved the memory in the errorless procedure of those participants. In their view, this finding supports the idea that the errorless benefit in amnesic learning reflects the operation of residual explicit memory processes since it is influenced by level of processing. In contrast, Page, Wilson, Shiel, Carter and Norris (2006) found that the errorless advantage for severely and moderately memory impaired participants was shown under both an implicit and an explicit task. They argue that their findings suggest that preserved implicit memory, in the absence of explicit memory, is sufficient for an errorless advantage to emerge.

To the best of our knowledge, the errorless and errorful paradigm has been used only twice with children. Haslam, Bazen-Peters and Wright (2012) compared lexical (but not semantic) learning in 12-year-old children with traumatic brain injury to that of controls and found that children with traumatic brain injury remembered better under an errorless procedure, whereas control participants remembered a similar number of words under errorful and errorless procedures. Haslam, Wagner, Wegener and Malouf (2015) tested semantic memory of 12-year-old children with traumatic brain injury at different intervals and again, these children showed better memory under an errorless procedure, regardless of the time elapsed between study and test. Unfortunately, that study did not employ a control group. Thus, to our knowledge, there have not been any studies that tested semantic learning under errorful and errorless procedures in healthy children. Moreover, previous studies showed that adults show errorful advantage in learning (e.g., Hamann & Squire, 1995; Cyr and Anderson, 2014), but there have not been any studies that tested at what age this errorful benefit emerges.

The age at which the errorful benefit emerges might thus help us understand the nature of errorless advantage over errorful procedure in amnesic adults. If an errorless advantage appears only under conditions in which there is virtually no explicit memory, then young children should not show an errorless advantage, since there is evidence that they have some explicit memory, although less developed than in older children. If, however, errorless advantage appears even in the face of only a little explicit memory, then even very young children should show an errorless advantage since they have the capacity for some explicit memory.

There are some limitations to the usage of this paradigm. Bauer, Leventon, and Varga (2012) pointed out three challenges in assessing very young children's memory.

First, language develops gradually and even preschoolers who already have verbal abilities cannot be counted upon to respond verbally reliably and it is unlikely that they comprehend complex verbal instructions. Second, young children are not particularly deliberate or strategic in their use of memory. Finally, the task must be fun.

The language issue constrained us to use 3-year-old children as the youngest group. We compared their performance to the performance of 5-year-old children. The issues of language and "fun" necessitated making some modifications to the Hamann and Squire (1995) paradigm, yet, we tried to make the minimal changes necessary. Based on the lower memory abilities of 3-year-old children, we predicted that 3-year-old children would remember less than 5-year-old children. The possible development of an errorful advantage will teach us about the nature of errorful and errorless learning.

2. Method

Participants: Participants were recruited from kindergartens and pre-schools in Kiriat Malachi (a small town in the south of Israel). All participants were Jewish. 54 children participated: 28 3-year-olds (46.4 percent female; mean age 3 yrs 2 mos, range 3:0 to 3:6) and 26 5-year-olds (50 percent female; mean age 5 years 2.5 months, range 5:0 to 5:6). Children with known developmental disorders or whom the kindergarten teacher suspected of having a developmental disorder were played with, but their data was not analyzed.

The ethical committee of the Ashkelon academic college approved the protocol and written parental consent was obtained for each child.

Material: The materials consisted of 20 three-word sentences (subject-verb-object, e.g., *"the child prepared rice"),* based on a set used in a previous study of semantic learning (Hamann & Squire, 1995). The sentences were child appropriate, using words which are familiar to children and relevant to their semantic world. Half of the sentences had a male subject and the other half had a female subject. The verbs in the sentences that were chosen were verbs that did not predict the object. For each 3-word sentence, 2 pictures that depicted the object and subject were chosen. When the experimenter presented the sentence to the child, he also showed the corresponding pictures.

Procedure: Children took part in six half hour sessions. The first 5 sessions were spaced approximately one week apart and the last session was spaced approximately 5 weeks after the last session. The experimental procedure was based on Hamann and Squire (1995) with a few modifications so that young children would be able to perform the task. The changes were: 1. Instead of reading the sentences the children heard the sentences read aloud. 2. In order to add a visual aspect to the learning, a picture that depicted the subject and object of the sentence were added. 3. We used a shorter learning list (20 sentences rather than 40). 4. Hamann and Squire used two learning trials during each session. In order not to fatigue the children we did only one learning trail in each session. 5. We modified the questions regarding the sentences and the answering scale. 6. No transfer test was conducted, as synonyms are often rare words and children might not know them.

Before training began with the errorful and errorless procedures, a pretest was administered to all children to determine the probability of completing sentence frames with the correct target word in the absence of prior study and to identify those sentence frames for which test participants had a strong preexisting response. In order to explain the task to the children, they were given examples such as *the mice eat* and were told they could finish the sentence with *cheese*. The experimenter used several examples until the child understood the task and responded with an appropriate target word. Children were reminded during the pretest that it was not necessary to give an answer to every cue, although they could do so if they wished. After the pretest was administered, the learning trials began.

Both age groups received 5 training trials with the 20 sentences (scheduled as 5 weekly sessions). For each child, half of the sentences (10) were trained with the errorful procedure, whereas the other 10 sentences were trained with the errorless procedure. Assignment of sentences to the errorful or errorless procedures was counterbalanced across participants. In the 5th week, there was a test of the 20 sentences studied during the previous 4 weeks, which was followed by an additional study phase. In this same session (5th week), an additional test (in a new random order) was given following the additional study phase. The additional learning and test trial phase was conducted in order to test the pattern of memory immediately after learning. At the end of the fifth session, children received a small toy for participating. Finally, a test to assess long-term retention was given on Week 10.

Errorful and errorless procedures.

Two learning procedures were used during training. In the errorful procedure, the experimenter said the first two words of the sentence and showed the picture of the subject, following which the child was asked to respond with the appropriate target word (during the first trial the target word had not been studied yet, therefore the instruction was simply to guess a word that could complete the sentence in a sensible way). After the child responded or after 15 s had elapsed, the experimenter said the target word aloud and showed its picture. The child then repeated the sentence aloud and rated how funny the sentence was on a 3-point scale: "How funny do you think this sentence is?": (1) *not funny,* (2) *a little,* (3) *a lot.* The answers were marked on a board with neutral smiley (for not funny) a small smile (for a little) and a smiling smiley for (a lot). The child was also asked to evaluate how many children in his/her kindergarten would guess the target word (also estimated on a 3-point scale). These two questions are included in order to assure an adequate level of cognitive processing.

In the errorless procedure, the experimenter said the first two words of the sentence and showed the picture of the subject, and after a short pause said the target word and showed the picture of the object, thereby completing the sentence. The small delay in the presentation of the target word allowed the child to see the sentence segmented into a cue and a response (as in the errorful procedure), but the target word appeared quickly enough to prevent the child from making an erroneous response to the cue. After the entire sentence had been presented, the child then repeated the sentence aloud and rated the sentence as described above.

The training schedule for each session consisted of presenting all 20 sentences in two blocks of 10 sentences each: the list assigned to be trained with the errorful procedure and the list assigned to be trained with the errorless procedure. The order of learning procedures (errorful or errorless) was counterbalanced across participants. The order of presentation of learning procedures was reversed for each child in each successive session. Training continued in weekly sessions until each child had received four trials across 4 weeks of training. Following training and testing on Week 5, there was an additional session of learning and testing. The session began with a cued test of all 20 sentence frames which were presented in a new random order. The experimenter said the first two words of the sentence and showed the picture of the subject, following which the child was asked to respond with the object word. If a participant was unsure of an answer, guessing was encouraged. No feedback was given. Next there was additional learning phase, similar to the ones in the previous weeks, followed by another test. To equate the retention interval between sentence presentation and the test for those sentences learned by the errorful procedure and those learned by the errorless procedure, the sentences were divided into sublists of 5 items each and were arranged in an ABBA order. Thus, for half of the children, the first 5 sentences were presented with the errorful procedure, followed by 10 sentences with the errorless procedure, followed by the remaining 5 sentences presented with the errorful procedure. For the other children, the errorless list was substituted for the errorful list in the ABBA design.

Long-delayed test of errorful and errorless learning.

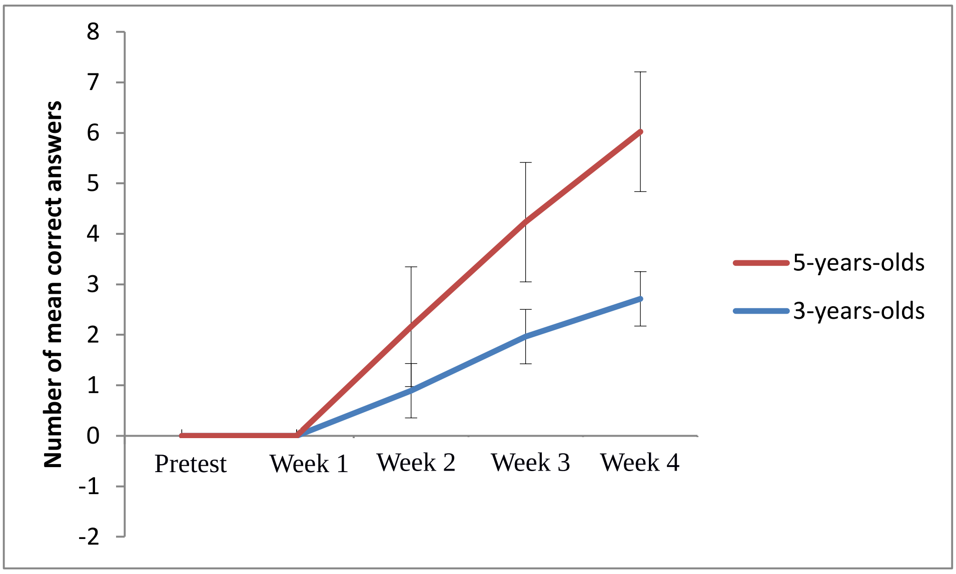
A final test of retention for all 20 sentences was given 5 weeks later (10 weeks after the first training session). This test was identical to the test of errorful and errorless learning that had been given in Session 5, except that the cues were presented in a new random order.

3. Results

On the pretest none of the children guessed the target word, indicating that the two first words did not predict the target word. For each child, the number of correct responses in the errorful procedure in each session and the number of correct responses on the three tests (fifth week before additional learning, fifth week after additional learning and tenth week) were collected.

Learning rate in the errorful procedure: Figure 1 presents the number of correct answers in the pretest and in the errorful procedure.

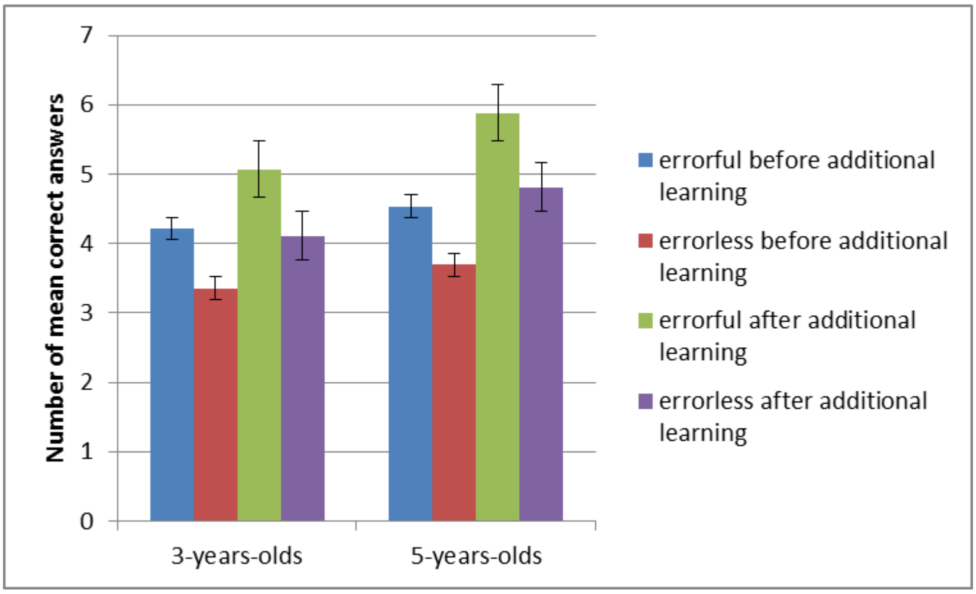
Figure 1: Number of correct answers in the pretest and errorful trials as a function of session and age group. Error bars indicate the standard error of the mean. For clarity, the error bars are omitted for the pretest and for week 1 (1.5 columns).



As can be seen, both groups showed an increase in the number of remembered target words in each session while 3-year-olds showed a slower learning curve compared to 5-year-olds. To test this observation, an analysis of variance was conducted with session number and age (3 vs. 5-year-olds) as the independent variables and number of remembered items as a dependent variable. We found a significant effect for session number $F(3, 156) = 193.565$, $p < 0.001$, $\eta_p^2 = 0.933$. The effect of age and the interaction between age and session number did not reach significance. $F(1, 52) = 2.422$, $p = 0.126$ for age and $F(3, 156) = 1.721$, $p = 0.165$ for the interaction.

Test of errorful and errorless learning: Figure 2 presents the number of correct answers in the test of errorful and errorless learning in the fifth week on both, test before additional learning and test after the additional learning.

Figure 2: Number of correct answers in errorful and errorless tests before and after the additional learning, as a function of age groups and session. Error bars indicate the standard error of the mean (1.5 columns).

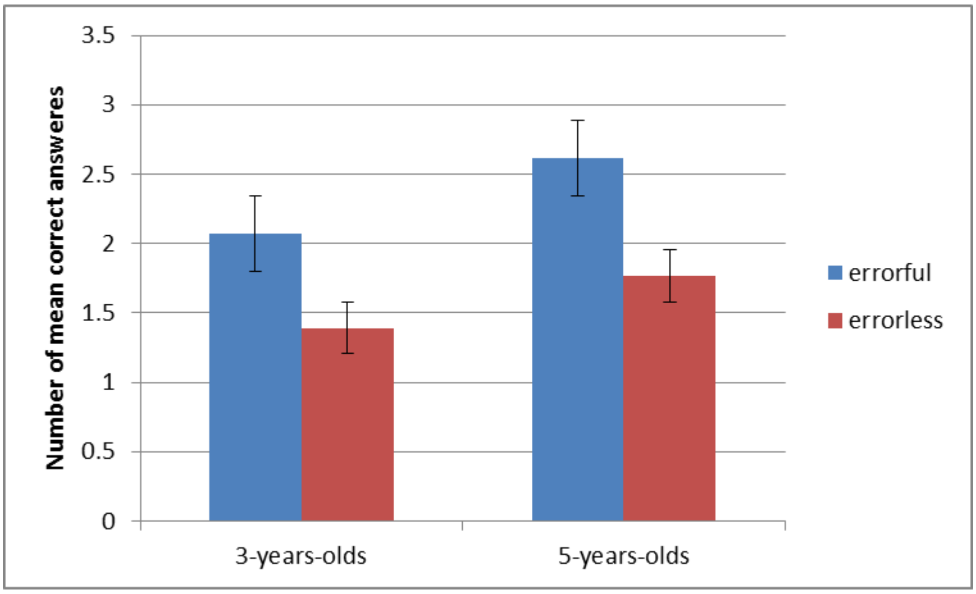


As can be seen from Figure 2, 3-year-olds learned less than 5-year-olds and after an additional study session, all age groups remembered better. It also seems that the additional study session improved 5-year-olds memory more than 3-year-olds. Most importantly, children showed errorful advantage in both ages. To test this impression, an analysis of variance with study procedure (errorful vs. errorless), session (before vs. after the additional study session) and age groups (3 vs. 5-year-olds) as independent variables and number of correctly remembered words as a dependent variable was conducted. We found a significant effect for session $F(1, 52) = 127.332$, $p < 0.001$, $\eta_p^2 = 0.71$, reflecting the fact that children indeed remembered better after the additional study session. We also found a significant effect for procedure $F(1, 52) = 68.282$, $p < 0.001$, $\eta_p^2 = 0.568$, reflecting the fact that the errorful procedure showed better learning compared to the errorless procedure. The effect of age group was only marginally significant $F(1, 52) = 3.481$, $p = 0.068$,

$\eta_p^2 = 0.063$. There was also a significant interaction between session and age group $F(1, 52) = 5.615$, $p < 0.05$, $\eta_p^2 = 0.097$, reflecting the fact that although both age groups showed better memory after the additional study session $F(1, 27) = 35.712$, $p < 0.001$, $\eta_p^2 = 0.569$, for 3-year-olds and $F(1, 25) = 108.017$, $p < 0.001$, $\eta_p^2 = 0.812$, for 5-year-olds, this effect was larger for the 5-year-olds. No other effect was significant. Moreover, the interaction between age groups and procedure and the interactions between age groups, procedure and session both were all statistically insignificant (Fs < 1).

Long delay errorful/errorless learning: Figure 3 presents the number of correct answers in the delayed learning.

Figure 3: Number of correct answers in errorful and errorless tests at the delayed test, as a function of age groups. Error bars indicate the standard error of the mean (1 column).



As can be seen from Figure 3, 5-year-old children remembered more than 3-year-olds and the errorful procedure was more efficient than errorless learning for both age groups. To test this observation, an analysis of variance with age groups (3 vs. 5-year-olds) and procedure as independent variables and number of correctly remembered words as a dependent variable was conducted. We found a main effect for procedure $F(1, 52) = 21.031$, $p < 0.001$, $\eta_p^2 = 0.288$, and for age group $F(1, 52) = 4.208$, $p < 0.05$, $\eta_p^2 = 0.075$. The interaction did not reach significance (F < 1).

4. Discussion

The present study was designed to test errorful and errorless learning in preschool children. We examined the memory of three year old and five year old children under errorful and errorless procedures. As expected, the older children generally remembered more than the younger ones, although this effect was not always statistically significant. We found that the errorful procedure was more efficient than the errorless procedure for both age groups. This was true after four weeks of learning sessions and also after a five week delay. Importantly, there was no interaction between learning procedure and age.

The fact that children as young as three years old showed an errorful advantage contradicts the position of Tailby and Haslam (2003) and shows that with even rudimentary explicit memory, an errorful advantage *does* appear. Note, however, that rudimentary explicit memory is apparently not the same as impaired explicit memory. It seems that in the continuity between early and later development of memory, there are more quantitative changes - the *amount* children are able to remember - than qualitative changes. Notably, it seems that the fact that younger children remember less than older children and adults does not imply that their memory processes resemble those of amnesics.

Some of the changes in memory observed across childhood may reflect developmental changes in neuroanatomy. Explicit memory relies on complex neuronal networks including the medial temporal lobes and prefrontal cortex. Anterograde amnesia can be caused by a bilateral damage to the hippocampus, bilateral damage to the mammillary bodies, or bilateral damage to the fornix (Aggleton & Brown, 2006). Neuroanatomical data has indicated that there is postnatal maturation of the primate hippocampal formation (Lavenex and Lavenex, 2013). Findings from humans showed that children had bigger right hippocampus head and tail but smaller body on both side than adults. Moreover, while source memory was negatively correlated with the hippocampal head volume and positively correlated with the hippocampal body volume in adults, this correlation was not found in children. The source memory in children was positively correlated with the hippocampus tail, but not in adults (DeMaster, Pathman, Lee & Ghetti, 2014). In contrast to explicit memory, implicit memory is hypothesized to depend on nondeclarative memory that operates independent of the medial temporal lobe memory system and instead depends on cortico-striatal circuits between the basal ganglia and cortical areas. Indeed, Gobel et al. (2013) found that whereas patients with mild cognitive impairment showed intact implicit memory whereas patients with Parkinson's disease showed impaired implicit memory (see also Haut, Hogg, Marshalek, Suter & Miller, 2017).

This study has several limitations. First, sample size is relatively small. Second, though we did try to minimize changes to the paradigm, our changes could possibly have been substantial enough to change the pattern of memory in the participants. Finally, we did not conduct any IQ or developmental assessments for the children, and it is possible that there were some differences between the groups not strictly associated with age alone.

Our findings have implications for teaching techniques. Metcalfe (2017) argues that whereas in the United State, teachers ignore or avoid mistakes, in Japan students first try to solve math problems on their own, a process that is likely to be filled with false starts. Only after these (usually failed) attempts by the students does the teacher direct an interactive discussion involving students and targeting students' initial efforts and core mathematical principles. Japan by far surpasses the United States in math scores; teaching techniques might not be the only reason for this difference in achievements, but it may account for some of the disparity.

To the best of our knowledge this is the first study to test errorful and errorless learning in young children. Our findings indicate that even though the memory of younger children is weaker than that of older children and adults, the pattern of memory is similar to that of older ages. As young as three years old, children already show better memory (for semantic information) in an errorful procedure, as opposed to the findings in people with amnesia. This study joins other work showing weaker memory in younger children but with patterns that resemble those of healthy adults (e.g., Perner & Ruffman, 1995; Cheke & Clayton 2015). Our data suggest that in healthy subjects, an errorful procedure is better for learning than an errorless procedure, even for children as young as three years.

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