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The Development of Implicit Memory From Infancy to Childhood: On Average Performance Levels and Interindividual Differences

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The present multimethod longitudinal study aimed at investigating development and stability of implicit memory during infancy and early childhood. A total of 134 children were followed longitudinally from 3 months to 3 years of life assessing different age-appropriate measures of implicit memory. Results from structural equation modeling give further evidence that implicit memory is stable from 9 months of life on, with earlier performance predicting later performance. Second, it was found that implicit memory is present from early on, and no age-related improvements are found from 3 months on. Results are discussed with respect to the basic brain structures implicit memory builds on, as well as methodological issues.

Memory is crucial for the acquisition of the tremendous amount of knowledge and skills infant and children acquire in the first years of life. A wealth of research over the last decades documented the impressive development of memory abilities from infancy to childhood (see, e.g., Hayne, Scarf, & Imuta, 2015). From a theoretical point of view, this area of research is mostly based on the distinction between implicit and explicit memory (see, e.g., Rovee-Collier, 1997 for an extensive review). The central role for differentiating these two systems plays consciousness in that explicit memory needs conscious awareness and implicit memory does not.

From a developmental point of view, a variety of studies showed that explicit memory is significantly increasing throughout infancy and childhood (Ornstein & Haden, 2001). More specifically, for example, with development, children imitate more

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demonstrated actions (e.g., Barr, Dowden, & Hayne, 1996; Graf et al., 2014), remember more items (e.g., Anooshian, 1999), and recall stories better than younger children (for an overview, see Fivush, 2011).

In contrast to explicit memory, age-related improvements in implicit memory are seldom documented, and if so, they are found to be comparably small (see, e.g., Schneider & Pressley, 2013). Typically, this age invariance is explained by the neural structures underlying implicit memory.

Research findings imply that implicit memory is mainly associated with the striatum, the cerebellum, and the amygdala with some additional activity found in the sensory and motor areas for some tasks (see, e.g., Jabès & Nelson, 2015; Kandel & Schwartz, 2000 for an overview). These brain areas are seen as phylogenetically old as they not only develop in humans but also in nonhuman primates (for an overview, see Rovee-Collier, Hayne, & Colombo, 2001, chapter 5). During human ontogeny, these brain areas are also the first to mature and are suggested to be fully developed in the first postnatal months (Nelson, 1995).

Due to this fully developed structures early in life, implicit memory is postulated to be unaffected by a various number of influences like for instance intelligence (for an overview, see Lloyd & Newcombe, 2009).

So far, behavioral data support this view of an ontogenetically old, early developing memory system. Reznick, Chawarska, and Betts (2000), for instance, investigated the development of implicit memory performance using the visual expectation paradigm (VExP). In this paradigm, participants are presented stimuli in a random and ordered series, and their reaction to those stimuli was recoded. Thereby, faster reaction to the stimuli of the nonrandom sequence represents implicit learning. Using this task, the authors compared 4-, 6-, 8-, 9-, and 12-month-old infants. The authors showed that performance improves in the course of the first 9 months but does not improve further between 9 and 12 months of age. Other studies assessing implicit memory using the VExP confirmed this view (e.g., Jacobson et al., 1992; Canfield et al., 1997) and suggested that during the first 9 months of life, older infants perform better in this paradigm than younger infants.

Age differences in later childhood or even adulthood, by contrast, are rarely evident for implicit memory (see, e.g., Lloyd & Newcombe, 2009). Parkin and Streete (1988) compared implicit memory in 3-, 5-, and 7-year-old children using a visual priming task. In this task, the children look at fragments of previously presented target pictures and new control pictures. The faster identification of the target pictures as compared to control pictures is referred to as the priming effect and indicates implicit memory. The authors found that irrespective of age, children showed a priming effect indicating comparable implicit memory performance. Billingsley, Smith, and McAndrews (2002) compared implicit memory performance of 8-year-old children and 19-year-old young adults, and found no age-related improvements with children performing as good as young adults. The authors concluded that children reach adult performance levels at least at 8 years of life for implicit memory. Similar findings have been repeatedly demonstrated in childhood and adulthood. Taken together, these findings demonstrate that implicit memory develops in the first 9 months of life but does not further improve thereafter.

From a methodological point of view, however, this conclusion is limited as results are based on cross-sectional design approaches having two important limitations. First, these studies are usually single-task approaches and consequently, their results and conclusions are limited to one task and not to implicit memory in general. Second and most importantly, developmental stability in the sense of describing interindividual differences in intra-individual change cannot be addressed properly through cross-sectional studies. A high developmental stability, for example, indicates that the memory ability of an individual indicated by its performance increases with age and that the differences between different individual subjects remain almost equal across time. In other words, subjects who are high performers and hence show good memory abilities at the first measurement occasion remain high performers across all following measurement points, whereas subjects performing comparably low remain low across time. This would be indicated by high correlations between measurement occasions. Low stability, in contrast, means that subjects change their rank order across time. As cross-sectional studies test different subjects at a specific age, inferences about stability of interindividual differences over time are precluded. In general, it is also difficult to draw conclusions about development when comparing group mean differences in children of different age groups.

Up to now, longitudinal studies testing infants and young children are generally rare in infant and early childhood research. In the domain of memory development, the existing longitudinal studies

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typically assess explicit memory with one particular memory task and in rather short time frames. Using the deferred imitation task, for example, Kolling, Goertz, Frahsek, and Knopf (2010), for instance, analyzed developmental stability of explicit memory with children at three measurement occasions through the 2nd year of life. The authors report that overall explicit memory performance improved through the 2nd year. Stability analyses indicated that stability was low at the beginning and increased through the 2nd year reaching moderate levels at the end of the 2nd year. Another series of longitudinal studies focuses on the prediction of future abilities by infant memory measures. Heimann et al. (2006), for example, investigated explicit memory performance at 6 and 9 months of age, and communication skills at 14 months. The authors found that the children's communication skills at 14 months could be predicted on the basis of their earlier memory performance, indicating that early explicit memory performance is predictive for later more complex cognitive abilities. Similarly, Fitzpatrick and Pagani (2012) predicted school readiness at 74 months (6;2 years) on the basis of working memory performance in early childhood (29 and 41 months).

Rather seldom there are studies investigating developmental stability of one memory domain over the course of multiple years using different paradigms successively and simultaneously. Rose, Feldman, Jankowski, and van Rossem (2012), for example, investigated stability of explicit memory from infancy to childhood. Their participants were tested twice in infancy (7 and 12 months), twice as toddlers (24 and 36 months), and once at school age (11 years) on different explicit memory tests (recall, immediate, and delayed recognition in infancy and toddlerhood, and various memory tests at school age). Using structural equation modeling, their results suggest that explicit memory, indicated by the different measures mentioned earlier, shows developmental stability in that memory performance in infancy predicts memory performance in toddlerhood, which in turn predicts memory performance at school age.

A common feature of these studies is that they primarily analyze the development of explicit memory. In contrast, implicit memory in early childhood has, to our knowledge, never been investigated in longitudinal studies. This lack of studies might be due to methodological issues, that is, development of subjects necessitates the adaptation of assessment procedures leading to difficult issues in measurement equivalency and difficult interpretation of simple cross-task correlations.

Structural equation modeling (SEM), however, allows analyzing performance on different measures of the same psychological construct, for example, memory ability. SEM allows the aggregation of various measures to an underlying construct, that is, a latent factor, enhancing reliability and validity in contrast to single-task approaches (Haden et al., 2011; Little, 2013). Combining SEM approaches with longitudinal studies allows for analyzing changes in a latent construct as well as interindividual differences in development.

The aim of the present study was therefore to investigate longitudinally the developmental stability of implicit memory in the first 4 years of life using SEM. Children in the present study were tested repeatedly with different implicit memory tasks from infancy to childhood. Assuming that all of these tasks measure implicit memory ability, we aggregated them in order to investigate the development of implicit memory in the first 4 years of life, regardless of the assessment method used. As implicit memory performance relies on ontogenetic old brain structures (Jabès & Nelson, 2015), performance in implicit memory tasks might be more influenced by biological and genetic factors and less affected by environmental influences and thus experience. Consequently, it might show less development; hence, only modest age-related improvements are expected for overall performance over time (Hypothesis 1).

Additionally, we hypothesize that, because implicit memory relies on early developing brain structures and is less affected by environmental influences that might also be attention or mood, individual differences in implicit memory become stable rather early during development. As the measurement of implicit memory (but not the ability itself) may be more influenced by factors such as general alertness or mood in very early infancy, unsystematic intraindividual variability is generated. This, in turn, reduces cross-age correlations impairing stability. In later infancy and (early) childhood, this intraindividual variability due to environmental factors occurring in the test situation might be reduced, as older children are less irritable than babies and extend their ability to maintain attention when asked to or experiencing something new. Consequently, this might lead to higher stability of implicit memory performance. We therefore expect that interindividual differences are less stable in early infancy and become more and more stable during the course of development (Hypothesis 2).

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Method

Participants

This research was part of a broader longitudinal study conducted in Germany and Kumbo, Cameroon, by four German universities (Bielefeld, Giessen, Frankfurt/Main, and Osnabrück) from 2008 to 2013. In the course of this project, the children were tested in a variety of tasks, that is, implicit and explicit memory performance, face recognition, language development, or general cognitive development. Parts of the results of the project were already published (see, e.g., Fassbender et al., 2012; Graf et al., 2014; Suhrke et al., 2014; Teubert et al., 2012; Vöhringer et al., 2015). As for the present study, only the German subsample is included in the analysis, the following description only applies to the subsample. The participating middle-class families lived in the (sub)urban area of these university cities. The participants were recruited via flyers sent to midwives, pediatricians, or family education centers, or by contacting families through population registers. The infants and their families were repeatedly invited to the laboratories at ages 3, 6, 9, and 40 months, where all testing was conducted by trained graduate students and psychologists. Each child was tested individually in the same laboratory at each measurement occasion on the specific testing site. Babies were included in the study if birth weight was within standard norms (between 2,500 and 4,500), if they were born full-term and if the Apgar score was within normal values (between index scores 8 and 10 measured 1, 5, and 10 minutes after birth). About 10% of families had a migration background with both parents not being born in Germany but living in Germany for $M = 16.5$ years ($SD = 10$) before the birth of the child participating in this study. However, 95% of the families stated that German is the mother language of their children. Families had on average $M = 1.6$ children ($SD = 0.9$). Parental education was $M = 12$ years ($SD_{\text{mothers}} = 1.28$, $SD_{\text{fathers}} = 1.31$). Approximately half of the parents had a university degree (47.8% of both mothers and fathers). According to these family characteristics and the families' monthly net income, the sample can be described as Western middle class. All parents gave written consent prior to participation.

The longitudinal study started with a sample size of 285 babies. Of the original sample, 34% ($n = 99$) dropped-out of the study because of relocation, among other reasons. Additionally, children who completely missed one measurement occasion were also excluded from analyses ($n = 52$). The final sample used for the analyses of the present article therefore consisted of 134 (66 male) children. At the 3 months measurement, infants had a mean age of 95 days ($SD = 2.8$); at the 6 months measurement, they had a mean age of 187 days ($SD = 4.5$); at the 9 months measurement, they were at average of 279 days old ($SD = 4.7$); and at 40 months measurement (3;4 years), they were 1,230 days old ($SD = 9.2$).

Materials and Procedure

Figure 1 displays the tasks and materials used. As shown, at the first three measurement occasions, infants were administered a VExP. At the fourth measurement occasion, implicit memory was assessed via a priming task. These two tasks were chosen because of different reasons. First, these measures have turned out to be the most often used paradigms in early childhood research on implicit memory. Second, alternative methods are more critical in their theoretical anchor (e.g., the mobile conjugate reinforcement task which can be argued to assess not only implicit but also explicit memory). Third, the two tasks are not only theoretically clearly assessing implicit memory but are also comparably reliable. The respective tasks and measures will be described in detail below.

3, 6, and 9 Months Measurement

In the VExP task, smiling female faces were presented consecutively at different locations on a computer screen following a simple left–right sequence. The stimuli were 24.7 cm × 18.7 cm in size and appeared for 1 s followed by a 1.5s interstimulus interval, where nothing was shown on the screen. The task consisted of 18 trials. Each infant saw female faces that were presented in three poses: a full frontal view, a left three-quarter turned, and a right three-quarter turned profile view. Infants were seated on their parents' lap and watched a screen that was located in an enclosure to ensure that the children were not distracted by other stimuli in the environment. The enclosure had dark gray sound-absorbing walls and was open to one side for entering. It was constructed in a way that did not allow the parents to see the screen in order to prevent unintended influence from the parents on the babies. The infants' head was about 60 cm away from the screen measuring 40 cm × 17 cm. The babies' gaze movement was recorded via video and analyzed frame by frame for each learning trial by two independent coders.

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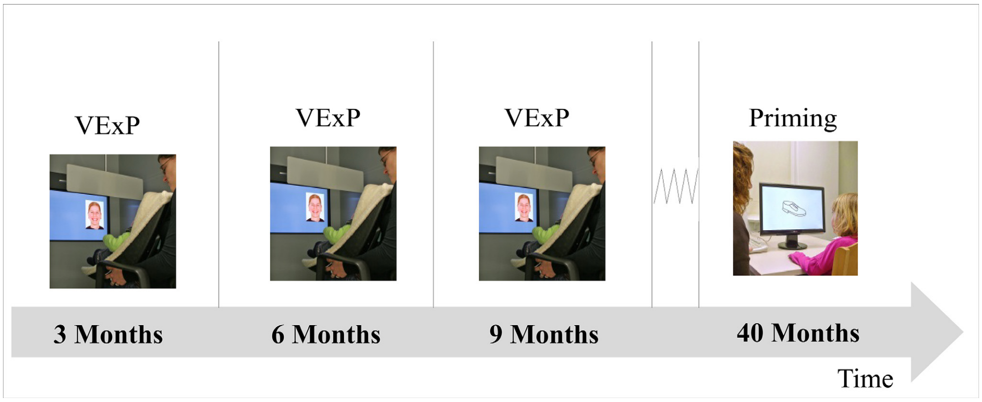

Figure 1. Memory tasks and memory material at the four measurement occasions. VExP = visual expectation paradigm. [Color figure can be viewed at wileyonlinelibrary.com]

A more detailed description of the analysis is provided by Teubert et al. (2012) and Fassbender et al. (2012). It is expected that infants learn the sequence of the stimulus presentation and accelerate the direction of their gaze to the following stimulus up to anticipatory reactions in which the infants look at the position of the following stimuli prior to its appearance (Haith, Hazan, & Goodman, 1988). In the present study, mean reaction times to each stimulus and the percentage of anticipatory reactions and their interrelations were used as indicators of implicit memory.

40 Month (3;4 Years) Measurement

The children passed through a picture fragment completion task as indicator of implicit memory. In this task, the children were seated in front of a computer screen (40 cm × 17 cm) and were shown five target pictures successively. The pictures showed common daily and well-known objects or animals, which the children were asked to look at and name. Each picture was presented for 5 s, and the new picture was shown when the child correctly named the presented picture. Then, an average delay of 9 min was initiated. After this delay, 10 fragmented pictures, 5 targets along with 5 new control pictures, were presented in randomized order, and the children were instructed to tell what was shown on the picture. Thereby, the same picture was presented with increasing amount of information in terms of visible lines with each subsequent fragmentation level containing additional 15% of information until the child recognized the displayed object. The task was presented using Eprime (Psychology Software Tools, Sharpsburg, PA, USA) software. For each picture, the level of fragmentation and the time needed to identify the picture were recorded. Implicit memory was indicated by a *priming effect*, which means that target pictures are identified with less information as well as less time than control pictures. Consequently, differences between mean identification levels (mean reaction latencies, respectively) on targets and controls indicate the amount of implicit learning, and were chosen as indicators for the present study.

An overview of the indicators of implicit memory derived from the two paradigms is provided in Table 1. For further analysis, the indicators' metric was adjusted as model estimation problems, like nonconvergence or Heywood cases, can occur due to highly different metrics (Little, 2013; Muthén & Muthén, 1998–2012). Additionally, indicators were recoded so that high values are indicating better performance.

Data Analytic Plan

We estimated two structural equation models, illustrated in Figure 2, to answer the questions on development and stability in implicit memory performance.

Both models match in their measurement model. In detail, in both models, implicit memory performance at the ages 3, 6, and 9 months was indicated by mean reaction times and the percentage of anticipations. As the mean reaction time children show during the experiment is influenced by both their implicit memory (in that they accelerate their reaction to the presented stimuli as they learn the sequence) and the children's general processing

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Table 1
Means and Standard Deviations for the Indicators of Implicit Memory Derived From the Three Different Paradigms

Age (months)	Paradigm	Indicator	*N*	*M*	*SD*
3	VExP	Mean reaction time (mrt)	124	8.83	5.37
		Percentage of anticipations (pa)	127	39.36	24.05
6	VExP	Mean reaction time (mrt)	134	5.55	5.04
		Percentage of anticipations (pa)	134	47.04	22.82
9	VExP	Mean reaction time (mrt)	133	5.03	3.81
		Percentage of anticipations (pa)	134	50.47	18.54
40	Priming	Difference in identification scores (id)	127	0.48	0.60
		Difference in reaction latencies (rl)	122	992.29	2,606.48

Note. Raw data are presented. VExP = visual expectation paradigm.

speed, these two aspects are separated and controlled for statistically. The common variability in mean reaction time and percentage of anticipations is allocated to the underlying construct of implicit memory. Common variability in mean reaction time at the different measurement occasions, however, is likely to be caused by the general processing speed of the children under study and controlled for by correlated error variances. At 40 months, the difference between identification scores as well as reaction latencies on targets and controls in the priming task was used in order to indicate implicit memory. To address the issue of measurement invariance, factor loadings of the repeatedly assessed indicators were equated in both models.

To analyze development, a latent change model (Steyer, Eid, & Schwenkmezger, 1997) was defined ("development model" in the following). In this sort of models, also called true change models (Steyer et al., 1997), latent factors are defined to represent either the underlying ability that affects manifest performance in the presented paradigms at one measurement occasion (called "implicit state" in the following) or the change in the latent factor between two subsequent measurement occasions (called "implicit change" in the following). The "implicit state" factors are indicated by the above-mentioned indicators. In a perfect regression of the following "implicit state" factors by the preceding "implicit state" and "implicit change" factors, mean values of the "implicit change" factors can be derived and interpreted in terms of "true changes" of the latent construct that was measured (Geiser, 2011). That is, conclusions about development of implicit memory in this model are derived from the mean values of the "implicit change" factor. As the "implicit change" factors represent the difference between two subsequent measurement occasions, a mean value that does not significantly differ from zero indicates no development of the underlying ability in terms of mean changes. Variances in the "implicit change" factors indicate if there are individual differences in the degree of change over time. However, parameters of the structural or measurement model are of minor interest for interpreting the results as they are mostly restricted due to the estimation method (Geiser, 2011).

To analyze stability, the correlation between the "implicit state" factors was assessed in a different model ("stability model" in the following). This was necessary as correlations were fixed to zero in the "development model" for estimation purpose due to the perfect regression.

Model estimation was performed in M*plus* (Muthén & Muthén, 1998–2012) using the full information maximum likelihood (FIML) estimation. Goodness of fit for each model was judged using the goodness-of-fit measures chi-square in relation to its degrees of freedom ($\chi^2 < 2\ df$ for good fit, $\chi^2 < 3\ df$ for acceptable fit), the root mean square error of approximation (RMSEA; ≤ .05 for good fit, ≤ .08 for acceptable fit), the comparative fit index (CFI; ≥ .97 for good fit, ≥ .95 for acceptable fit), and the standardized root mean square residual (SRMR; ≤ .05 for good fit, ≤ .10 for acceptable fit). These goodness-of-fit borders are consistent with the suggestions of Schermelleh-Engel, Moosbrugger, and Müller (2003).

Results

Preliminary Analyses

Gender and Site Effects

In order to test whether memory performance varies as a function of gender or laboratory site, multivariate analyses of variance using Pillai's trace with all variables as dependent variables were conducted. Neither a gender nor a site effect was

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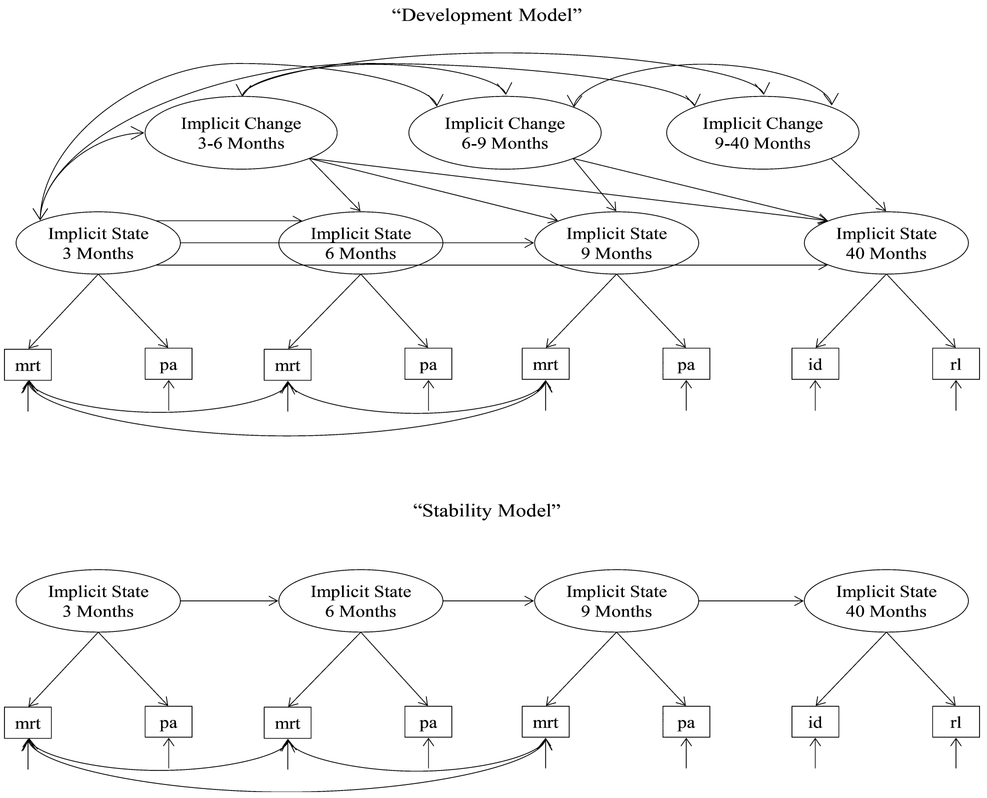

Figure 2. Models of longitudinal development and stability. Note that the two models do not differ with respect to the measurement model. VExP = visual expectation paradigm; mrt = mean reaction time in VExP; pa = percentage of anticipations in VExP; id = difference score of identification levels in priming; rl = difference score of reaction latencies in priming.

evident, $F_{\text{gender}}(8, 102) = 0.379$, $p = .93$ and $F_{\text{site}}(16, 204) = 1.346$, $p = .17$, respectively. The data were therefore collapsed along these dimensions for further analysis.

Distribution

We checked normal distribution of each variable using the Kolmogoroff–Smirnov test as well as a graphical check in P-P plot as recommended for large samples (Field, 2013). Using Bonferroni-adjusted significance levels of $\alpha = .05/8 = .00625$ (as eight variables are tested), all variables were significantly normally distributed. Hence, the likelihood of multivariate normal distribution can be assumed to be sufficient (Field, 2013; Little, 2013).

Missing Values

Participants who completely missed at least one measurement occasion were excluded from all analyses (see Participants section). To check whether the remaining missing values (due to technical problems or classification of outliers; in total 3.3%) were missing completely at random (MCAR) according to the classification proposed by Rubin (1976), we compared children having missing values in one indicator to children without missing values on that indicator concerning their multivariate performance on all other indicators as supposed by Lüdtke, Robitzsch, Trautwein, and Köller (2007). Multivariate analyses of variance conducted to test these comparisons yielded that all missing values were MCAR, $F_{\text{A3\_mrt}}(7, 106) = 1.012$, $p = .43$; $F_{\text{A9\_mrt}}(7, 104) = 1.772$, $p = .10$; $F_{\text{P40\_id}}(6, 116) = 1.430$, $p = .21$; $F_{\text{P40\_rl}}(7, 108) = 0.617$, $p = .74$.

To handle MCAR values, direct maximum likelihood estimation using the FIML algorithm implemented in M*plus* (Muthén & Muthén, 1998–2012) was applied, which estimates the model on the basis of the available data without implementing or replacing missing values. Although FIML holds the assumption of multivariate normal distribution, simulation studies showed that even when assumptions are violated and up to 75% of the data are missing, FIML performs better than traditional methods in handling missing values (Enders, 2001; Newman, 2003).

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Model Estimation

The manifest intercorrelations among the measures and measurement occasions are shown in Table 2. Note that the modest cross-age correlations are not unusual for longitudinal measures assessed this early in life due to reliability problems and "noise" in the infant data (see Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004; Horowitz, 1990).

The estimated models (see Data Analytic Plan section) both fit the data very well with all goodness-of-fit statistics being within the borders of excellent fit as suggested by Schermelleh-Engel et al. (2003).

For the "development model," goodness-of-fit statistics were $\chi^2(15) = 10.241$, $p = .80$; RMSEA = .000 [CI .000–.053], CFI = 1.000, and SRMR = 0.031.

Goodness-of-fit statistics for the "stability model" were also good, $\chi^2(17) = 14.170$, $p = .66$; RMSEA = .000 [CI .000–.065], CFI = 1.000, and SRMR = 0.047. The models are displayed in Figure 3 and 4 with all paths and goodness-of-fit indices. Standardized factor loadings range from $\lambda = .249$ to $\lambda = .914$. All factor loadings except for the "id" indicator of the priming paradigm reached at least a 10% level of significance. The factor loadings for both models were comparable (indicated by overlapping confidence intervals), indicating that for both models the "implicit state" factors represent the same construct.

Analyzing Development and Stability

The mean values of the "implicit change" factors in the "development model" (depicted in Figure 3) indicate that implicit memory is age invariant from 3 months of life on, as all means do not differ significantly from zero, $M_{3to6} = -0.029$, $p = .17$; $M_{6to9} = 0.025$, $p = .25$; $M_{9to40} = -0.047$, $p = .89$. In detail, this means that between 3 and 6, 6 and 9, and 9 and 40 months no significant change in mean implicit memory performance takes places. Variances of the "implicit change" factors, however, indicate that there are significant differences between the children in their degree of change over time, $Var_{3to6} = 0.045$, $Var_{6to9} = 0.045$, $Var_{9to40} = 0.020$, all $p < .01$. That is, there is variability in development.

Whether there is also stability is answered by results of the "stability model" displayed in Figure 4. Latent paths between the "implicit state" factors indicate that implicit memory shows moderate but marginal significant stability only from 9 months, $\beta_{9to40} = .534$, $p < .10$. From 3 to 6 months and 6 to 9 months, however, no stability was found, $\gamma_{3to6} = -.020$, $\beta_{6to9} = .173$, $p > .10$ for both paths.

Discussion

The present study was motivated by the lack of longitudinal studies investigating implicit memory development. Using a multitask approach and structural equation modeling, we focused on two questions regarding average performance levels and intraindividual stability of implicit memory performance across the first 4 years of life.

First, concerning the question about development, we found that children's average performance levels did not increase with age, suggesting

Table 2
Manifest Correlations (Pearson) Between Measures for All Four Measurement Occasions

Age (months)		3		6		9		40	
Indicator		mrt	pa	mrt	pa	mrt	pa	id	rl
3	mrt	—	.761**	−.018	−.014	−.049	−.037	.053	−.117
	pa		—	.010	−.023	.090	.053	.043	−.065
6	mrt			—	.764**	.107	$.152^+$	−.027	.003
	pa				—	.118	.173*	−.006	.048
9	mrt					—	.699**	.051	.086
	pa						—	.112	.121
40	id							—	.262**
	rl								—

Note. Variables are scaled and recoded. Missing values are not imputed. VExP = visual expectation paradigm; mrt = mean reaction time in VExP; pa = percentage of anticipations in VExP; id = difference score of identification levels in priming; rl = difference score of reaction latencies in priming. $^+p < .10$, $^*p < .05$, $^{**}p < .01$.

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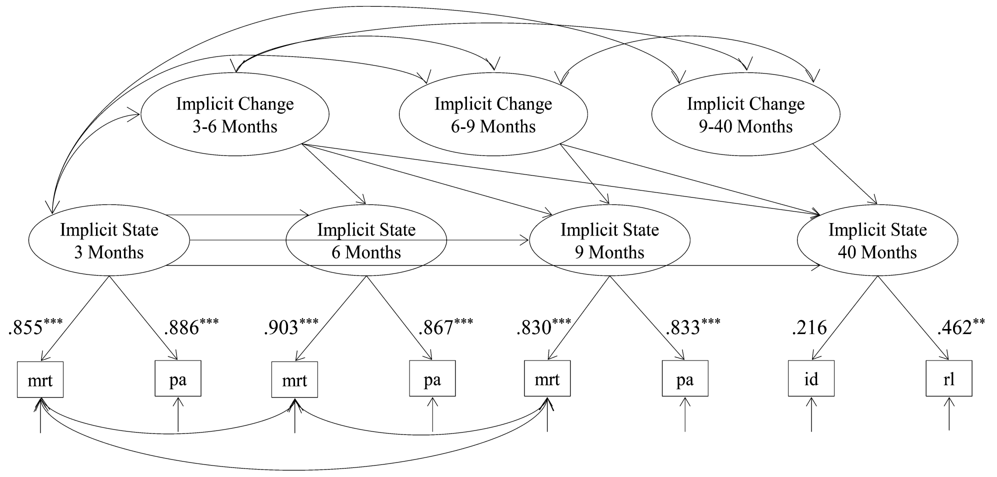
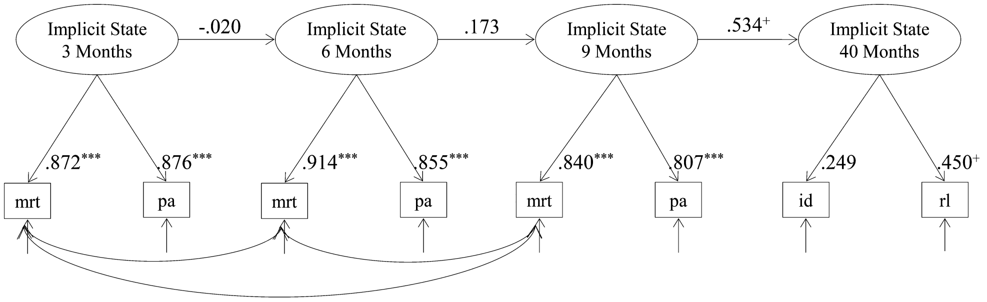


$\chi^2 = 10.241$ df = 15 – RMSEA = .000 [CI: .000-.053] – CFI = 1.000 – SRMR = .031

Figure 3. "Development model" of implicit memory development with factor loadings and goodness-of-fit indices. Paths between the latent factors are restricted according to the requirements of estimating a latent change model and are hence not reported in the figure. VExP = visual expectation paradigm; mrt = mean reaction time in VExP; pa = percentage of anticipations in VExP; id = difference score of identification levels in priming; rl = difference score of reaction latencies in priming.
Note. $^{**}p < .01$, $^{***}p < .001$.



$\chi^2 = 14.170$ df = 17 – RMSEA = .000 [CI: .000-.065] – CFI = 1.000 – SRMR = .047

Figure 4. "Stability model" of implicit memory development with all paths and goodness-of-fit indices. VExP = visual expectation paradigm; mrt = mean reaction time in VExP; pa = percentage of anticipations in VExP; id = difference score of identification levels in priming; rl = difference score of reaction latencies in priming; RMSEA = root mean square error of approximation; CFI = comparative fit index; SRMR = standardized root mean square residual.
Note. $+p < .10$, $^{***}p < .001$.

that implicit memory is developmentally invariant and stable. This finding is consistent with theoretical assumptions on the characteristics of implicit memory (e.g., Lloyd & Newcombe, 2009; Schneider & Pressley, 2013). Building on early developing brain structures, it is argued that implicit memory performance does not improve significantly over time because the underlying biological structures do not develop with age either.

Cross-sectional studies, however, yield contradicting results (e.g., Billingsley et al., 2002; Parkin & Streete, 1988; Reznick et al., 2000). Although studies on priming mostly agree that priming performance as an indicator of implicit memory does not differ according to the age of the participants, studies on the VExP indicate that there is some developmental difference with older infants performing better than younger infants. In these studies, however, manifest

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correlations were used to draw inferences about the development of an underlying construct. Hence, variability due to other sources like the assessment method was not controlled for. Consequently, age differences found in cross-sectional studies might also be due to the development of measurement-specific behaviors. For instance, the finding that in the VExP, age-related improvements are only found for the 1st months of life supports this idea (see Reznick et al., 2000). What might account for these age-related improvements in implicit memory performance might rather be attributed to occulomotoric improvements or maintenance of attention than to changes in the ability to build implicit memory.

Second, with regard to the question of the stability of interindividual differences, we found that implicit memory shows moderate stability from 9 months onward. From that early age onward, high-performing children tend to remain high performers up to at least 3 years of age. However, there was no stability found between 3 and 6 months and 6 and 9 months of life.

Although the relation between the infants' performance at 9 months and 3 years is significantly different from zero, differences in performance at the earlier age can only explain some variability at the following age. This indicates that despite remarkable stability, there is also discontinuity. As Sternberg and Okagaki (1989) pointed out, there is no either–or in the question about continuity or discontinuity. They argued that judging whether a growth curve or the results of correlational analyses show stability is subjective and assumed that development is both, and that the truth lies in between the two extreme viewpoints of continuity and discontinuity. The development of implicit memory seems to follow this rule: To some extent, there is stability with high performers at one age remaining high performers when they grow older. Yet there is, at least to some extent, also discontinuity in that only parts of later performance can be explained by earlier performance.

The present study is unique in several aspects. It is one of only few studies that assessed memory development longitudinally using different age-appropriate paradigms over the course of multiple years. Moreover, to our knowledge, it is the first to address the development of implicit memory. In doing so, this research stresses the importance of longitudinal studies as they can shed light on contradicting results from cross-sectional studies. In the present study, we found that using multiple indicators over multiple years yield evidence for developmental invariance of implicit memory, whereas cross-sectional studies suggested contradicting results with specific developmental paths according to the paradigm used (see Billingsley et al., 2002; Parkin & Streete, 1988; Reznick et al., 2000). The two different paradigms chosen here to indicate implicit memory are common in infancy and childhood and hence represent valid indicators of implicit memory research that is aggregate to indicate the underlying ability of building implicit memory.

The present study is, to the knowledge of the authors, the first study that assesses the development of implicit memory longitudinally in early infants with alternating assessment methods. As a consequence, the present study has limitations that need to be addressed in future research. Therefore, the results of the present study not only answer first questions about the development of implicit memory but also pose further questions that need to be addressed in future research.

First, the children of this study were only followed up to 3 years of life, and due to the implementation in a bigger research project, there is a large time gap between the last two measurement occasions (namely 9 and 40 months). Future research should therefore investigate development over a longer period using equidistant measurement points between the measurement occasions, allowing for the definition of a better model of development. At the same time, this large gap can also be interpreted as strengthening the conclusions of this study. Despite the long time between 9 months and 3 years, and the related development of the children in all aspects of human memory and cognition, there was still stability in implicit memory. Despite the manifold developmental milestones reached during this period, implicit memory performance could be predicted by earlier performance.

The present study uses two different assessment methods of implicit memory. However, there are manifold ways to assess implicit memory. In order to investigate overall implicit memory performance independently from the specific characteristics of manifest assessment methods, future research should use various assessment methods to investigate if the conclusions of the present study are as universal as the results suggest.

Along with this multitask structural equation approach, the problem of measurement invariance needs to be addressed. Usually, measurement invariance is required for longitudinal SEM. Measurement invariance is indicated by comparable

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factor loadings of the indicators at different time points. More specifically, the same latent construct at different time points should have the same impact on performance in the manifest indicators at each time point. This requirement holds true if measurement methods remain the same over time—for example, the same item of a repeatedly presented questionnaire should be influenced similarly by the underlying psychological construct at each presentation. Hence, measurement invariance was assumed for the repeatedly assessed VExP. In the case of changing measurement methods, as from 9 months to 3 years in the present study, it seems hard to argue theoretically why implicit memory should have the same impact on, for example, anticipatory reactions in a VExP as it has for difference in identification between targets and controls in the priming task. Consistent with theoretical considerations, both indicators assess implicit memory (e.g., Roediger, 2003; Toth, 2000), but why should they be comparable in the magnitude of their relation to implicit memory? As this question is hard to approve, measurement invariance was not considered for the last two measurement occasions. However, as both paradigms have repeatedly been shown to assess implicit memory, their validity was assumed to hold true.

A further limitation refers to a general problem that developmental psychology in early infancy has to deal with, that is, the reliability of the assessment methods used. Often, reliability of the methods is hard to assess (due to the developing participants), and if assessed, reliability is often low. This is a common phenomenon in early infancy research and hence also a limitation of the present study. As we used SEM, however, we partly overcame this problem. Results obtained from SEM are based on correlations and as only true values can correlate, the results already control for low reliability. Nevertheless, the higher the reliability, the easier relations between latent structures can be detected by the estimation algorithm. Hence, future research should be also dedicated to assess and enhance reliability of early memory measures.

As this is the first study investigating longitudinal development of implicit memory using SEM, the defined models cannot meet the requirements of being confirmatory models. However, they are also not exploratory in nature, as they are derived from theoretical rationales and conceptualized before estimation. Still, future studies replicating the results of this study are needed to underline its conclusions.

Conclusion

In the present study, we investigated the longitudinal development of implicit memory and found that this memory structure does not show age-related improvements from 3 months onward with older children performing as well as younger children, which is consistent with theoretical rationales and different cross-sectional studies especially on priming performance. What can be affected by age, and therefore leading to age differences in manifest measures of implicit memory performance, are the behaviors that are used to indicate implicit memory. If these behaviors are also under development, assessment of the underlying memory ability can be confounded.

Second, we found that interindividual differences in implicit memory performance are stable from 9 months of life onwards. However, although stability coefficients are significant, they are small, accounting only for some parts of the performance's variability at the subsequent ages. This is consistent with the postulation by Sternberg and Okagaki (1989) that development contains both continuity and discontinuity. To some part, performance in implicit memory tasks is predictable by prior performance; however, there is still discontinuity in that low performers can catch up but also vice versa. This lack of stability might be at least partially attributed to environmental factors and the children's general development especially during the 1st months of life, leading to less intraindividual variability when growing older.

In conclusion, implicit memory seems to be age invariant with partial stability. More specifically, while the average performance remains comparable across time, high performers tend to be high performers at any point in time.

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