**Exploring Factors Underlying Children's Acquisition and Retrieval of Sound-Symbol
Association Skills**

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Abstract

Letter knowledge is considered an important cognitive foundation for learning to read. The underlying mechanisms of the association between letter knowledge and reading skills are, however, not fully understood. Acquiring letter knowledge depends on the ability to learn and to retrieve sound-symbol pairings. In the present study, this process was explored by setting preschool children's ($N = 242$, mean age = 5.57 years) performance in the acquisition and in the retrieval of a paired associates learning task (PAL) in relation to their letter knowledge as well as to their performance in tasks assessing precursors of reading skills (e.g. phonological awareness, rapid automatized naming, the phonological short-term memory, backward recall, and response inhibition). Multiple regression analyses revealed that performance in the acquisition of the PAL task was significantly associated with phonological awareness and backward recall, whereas performance in the retrieval of the PAL task was significantly associated with rapid automatized naming, phonological awareness, and backward recall. Moreover, PAL proved to be mediating the relation between reading precursors and letter knowledge. Together, these findings indicate that the acquisition of letter knowledge may depend on a visual–verbal associative learning mechanism and that different factors contribute to the acquisition and to the retrieval of such visual–verbal associations.

Keywords: visual–verbal associative learning, phonological awareness, letter knowledge, rapid automatized naming, working memory

Introduction

Learning to read is assumed to depend on phonological representations and a unique crossmodal associative learning process of mapping orthographic and phonological units. The process of mapping is critical for learning letter-sound correspondences at the level of single letters, letter groups, and whole words when acquiring a word recognition system (Hulme & Snowling, 2013). Basically, paired associate learning (PAL) tasks, which require (1) pairing of a stimulus and response item in memory and (2) retrieval of these pairings from memory, are thought to tap this associative learning mechanism. Evidence indeed suggests that visual-verbal PAL (i.e., pairing a visually presented symbol with a verbal output) shares a robust and specific relationship with reading abilities (Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Litt, de Jong, van Bergen, & Nation, 2013; Litt & Nation, 2014). Differences in PAL abilities have been demonstrated between children with and without dyslexia (Messbauer & de Jong, 2003; Wimmer, Mayringer, & Landerl, 1998) as well as in studies predicting reading skills with PAL (e.g. Georgiou, Liu, & Xu, 2017; Hulme et al., 2007; Lervåg, Bråten, & Hulme, 2009; Poulsen & Elbro, 2018).

Although significant work has been carried out to clarify the relationships between PAL and reading, only few studies examined the factors underlying sound-symbol association skills (e.g. de Jong, 2007; Windfuhr & Snowling, 2001). More specifically, to our knowledge, no study exists examining possible differences in factors underlying the acquisition and retrieval of new sound-symbol pairs. The present concurrent study, therefore, investigates the relationships between the acquisition and retrieval of sound-symbol pairs and other cognitive skills associated with the acquisition of reading skills in a sample of pre-kindergarten children.

PAL can be seen as a basic learning mechanism that requires the storage and retrieval of arbitrary associations between stimulus (i.e., input) items and response (i.e., output) items

in memory. These pairings can be unimodal (e.g., visual–visual, verbal–verbal) or crossmodal (e.g., visual–verbal, verbal–visual). In the context of reading, crossmodal PAL, defined as any association requiring a connection between a visual stimulus and a verbal stimulus, is in the focus of interest (Lervåg et al., 2009; Litt et al., 2013; Warmington & Hulme, 2012; Windfuhr & Snowling, 2001). The association and retrieval of letter names and sounds or learning of sight vocabulary, that is, association of printed words with their pronunciations, are excellent examples of crossmodal PAL. This may be especially true for irregular sight words in deep orthographies such as English (Hulme et al., 2007; Windfuhr & Snowling, 2001). Finally, reading can also be seen as a form of crossmodal visual–verbal PAL, particularly during the early stages of development (Litt et al., 2013).

The empirical implementation of the visual–verbal PAL paradigm has a similar format. The visual stimuli, which can be abstract symbols (e.g. a dot; Horbach et al., 2015), photographs (e.g. of children; Mayringer & Wimmer, 2000), drawings (e.g. cartoon animals; Poulsen & Elbro, 2018), and unfamiliar letters (e.g. Greek, Hebrew, and Arabic; Lervåg et al., 2009) or even letters of extinct languages (e.g. Akkadian; Litt et al., 2013) are presented together with the verbal stimuli, which are usually names, nonword names or syllables. Thus, differences in the complexity of the stimulus material are found, which is mainly due to the adaptation of the tasks to the respective age range of the participants. Irrespective of the exact stimuli, performance on any PAL paradigm depends on successful learning of three distinct components, i.e. the visual stimulus, the verbal stimulus, and the association between these two items. Individual performance differences may thus stem from processes operating at any of these three levels (Litt et al., 2013). Moreover, individuals may differ with regard to their ability to retrieve learned associations from memory. Accordingly, the question arises which individual abilities are responsible for individual differences in visual–verbal PAL tasks.

Since reading can also be classified as a form of crossmodal visual–verbal PAL, it is reasonable to assume that skills which are of importance for reading acquisition may also be crucial for PAL performance. There is some empirical evidence supporting this suggestion. For instance, de Jong et al. (2000) asked children to associate nonnames with cuddly toys. They found that measures of phonological awareness, letter knowledge, and phonological short-term memory (nonword repetition) were related to performance in the PAL task. Additionally, the findings implicate a direct role of phonological awareness in the development of visual–verbal PAL ability: training in phonological awareness improved visual–verbal PAL performance in kindergartners (de Jong et al., 2000). Correspondingly, Windfuhr and Snowling (2001) found that the performance of English school children on a phonological awareness test was a strong predictor of their ability to map abstract visual shapes with spoken nonwords, whereas their phonological memory explained no further variance in PAL. Similarly, the results of de Jong (2007) show that individual differences in phonological awareness strongly affect letter–sound learning even after current letter knowledge was controlled. In the study of Lervåg and colleagues (2009), PAL, measured by three tests in which kindergarten children learned to pair three nonword names with three pictures, was associated with the phonological skills of phonological awareness, phonological working memory, letter knowledge, and RAN, and particularly with verbal abilities. Less strong correlations are reported by Litt and colleagues (2013), who requested school-aged children to map abstract symbols of the extinct language Akkadian with nonwords. The performance in this PAL task was only moderately related with phonological awareness, whereas no significant correlation was found with RAN (see also Georgiou et al., 2017, Poulsen & Elbro, 2018, and Poulsen, Juul, & Elbro, 2015).

Differences in stimulus type may modulate the relationships between PAL performance and other reading precursors. For example, complex material may require more phonological

working memory capacity; clearly distinguishable nonwords may be less stressful for phonological awareness; and regular words, for which lexical entries exist, may require little phonological skills when mapping to new symbols is requested (cf. de Jong et al., 2000). Inconsistent results concerning the relationship of PAL and phonological skills may also be due to the age of the participants. For instance, higher correlations between phonological skills and PAL are found in studies with children prior to formal reading instruction than in studies with school-aged children. Another issue that might have led to differences in the associations with other variables across studies is measurement error and the use of observed vs. latent variables. Except for the study by Lervåg and colleagues (2009, partly also Litt et al., 2013), PAL performance and most of the other reading precursor skills were adopted as observed variables (de Jong et al., 2000; Georgiou et al., 2017; Hulme et al., 2007; Mourgues et al., 2016; Poulsen & Elbro, 2018; Warmington & Hulme, 2012; Windfuhr & Snowling, 2001).

However, phonological and other reading precursor skills may also contribute differentially to various phases of PAL tasks, that is, a phase with corrective feedback (learning phase) and a phase without corrective feedback (retrieval phase). For example, RAN as an indicator of efficient retrieval of phonological codes from long-term memory proved to be less important in learning of phonological codes (e.g. de Jong, 2007). In a retrieval phase in which no feedback is provided the efficient retrieval of phonological codes from long-term memory may be more important. Moreover, research shows that central executive skills, e.g. updating and manipulating captured by backward recall, are of particular importance for acquiring new knowledge, whereas they play a minor role when knowledge is automatically accessed and well-learned (Baddeley, 1996). Accordingly, in the retrieval phase of the PAL paradigm, the more passive storage mechanisms of the phonological short-term memory should be sufficient and the central executive skills of updating and manipulating are

less relevant. However, it could also be argued that an adaptive cognitive control system for selecting relevant information is especially necessary in the retrieval phase. For example, when confronted with a particular symbol in the PAL paradigm, irrelevant information has to be discarded and the correct sound has to be named. Thus, it can be assumed that poor performance in the retrieval phase of the PAL paradigm may also be attributed to inefficient inhibitory mechanisms. So far, no data are available regarding this research question because existing studies do not distinguish between a learning and a retrieval phase. Apart from de Jong and colleagues (2000), researchers have provided corrective feedback when investigating PAL abilities (de Jong, 2007; Georgiou et al., 2017; Hulme et al., 2007; Lervåg et al., 2009; Mourgues et al., 2016; Warmington & Hulme, 2012; Windfuhr & Snowling, 2001). Alternatively, the correct answer was presented regardless of the accuracy of the response (Litt et al., 2013; 2014). Since backward recall and inhibition abilities have not been put into relation to PAL abilities, it is still not clear whether these abilities are of importance for the acquisition and/or retrieval of new sound-symbol pairs.

When considering the relation between reading precursor skills and PAL tasks, the relation between letter knowledge and PAL deserves attention. This can be viewed from two perspectives: On the one hand, PAL is required to establish letter knowledge. On the other hand, pronounced letter knowledge may facilitate learning new sound-symbol pairs, since knowledge of the alphabetic principle is available, that is, the understanding that the letters in printed words map onto the phonemes in spoken words (Byrne, 1998). However, because variance in letter knowledge is rarely found in studies with children after the start of formal reading instruction, only a few PAL studies have also assessed letter knowledge. For example, de Jong (2007) found low correlations between sound (re-)learning and letter knowledge ($r = .24$ and $.24$), de Jong and colleagues (2000) a moderate correlation ($r = .34$) between the ability to associate nonnames with cuddly toys and letter knowledge, whereas

Lervåg and colleagues (2009) reported a rather high correlation ($r = .57$). Thus, it is not sufficiently clear how much variance PAL abilities and letter knowledge share with each other and whether the association with letter knowledge is comparable for both performance in the learning and performance in the retrieval phase of the PAL paradigm.

Although letter knowledge may predict PAL abilities, it is more reasonable to assume that PAL predicts letter knowledge since PAL tasks simulate the building of lexical entries for sound-symbol pairs in long-term memory. That is, paired associate learning may be considered as the process of acquisition, whereas letter knowledge should be considered as the result of this process. Thus, PAL abilities may act as a mediator when considering the interplay of different reading precursor skills and letter knowledge. According to de Jong and Olson (2004), letter learning involves a) the formation of a temporary phonological representation of a letter name or sound in phonological memory and b) the association of this representation with the form of the respective letter and its storage in long-term memory. In accordance with the finding that phonological short-term memory is involved in the acquisition of novel phonological representations (Baddeley et al., 1998; de Jong & Olson, 2004), the simultaneous acquisition of several sound-symbol pairs may capture more phonological short-term memory capacity compared to letter knowledge tasks where lexical entries are built over a longer period of time. Phonological short-term memory may thus influence letter knowledge more indirectly via PAL abilities. Moreover, the association of temporary phonological representations with the form of letters and its storage in long-term memory is considered as pure association learning (de Jong & Olson, 2004). As suggested by de Jong and Olson (2004), RAN reflects association learning and therefore contributes to the acquisition of letter knowledge. However, while RAN should rather be considered as the product of associative learning processes, performance in a PAL task can be taken as an indicator of associative learning processes per se. Accordingly, RAN may also influence

letter knowledge indirectly via PAL abilities. Since only a few studies of PAL have assessed letter knowledge, it is still an issue whether PAL abilities mediate the relation between the different phonological and other reading precursor skills on the one hand and letter knowledge on the other hand.

Present Study

The aim of the present study was to explore which cognitive factors underlie sound-symbol association skills. In detail, we wanted to find out (1) whether the same cognitive predictors are of importance for the learning and retrieval of new sound-symbol associations, (2) whether the association with letter knowledge differs for the learning and the retrieval phase of the PAL paradigm, and (3) whether PAL performance mediates the association between specific reading precursor skills and letter knowledge. In addition, we used latent variables to avoid the potential confounding of measurement errors that might have happened in several of the earlier studies using observed variables. This is particularly important since the reliability of PAL tasks, indicated by Cronbach's alpha, can be called into question (Poulsen et al., 2015).

Based on findings from previous studies (Mourgues et al., 2016; Windfuhr & Snowling, 2001) and the notion that awareness of the phonological structure of spoken words facilitates the creation of new phonological representations (de Jong, 2007), we hypothesized phonological awareness and phonological memory to be of particular importance for the learning phase; and RAN, phonological memory and response inhibition to be of importance for the retrieval phase. Additionally, we expected PAL abilities to mediate the relation between the different reading precursor skills and letter knowledge.

Method

Sample and Procedure

Data collection was carried out in the context of the project TRIO, which examines the effects of language education in kindergartens in the area of Frankfurt am Main, Germany. The study was commissioned by the German Federal Ministry of Education and Research (BMBF; GRANT number: blind for review). Parents of participating children provided written informed consent prior to participation. In total, $N = 247$ children took part (all are non-readers). The mean age of the sample was $M = 5;7$ years ($SD = 0;4$); the percentage of girls was 46.6% ($n = 115$) and of boys 53.4% ($n = 132$). The sample was composed of $n = 131$ monolingual German, $n = 47$ simultaneous bilingual, and $n = 68$ successively bilingual children (language information was missing for one child). Data collection was distributed over three sessions, each lasting up to 45 min. Since five children refused to participate in nearly all tests, our analyses are based on data from 242 children.

Instruments

PAL. PAL was measured by using a computer-based paradigm (see Horbach, Scharke, Cröll, Heim, & Günther, 2015) in which the child learns to pair three syllables with three symbols (learning phase) and to retrieve the newly learned associations (retrieval phase). The task started with introducing the three symbols: a triangle “▲”, a square “■”, and a circle “●”. Each symbol was presented separately in the middle of the screen (14.1-inch). The child was told that the triangle was called /pa/, the square was called /ma/, and the circle was called /ta/. The child was then instructed to name the symbols. In the learning phase, each symbol was presented ten times in an alternating but fixed order. If the children responded correctly, they received positive feedback (e.g., “Yes, this was /pa/”) and the next trial appeared. If the children responded incorrectly, the experimenter provided corrective feedback (e.g., “No, this was /pa/”). A score of 1 was given each time the child remembered a name correctly (maximum score = 30). The retrieval phase was reached independently from the number of correctly solved trials in the learning phase.

The retrieval phase required the children to apply the newly learned sound-symbol correspondences. During this phase, 12 trials were presented in the same way as in the learning phase except that feedback was no longer given (see Figure 1). The retrieval phase started immediately after the learning phase and was discontinued after seven errors. The internal consistency of both the learning and retrieval phase was Kuder-Richardson-20 Test = .90.

Rapid automatized naming (RAN). The RAN task consisted of two nonalphanumeric subtests and assessed naming speed for colors (green, yellow, red, blue, and black), and objects (tree, dog, ball, fish, ice; items adapted from Preßler, Könen, Hasselhorn, & Krajewski, 2013). In each subtest, items are arranged randomly in two rows of 10 on a white paper (A4). The child's task is to name all items as quickly as possible while making as few errors as possible. Naming time (in seconds) served as the dependent variable, that is, lower scores indicated higher performance. Each subtest was preceded by a short practice trial (i.e., one row à five items) to familiarize the child with the material.

Phonological Short-Term Memory and Central Executive. To assess the phonological short-term memory and the central executive skills of updating and manipulating, four subtests from the computerized and adaptive *Arbeitsgedächtnistestbatterie für Kinder von 5 bis 12 Jahren* (AGTB 5–12; Hasselhorn et al., 2012) were administered. The AGTB 5–12 is a German computerized test battery, which assesses working memory functioning according to Baddeley's (1986) multicomponent model, and shows good construct validity (Michalczyk, Malstädt, Worgt, Könen, & Hasselhorn, 2013) and criterion validity with respect to reading and spelling tests (Hasselhorn et al., 2012). Both phonological short-term memory and the central executive skills of updating and manipulating were assessed with verbal span procedures, they differed only with respect to the order of recall: forward recall (phonological short-term memory) and backward recall (updating and

manipulating). That is, in the phonological short-term memory part the child's task is to repeat the sequence orally in the same serial order as presented, in the backward recall part the sequence has to be reproduced immediately in the reverse order. Specifically, we assessed memory spans for digits and words respectively. In the digit span task, increasing sequences of different digits are presented audibly at the rate of one digit every 1.5 s. No digit appears twice in a particular sequence. Similarly, the word span task requires the serial repetition of high-frequency words, which are presented audibly at the rate of one word every 1.5 s. Word sequences are constructed out of nine phonologically and semantically dissimilar German monosyllabic nouns. Each word appears only once within a particular sequence.

All four tasks are span measures with an adaptive testing procedure. They consist of 10 trials, divided into five testing blocks with two trials each. The first testing block starts with a two-item sequence, and sequence length is adjusted after each response: If the child recalls the presented trial correctly, the sequence length of the subsequent trial increases by one item. If, however, the child's recall is incorrect, the sequence length of the next trial decreases by one item (or remains at the two-item sequence, respectively). In the remaining four testing blocks, the sequence length is adjusted more conservatively as follows: If the child recalls both trials of the testing block correctly, the span length of the next block increases by one item. If the recall is incorrect for only one of the two trials, the span length remains the same. If, however, the child recalls both trials incorrectly, the span length decreases by one item. The calculation of the span score is based on the mean performance of all testing blocks (the last eight trials): For each correct response, the child receives a score that corresponds to the span length. For instance, if the child correctly recalls a four-item sequence, he or she receives four points. A false response is assigned the span length decreased by one item (e.g., incorrect repetition of a four-item sequence results in three points only).

Phonological Awareness. Phoneme deletion was used to assess phonological awareness. The task comprising drawings of seven familiar words (e.g., house, fork) was adapted from the *Comprehensive Test of Phonological Processing battery* (Wagner, Torgesen, & Rashotte, 1999). At the beginning of each trial, the children were asked to name the drawing to ensure that they were familiar with the word. Then, the task required the children to first name the initial phoneme of the word (phoneme detection, e.g., “Wal” → /w/) and, next, to say the word without saying the initial phoneme (rest word, e.g. “Wal” without /w/ becomes “al”). The internal consistency (KR₂₀) of the phoneme detection task was .87, respectively .80 for the rest word task.

Response inhibition. A computerized go/ no-go task, based on the paradigm of Berlin and Bohlin (2002), was used to test the child’s ability to inhibit a prepotent response. Children were shown a red square, a red triangle, a blue square, and a blue triangle, one at a time on a computer screen (Stimulus presentation 800 ms, response interval 1700 ms). Altogether the task included four blocks with 30 trials, with a ‘go-rate’ of 70%. In block 1 and 3, the children were instructed to press a key (‘go’) as soon as possible whenever one of the blue shapes appeared on the screen, but to press no key (‘no-go’) when the red shapes appeared. The same stimuli were used for block 2 and 4, but the children were then instructed to press a key every time they saw a square and to inhibit their response every time they saw a triangle, irrespective of color. The score derived from the task was the sensitivity parameter A’, a nonparametric measure according to signal detection theory, which takes the hit and false-alarm rate into account, and which typically ranges from .5, indicating that signals cannot be distinguished from noise, to 1, which corresponds to perfect performance (Stanislaw & Todorov, 1999).

Letter knowledge. This task comprised the twelve most common German letters (E N I R A T S H D U L C), each of which was presented separately on a white sheet of paper. The

children's task was to provide the corresponding letter name. In German, the names of the vowels correspond to the sounds. Most consonant names contain corresponding letter sounds, either as initial phoneme, that is following the acrophonic principle (H, D, T) or as final phoneme (R, L, S, N). Only the consonant name of C is inconsistently related to letter sounds. One point was given for each correctly pronounced letter (both letter names and letter sounds were possible answers).

Procedure

Testing was done in three sessions (distributed over three days). Children were tested individually at child daycare center in a quiet room by trained university students. In the first session, the task for RAN was administered (together with some games for the purpose of getting to know each other and in order to avoid a test atmosphere). In the second session backward recall, PAL, and letter knowledge were administered and in the third session response inhibition and phonological awareness were administered.

Statistical Analyses

To avoid measurement error, latent variables were used. First, a regression model with latent variables was evaluated with PAL learning and retrieval phase as separate but correlated dependent variables. In these structural equation models (SEM), regression paths were evaluated from every predictor to the dependent variable while correlations between the predictors were permitted. Second, we applied confirmatory factor analysis (CFA) to compare the latent correlations between the PAL learning and retrieval phase with letter knowledge. To check whether the correlation between letter knowledge and PAL learning phase is comparable to the correlation between letter knowledge and PAL retrieval phase, the correlations were set to be equal and compared to a free estimating model. In a third step, a SEM was evaluated to explain variance in letter knowledge, the cognitive predictors mediated by PAL.

We used Mplus 8.0 (Muthén & Muthén, 1998-2017) to estimate latent variables models with missing data. To estimate the models, the robust full information maximum likelihood method MLR was used. This estimation method allows data from all individuals to be included regardless of their pattern of missing data (Rubin, 1974). To evaluate the goodness of fit for the CFA and SEM, we used the chi-square test statistic and several commonly recommended descriptive measures of model fit (Hu & Bentler 1998): the standardized root mean squared residual (SRMR) and the root mean square error of approximation (RMSEA) as well as the comparative fit index (CFI) and the Tucker-Lewis Index (TLI). Models were evaluated as fitting well when the baseline fit indices (SRMR and RMSEA) were <0.08 and the incremental fit index (CFI) was 0.95 or larger. To examine differences in correlations and regression weights, we report Wald tests (instead of chi-square-diffest). Preacher and Hayes's (2008) bootstrapping technique (with 1000 resamples) that allowed us to establish confidence intervals (CIs) was used to test possible indirect effects more adequately.

Results

Descriptive statistics and latent correlations for all variables are found in Tables 1 and 2. The mean score for the PAL learning phase, where a maximum score of 30 is possible, was $M = 12.50$ ($SD = 7.29$), for the retrieval phase, with a maximum score of twelve, was $M = 5.70$ ($SD = 3.70$). Out of the twelve letters, the participants named $M = 4.98$ ($SD = 4.04$) letters correctly. To obtain indicators of the latent PAL factors, three item parcels were constructed, i.e. the sum of the responses to the different symbols. The factor loadings and residuals were fixed to be equal across parcels. Correlations between the residual variances of the same indicators (e.g. the symbol named "pa") were allowed but fixed to be equal. The correlations were constrained to be equal. The latent correlations of the different variables are based on a CFA, $\chi^2(141) = 231.500$, $p < .05$, CFI = .928, TLI = .940, RMSEA = .051, SRMR = .069.

Explaining Variance in the PAL Learning and Retrieval Phase

To find out whether the same cognitive predictors are of importance for the learning and retrieval of new sound–symbol associations, a SEM with the PAL learning phase and the PAL retrieval phase as separate but correlated dependent variables was carried out. In this model, identification was achieved by fixing the factor loadings of each predictor to the same value and the variance to 1. This was done to test for possible differences (see Kwan & Chan, 2011). Moreover, the residuals of the different indicators of each factor were constrained to be equal (e.g. the residuals of the digit and word-span task as indicators of the phonological short-term memory). The model fitted the data well, $\chi^2(130) = 216.320, p < .001$, CFI = .941, TLI = .930, RMSEA = .052, SRMR = .070.

The results of this regression are shown in Table 3. As can be seen, backward recall was important for both the learning phase ($\beta = .52$) and the retrieval phase ($\beta = .43$). However, the Wald test revealed that the regression weight on the learning phase was significantly higher, $\chi^2(1) = 9.144, p < .001$. In addition, the table shows that phonological awareness was of importance for the learning ($\beta = .36$) and for the retrieval phase ($\beta = .22$; constraining parameters to be equal: Wald $\chi^2(1) = 8.877, p < .01$). At a first glance, this seemed also to be true for RAN yet in the opposite way: A significant regression weight was found on the retrieval ($\beta = -.19$) but not on the learning phase ($\beta = -.04$). However, a closer analysis revealed that the regression weights were not significantly different (Wald $\chi^2(1) = 0.246, p = .59$). No sufficient regression weights were found for the phonological short-term memory and for response inhibition (see Table 3).

Association of Letter Knowledge with PAL Learning and Retrieval

As can be seen in Table 2, significant correlations are found between all predictors. The correlation between the PAL learning and retrieval phase was high ($r = .86$), indicating that children who learned the new sound–symbol associations quite well made fewer

mistakes in the retrieval phase. The correlation between the PAL learning phase and letter knowledge was $r = .42$, while the correlation between the PAL retrieval phase and letter knowledge was $r = .49$. The Wald's test suggested that this association was significantly different, $\chi^2(1) = 9.90, p < .001$.

Explaining Variance in Letter Knowledge

To find out whether PAL mediates the relation of the cognitive predictors to letter knowledge, different structural models were calculated with letter knowledge as the dependent variable and PAL as a mediator of the different predictors. Figure 2 shows the final structural model in which the PAL learning and retrieval phase were predicted by the five cognitive factors, while letter knowledge was predicted by the five cognitive factors as well as PAL. This model fitted the data well, $\chi^2(155) = 248.287, p < .001$, CFI = .938, TLI = .932, RMSEA = .050, SRMR = .070; and accounted for a substantial proportion of the variance of PAL learning ($R^2 = .41$), PAL retrieval phase ($R^2 = .76$), and letter knowledge ($R^2 = .35$). As depicted in Figure 2, out of the five cognitive predictors only phonological awareness was uniquely related to letter knowledge ($\beta = .35$). Furthermore, the PAL retrieval phase accounted for a substantial proportion of the variance of letter knowledge ($\beta = .37$). Whereas a direct relation between the PAL learning phase and letter knowledge could not be found, a significant indirect relation via PAL retrieval phase could be detected ($\beta = .28$; 95% CI = [.119, .444]). A small but significant relation could even be found via this connection (Backward recall*PALlearning*PAL retrieval) for the backward recall ($\beta = .13$; [.043, .232]) and phonological awareness (phonological awareness *PALlearning*PAL retrieval; $\beta = .08$; 95% CI = [.030, .178]). An indirect effect of RAN via PAL retrieval was not found ($\beta = -.07$; $p = .101$; 95% CI = [-.009, -.174]). Thus, the unique contribution of PAL on letter knowledge was $R^2 = .14$ (PAL letter knowledge coefficients minus the total indirect effect through PAL).

It should be noted that phonological awareness and the backward recall were no longer directly related to the PAL retrieval phase when PAL retrieval phase was regressed by PAL learning phase (see Figure 2). However, a significant indirect relation of backward recall via PAL learning phase was found ($\beta = .37$; 95% CI = [.216, .515]).

Discussion

The aim of the present study was to explore underlying factors of sound-symbol association skills. The results revealed a number of critical findings concerning the interrelationships among the association and retrieval of new sound-symbol correspondences, phonological awareness, RAN, backward recall, and letter knowledge. First, phonological awareness and backward recall are predominantly important when acquiring new sound-symbol pairs, whereas RAN, phonological awareness and backward recall are of importance when new sound-symbol pairs have to be retrieved. Second, letter knowledge is more strongly associated to retrieval compared to learning of new sound-symbol pairs. Third, PAL abilities can be seen as mediators of associations between different reading precursor skills and letter knowledge.

Viewed descriptively, phonological awareness, that is, the ability to recognize, discriminate, and manipulate smaller units of spoken words, was found to be positively related to both PAL phases (learning phase $r = .50$; retrieval phase $r = .39$). The findings from the regression analyses suggest that phonological awareness is especially necessary when acquiring new sound-symbol pairs. This finding is in line with the results of previous studies demonstrating the close relationship between PAL tasks (with corrective feedback) and phonological awareness (e.g. de Jong, 2007; Mourgues et al., 2016; Windfuhr & Snowling, 2001). Moreover, the close relationship between phonological awareness and the acquisition of new sound-symbol pairs is plausible because paired associate learning requires children to discriminate between different verbal stimuli (e.g., ma, pa, and ta in the present study).

However, the findings from the regression analyses further suggest that phonological awareness is less important when new sound-symbol pairs have to be retrieved. This is interesting since de Jong and colleagues (2000) showed that (1) phonological awareness and PAL performance in a task without corrective feedback are closely related and (2) training of phonological awareness improves visual-verbal performance in that task. At first glance, these findings are contradictory to our results. However, the performance in the PAL retrieval phase highly depends on performance in the learning phase. This means that an improvement in the learning phase, where phonological awareness is of great importance, will enhance the performance in the retrieval phase. Moreover, in the present study, both PAL phases are considered in one regression analysis as dependent variables. Thus, it was possible to disentangle the relation between phonological awareness and the different PAL phases.

The regression analysis revealed that RAN effects less the learning but more the retrieval of new sound-symbol pairs. That is, the speed at which phonological information is retrieved from visual stimuli is important when sound-symbol associations have to be named without corrective feedback. By contrast, the correlation with RAN is smaller when the possibility is given to consolidate and/or correct sound-symbol associations, e.g. based on corrective feedback or the presentation of the correct answer regardless of the accuracy of the response. This could explain why previous studies reported smaller correlations (Georgiou et al., 2017; Lervåg et al., 2009) or even no correlation between PAL abilities and RAN (e.g. Litt et al., 2013, 2014). Moreover, the fact that phonological awareness is more strongly associated with PAL learning phase and RAN is more closely related to the PAL retrieval phase fits well to findings showing that phonological awareness is of particular importance at the beginning of reading acquisition whereas RAN is considered to be of importance in the further course of reading acquisition, especially for retrieving words based on their graphic characteristics (orthographical processing; Frith, 1985).

Our results are in accordance with a broader body of evidence suggesting that working memory capacity is involved in the acquisition of novel phonological representations (Baddeley et al., 1998). More precisely, less the phonological short-term memory but rather the abilities of updating and manipulating (backward recall) proved to be of particular importance for performance in both the acquisition and in the retrieval phase of the PAL paradigm. The association between backward recall and performance in the acquisition phase might be due to the fact that the simultaneous acquisition of new sound-symbol pairs means that the sound-symbol pairs have to be simultaneously present in the mind. That is, when mapping a symbol to the associated sound, the other sound-symbol pairs have to be present to avoid incorrect associations. This task rather seems to involve backward recall than the phonological short-term memory (Baddeley, 1996). However, the missing influence of the phonological short-term memory can also be explained from a methodological perspective (which is directly related to an old problem regarding the assessment of updating and manipulating): The shared variance of PAL abilities and phonological short-term memory might be captured by backward recall, because repeating nonwords and digits in the reverse order requires the child to have these sequences in mind in the given order.

Backward recall was also of importance for performance in the retrieval phase of the PAL paradigm. One possible explanation is that the sound-symbol associations were not yet automatically accessible due to the relatively short acquisition phase. Thus, while the relatively passive storage mechanism of the phonological short-term memory does not seem sufficient for successful retrieval, backward recall might be necessary for actively retrieving newly learned sound-symbol associations (Miyake & Shah, 1999).

The results revealed that response inhibition is related to PAL abilities but does not explain any further variance in learning and retrieving sound-symbol associations when other factors are considered. One possible reason for the missing effect might be that there is no

dominant response which has to be inhibited in the PAL paradigm. For example, in contrast to classical response inhibition tasks, the present PAL task does not require the child to react within a specified timeframe. The fact that response inhibition does not explain any further variance is also likely due to backward recall measurement, capturing the shared variance of PAL abilities and response inhibition.

Considering the interplay and contribution of the different cognitive skills on letter knowledge, critical findings were revealed. First, performance in the retrieval phase of the PAL paradigm was found to be more strongly associated with letter knowledge than performance in the learning phase ($r = .49$ vs. $.42$). However, as can be seen in Table 2, the relations of the cognitive factors with PAL learning and letter knowledge are very similar (except backward recall) and differ from those with PAL retrieval. Moreover, also the comparison of the present results with findings of previous studies provides little clarity. For example, the correlations with letter knowledge for the learning and retrieval phase are higher compared to the correlation found by de Jong and colleagues (2000; $r = .34$; see also de Jong, 2007; $r = .25$ and $.24$) and smaller compared to findings from Lervåg and colleagues (2009; $r = .57$). Interestingly, de Jong and colleagues (2000) assessed PAL abilities without corrective feedback, whereas corrective feedback was given by Lervåg and colleagues (2009). Therefore, it is hard to conclude that learning and retrieving new sound-symbol associations are differently related to letter knowledge and the fact that corrective feedback is given or not has an impact on that association. Perhaps the time between the learning and retrieving phase is of greater importance and leads to differentially effects. In the present study, the retrieval phase took place immediately after the learning phase.

Second, the PAL abilities can be seen as mediators between different cognitive factors and letter knowledge. A direct relation with letter knowledge was found only for phonological awareness, emphasizing the close relationship of these to skills (Burgess & Lonigan, 1998).

The indirect effect of RAN on letter knowledge underlines the assumption of de Jong and Olson (2004), according to which the contribution of RAN to the acquisition of letter knowledge is due to PAL (more precisely: PAL retrieval phase). Moreover, the indirect effect of backward recall on letter knowledge via PAL also shows that these are involved in the acquisition of novel sound-symbol pairs but are not necessary for performance in letter knowledge tasks in which lexical entries are built over a longer period of time (Baddeley et al., 1998; de Jong & Olson, 2004). Thus, different abilities are important for the three measures – PAL learning, PAL retrieval, and letter knowledge – which can be interpreted as three different stages of the acquisition of sound-symbol associations: learning phase of new associations, retrieval phase of new associations, and retrieval phase of associations from the long-term memory, respectively. However, since a considerable amount of the variance of letter knowledge remains unexplained the question arises which further abilities are related to letter knowledge.

Limitations and Directions for Further Research

Several limitations of this study have to be considered. First, it is important to note that the data are correlational in nature. Any causal interpretations, even though based on relevant theories, thus have to be treated with caution. In order to analyze effects of reading precursors on the different PAL phases and to test possible indirect effects on letter knowledge, longitudinal data are needed. In our study, we assumed directions of causality on the basis of previous studies suggesting (1) phonological awareness, RAN, and working memory to predict PAL (e.g. Mourgues et al., 2016), (2) PAL to display an early stage of acquiring letter knowledge (e.g. de Jong & Olson, 2004), and (3) that PAL mediates the relation between the different reading precursors and letter knowledge (e.g. de Jong & Olson, 2004).

Second, since the study focused on preliterate children, reading abilities could not be assessed. Thus, this study does not contribute to the question of the association between children's sound-symbol association skills and their reading skills. However, based on the results of the present study as well as previous studies, it is reasonable to assume that children's sound-symbol association skills are mainly the product of phonological awareness, backward recall, and RAN. Thus, when these capabilities and letter knowledge are regressed on word reading, an additional, direct, and unique contribution of PAL to word reading is expected to be small or even non-existent (cf. Poulsen & Elbro, 2018). Therefore, future studies should assess a broader scope of reading precursors to clarify whether PAL is not only robust and independent from phoneme deletion and RAN (Litt et al, 2013), but also from backward recall and letter knowledge.

Third, PAL abilities were assessed for an age range in which the majority of children are familiar with at least some letters. In the current study, children with pronounced letter knowledge may, therefore, have had an advantage in learning new sound-symbol pairs since these children are familiar with these kinds of associations. Thus, to more thoroughly analyze the implied causality of PAL predicting letter knowledge acquisition, PAL abilities should be assessed earlier in development or in samples of children without letter knowledge in longitudinal studies. Moreover, in the present study, no criterion was used to specify whether or not the children learned the stimuli correct. The retrieval phase started regardless of how good the child learned the sound-symbol associations. Therefore, the retrieval phase can also be interpreted as a retention phase in which children have the opportunity to show what they have learned. In future studies, one possible indicator for the learning phase can be the number of trials necessary for learning the sound-symbol associations correctly, in order to better differentiate between retrieval and retention.

Fourth, the question arises whether the PAL paradigm is suitable to simulate the acquisition and retrieval of letter knowledge. Whereas the simultaneous acquisition of several sound-symbol pairs requires pronounced backward recall abilities, it is reasonable to assume that the requirements are less pronounced in the actual educational context. Prior to school entry or in the first school year, wherever letters are introduced, they are presented separately, mostly in combination with words (“A like apple”), and repeated many times before new letters are introduced. That is, lexical entries of letters are built over a longer period of time, limiting the comparability to short experimental settings.

Conclusion

The empirical findings of this study present an important contribution to understanding the relation between PAL and different reading precursors. Our results shed new light on the requirements in the two PAL phases by disentangling the role of the different reading precursors. More specifically, phonological awareness and backward recall are predominantly important when acquiring new sound-symbol pairs, whereas RAN, phonological awareness and backward recall are of importance when new sound-symbol pairs have to be retrieved. Additionally, PAL proved to be mediating the relation between reading precursors and letter knowledge. Further longitudinal studies should take a possible mediation of PAL into consideration when investigating the contribution of the different precursors to reading.

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Table 1

Number of Participants, Means, Standard Deviations, Min, Max, Skewness, and Kurtosis for All Variables

	<i>n</i>	<i>M</i>	<i>SD</i>	Min	Max	Skewness	Kurtosis
PAL Learning Phase	232	12.50	7.29	0	29	.27	-.81
PAL Retrieval Phase	203	5.70	3.68	0	12	.19	-1.13
Letter Knowledge	219	4.98	4.04	0	12	.16	-1.13
Phonological Awareness							
Phoneme detection	217	2.15	2.40	0	7	.70	-.93
Rest word	217	0.84	0.84	0	7	2.13	3.62
RAN							
Objects	240	25.67	7.18	12.89	64.60	1.63	4.50
Colors	239	26.65	8.18	13.20	53.95	1.10	1.13
Response Inhibition							
Block 1	232	.91	.13	.23	1.00	-3.06	10.96
Block 2	223	.86	.16	.17	1.00	-2.05	4.67
Block 3	228	.88	.13	.35	1.00	-2.08	4.73
Block 4	224	.82	.18	.23	1.00	-1.41	1.23
Phono. Short-Term Memory							
Word Span	239	2.65	.66	1	4.38	-.45	.46
Digit Span	235	2.76	.72	1	4.75	-.20	.23
Backward Recall							
Word Span	228	1.82	.52	1	3.13	-.21	-.76
Digit Span	228	1.74	.60	0	3.25	-.37	.49

Table 2
Estimated Correlations Between the Latent Variables

	1	2	3	4	5	6	7
(1) PAL Learning Phase	—						
(2) PAL Retrieval Phase	.86	—					
(3) Letter Knowledge	.42	.49	—				
(4) Phonological Awareness	.50	.39	.49	—			
(5) RAN	-.45	-.35	-.31	-.26	—		
(6) Response Inhibition	.26	.35	.21*	.31	-.41	—	
(7) Phonological Short-Term Memory	.34	.30	.32	.40	-.38	.47	—
(8) Backward Recall	.57	.56	.37	.37	-.56.	.53	.59

Note. RAN = rapid automatized naming; all significant at $p < .01$ (two-tailed); * $p < .05$.

Table 3
Standardized Effects on the PAL Learning and Retrieval Phase

	Learning Phase		Retrieval Phase	
	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>
Phonological Awareness	.36**	.10	.22*	.03
RAN	-.04	.10	-.19*	.10
Backward Recall	.52**	.13	.43**	.13
Phonological Short-Term Memory	-.09	.10	-.14	.11
Response Inhibition	-.09	.12	.06	.12
	$R^2 = 40^{**}$		$R^2 = 44^{**}$	

Note. RAN = rapid automatized naming; ** $p < .01$. * $p < .05$.

Figure 1. Graphical representation of the task procedure of the PAL paradigm.

Figure 2. Final structure model showing letter knowledge to be directly related to phonological awareness and the PAL retrieval phase (only significant paths are estimated). For the sake of clarity, the correlations between the exogenous measures and the correlation between the residuals of the PAL indicators are not depicted.

** $p < .01$. * $p < .05$.