The Role of Paired Associate Learning in Acquiring Letter-Sound Correspondences: A Longitudinal Study of Children at Family Risk for Dyslexia

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This manuscript has been accepted for publication in *Scientific Studies of Reading*.

Abstract

Visual-verbal paired associate learning (PAL) is strongly related to reading acquisition, possibly indexing a distinct cross-modal mechanism for learning letter-sound associations. We measured linguistic abilities (nonword repetition, vocabulary size) longitudinally at 3.5 and 4.0 years, and visual-verbal PAL and letter knowledge at 4.0 and 4.5 years, in pre-reading children either at family risk for dyslexia (N=27) or not (N=25). Only nonword repetition predicted individual differences in later letter-sound knowledge, and PAL did not make a cross-sectional nor a longitudinal contribution. The data show a continuous relationship between linguistic processing abilities and letter-sound learning, with no independent role for PAL.

Keywords: dyslexia, paired associate learning, phonological processing, vocabulary, family risk

Children with developmental dyslexia show difficulties in visual-verbal paired associate learning (PAL) tasks across languages (Elbro & Jensen, 2005; Kalashnikova & Burnham, 2016; Li, Shu, McBride-Chang, Liu, & Xue, 2009; Litt & Nation, 2014; Litt, Wang, Sailah, Badcock, & Castles, 2019; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003; Vellutino, Scanlon, & Spearing, 1995; Vellutino, Steger, Harding, & Phillips, 1975; Wimmer, Mayringer, & Landerl, 1998). Accordingly, visual-verbal PAL has been proposed as a unique cause of reading difficulties (Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Li et al., 2009; Warmington & Hulme, 2012). While phonological awareness, rapid automatized naming (RAN) and letter knowledge are the strongest predictors of reading acquisition across languages (Kirby, Parrila, & Pfeiffer, 2003; Lyytinen et al., 2004; Swanson, Trainin, Necoechea, & Hammill, 2003; Ziegler, Pech-Georgel, Dufau, & Grainger, 2010), it is possible that individual differences in a cross-modal associative visual-verbal learning process may be an independent causal factor in dyslexia. This possibility is of theoretical interest as it may provide a simple indicator of risk for reading difficulties (Ho, 2014; Mourgues et al. 2016). Indeed, studies of typically-developing children also show an association between PAL and reading development, particularly regarding reading accuracy (Lervåg, Bråten, & Hulme, 2009; Warmington & Hulme, 2012; Windfuhr & Snowling, 2001). It has been suggested both that visual-verbal PAL may index a child's ability to form arbitrary connections between letters and sounds (Hulme et al., 2007), and that it may index the ability to form the connections between orthographic units and phonological units required to enable word recognition (Wang, Wass, & Castles, 2017; Warmington & Hulme, 2012). A series of studies with children with developmental dyslexia and with typically-developing children have thus sought to establish whether the cross-modal associative learning process measured by visual-verbal PAL tasks is an independent predictor of reading ability and dyslexia.

By the independent account, PAL performance is expected to explain significant unique variance in letter knowledge and/or reading ability after the variance explained by phonological awareness has been assessed. This prediction has received some support (Clayton, Sears, Davis, & Hulme, 2018; Ehm, Lonnemann, & Brandenburg, 2019; Georgiou, Liu, & Xu, 2017; Hulme et al., 2007; Mourgues et al., 2016). On the other hand, many other studies suggest, as first proposed by De Jong and his colleagues, that the verbal demands of the visual-verbal PAL task underpin the associations found between PAL and reading development (De Jong, Seveke, & van Veen, 2000; Messbauer & de Jong, 2003). Strong evidence for this verbal explanation was provided in an intervention study by De Jong et al. (2000). They demonstrated that five-year-old children's PAL performance improved significantly after receiving training in phonological sensitivity, compared to control children who were trained in semantic categorization skills. This verbal account of the association between PAL and dyslexia is predicated on the assumption that a child's ability to develop well-specified phonological representations is the key factor governing individual differences in reading development (Litt, de Jong, van Bergen, & Nation, 2013). With respect to dyslexia, a corollary of this assumption is that children affected by this disorder should develop poorly-specified phonological representations for word forms and this is, in fact, supported by a vast body of research (Melby-Lervåg, Lyster & Hulme, 2012; Ziegler & Goswami, 2005; for reviews).

By the verbal account, performance on PAL tasks that require verbal output on the part of the child, that is oral production of the verbal labels learned during the arbitrary visual-verbal pairings, is particularly likely to show associations with reading. This has been shown to be the case for both children with and without dyslexia (Clayton et al., 2018; Kalashnikova & Burnham, 2016; Litt et al., 2013; Litt et al., 2019; Litt & Nation, 2014), which has led researchers to suggest that the verbal account can be more accurately termed a “phonological form learning” account (Litt & Nation, 2014), or even that visual-verbal PAL reflects specific impairments to a “phonological output” system (Litt et al., 2019). However, auditory learning also appears to be important in explaining the association between visual-verbal PAL and reading. In a recent comprehensive assessment of PAL in typically-developing children aged eight to ten years, Clayton et al. (2018) created six novel PAL tasks, three that tapped visual-articulatory learning abilities (visual-phoneme pairs, visual-nonword pairs, visual-nonverbal pairs – the latter pairing sounds like coughs with novel visual stimuli), and three that tapped auditory-articulatory learning abilities (phoneme-phoneme pairs, nonword-nonword pairs, nonverbal-nonverbal pairs). Although performance in the visual-articulatory and the auditory-articulatory PAL tasks was correlated, path analyses showed that only the auditory-articulatory PAL tasks predicted children’s reading. Clayton et al. also noted that, to their surprise, the nonverbal-nonverbal PAL task (e.g., associating a cough with a lip pop sound) was a stronger predictor of reading than the phoneme-phoneme PAL task. This appears to suggest that acoustic processes as well as verbal processes may well be involved in the robust relationship between PAL and reading development. This possibility is interesting, as difficulties in auditory processing may underlie those difficulties experienced by children with dyslexia in forming well-specified phonological representations of words (Goswami, 2011, 2015a; Goswami et al., 2002). For example, Thomson and Goswami (2010) showed that for children with dyslexia, performance in visual-verbal PAL tasks was significantly associated with amplitude rise time discrimination, an auditory processing measure of sensitivity to changes in intensity in ongoing acoustic signals. The severity of children’s deficits in auditory processing skills in dyslexia were associated with poorer visual-verbal PAL. Early auditory processing skills in children at risk for dyslexia is one focus of the longitudinal “Seeds of Literacy” cohort comprising children at family risk for dyslexia and children not at risk for dyslexia (not-at-risk, NAR group) from which the current sample is drawn.

Despite extensive research investigating the link between children's concurrent PAL and reading skills, evidence for PAL as a potential predictor of *future* reading development and of potential future reading deficits in children continues to be very limited, and available investigations have produced mixed results. For example, research by Ho and colleagues (Ho, 2014; Ho, Leung, & Cheung, 2011) with children learning to read in Cantonese demonstrated that PAL measures taken at five and six years were significantly correlated with Chinese character recognition at seven years. By contrast, Lervåg et al. (2009) assessed PAL performance in Norwegian six-year-old children and found that while PAL showed a significant concurrent relationship to letter knowledge at age six years, it was not a significant predictor of reading ability measured two years later. Only letter knowledge and phonological awareness were significant predictors of Norwegian children's later reading scores (Lervåg et al., 2009).

Here we address this predictive issue in a sample of pre-school aged children who were at family (genetic) risk for dyslexia (at-risk, AR group) or not at risk for dyslexia (not-at-risk, NAR group), drawn from the "Seeds of Literacy" cohort. These two groups of children were compared on their performance on a visual-verbal PAL task administered twice six months apart at four years and four and a half years. We employed a version of a PAL task designed by Kalashnikova and Burnham (2016) to distinguish children's ability to learn paired associates from their ability to retrieve and produce the novel verbal labels learned during the task. This distinction was achieved by including separate phases in the task that tested children's comprehension (recognition) of the paired associates versus their verbal retrieval (production). Kalashnikova and Burnham reasoned that if phonological processing difficulties in dyslexia lead to children forming under-specified representations of novel phonological stimuli in PAL tasks, then those under-specified forms may be sufficient for successful recognition in a comprehension test, but insufficient for successful verbal retrieval in an oral production test. Supporting this prediction, they found that, compared to age-matched controls, children with dyslexia between six and 10 years of age only showed significant deficits in the PAL retrieval test and not in the PAL comprehension test.

Accordingly, we made the same prediction for our sample here. We expected the at-risk four-year-olds to perform at the same level as the not at-risk children on the comprehension test of PAL, but to perform significantly more poorly on the retrieval test of PAL. Even though the dyslexia status of these children was unknown at the time of testing, our previous investigations with this cohort demonstrate that compared to their NAR peers, children in the AR group demonstrate deficits in auditory and linguistic processing assessed from 10 to 19 months of age (Kalashnikova, Goswami, & Burnham, 2018, 2019a, 2020), as well as deficits in verbal processing (vocabulary acquisition) at 3 years (Kalashnikova, Goswami, & Burnham, 2019b). In order to assess the emerging literacy skills in our young sample, we measured early letter knowledge. Early letter knowledge is one of the most robust predictors of later reading ability in young children (Byrne, 1998; de Jong & van der Leij, 1999; Hulme et al., 2007; Lervåg et al., 2009; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). Studies across languages consistently report early delays in letter knowledge for children who are at-risk for reading delay and dyslexia (Gallagher, Frith, & Snowling, 2000; Snowling, Gallager, & Frith, 2003; van Bergen et al., 2011). If PAL is a significant predictor of literacy skills, then the verbal retrieval test of PAL used here should be a significant independent predictor of concurrent and future letter knowledge, even when early phonological skills are taken into account. Earlier phonological skills were measured here by a nonword repetition task, administered at 3.5 years of age. In addition, we included standardized measures of vocabulary size and non-verbal IQ in our analyses, in order to control for children's general linguistic and cognitive development when assessing the concurrent and longitudinal relations between PAL performance and letter knowledge.

Method

Participants

Fifty-three children participated in this study; 26 (18 female) were not at family risk for dyslexia or any other developmental disorder, and 27 children (12 female) were at family risk for dyslexia. All children were originally recruited to participate in the longitudinal project "Seeds of Literacy" at the age of five months and were included in this study based on their availability to visit the lab at the age of four years. Four additional children took part but were excluded from this study for failure to complete the required number of visits (3 NAR, 1 AR). The 51 children were assessed at 3, 3.5, 4, and 4.5 years of age for this study. All children were raised in a monolingual English language environment and were not at risk for any other developmental disorder.

Children were allocated to the at-risk (AR) and not at-risk (NAR) groups based on their parents' existing formal dyslexia diagnosis, and/or their parents' performance on our extensive screening battery completed at the start of the "Seeds of Literacy" project. According to this battery, a child was allocated to the AR group if one of their parents (1) obtained a score of 1.5 SD below the average in a measure of word or nonword reading and in at least two of the following tests – oral reading (accuracy, fluency, and rate), spelling, Rapid Picture Naming (RAN), and digit span, (2) indicated history of experiencing reading difficulties in childhood, and (3) obtained an average score (within .5 SD from the standardized mean) on a measure of non-verbal IQ. A child was assigned to the NAR group if both their parents obtained average scores on all the tests in (1) and (3) and indicated no history of reading difficulties in childhood. Household annual income based on the postcode of residence and maternal education were used as proxies of families' socio-economic status. The NAR and AR groups did not differ according to their income, Kolmogorov-Smirnov Z =.681, p =.743, or maternal education, Z = .406, p = .996.

This study conformed to the ethical standards established in the Declaration of Helsinki. It was approved by the Western Sydney University Human Research Ethics Committee (approval: H9142, title: "Seeds of Literacy"). Caregivers of all children provided informed written consent prior to participation in the study, and all children provided verbal assent prior to taking part in each task.

Procedure

Paired Associate Learning. Children completed the PAL task at 4 and 4.5 years of age. In this task, children are required to learn the associations between four novel objects and novel words and are assessed on their ability to (1) find the correct object when they hear each novel word and (2) produce the novel word when they see each object (Kalashnikova & Burnham, 2016). The four novel objects are depicted in Figure 1 (objects selected from the Fribbles dataset, Yildirim & Jacobs, 2013) and the four novel words were *deev*, *wug*, *tib*, and *kooz*.

[insert Figure 1 here]

Learning phase. First the experimenter introduced the object-label pairings to the child by showing an image of each object and naming it (e.g., "This is a deev! See, it's a deev"). Next, the experimenter showed each object successively to the child and asked them to name it. If the child failed to respond or produced an incorrect label, the experimenter named the object again. The learning phase continued until the child was able to name all four objects correctly in two consecutive rounds or until completing five naming rounds.

Comprehension phase. This phase consisted of 36 trials presented as part of a computer game. On each trial, the child saw two objects appear on the left and right sides of a

24in computer screen and heard an audio recording of a male voice requesting one of the objects (e.g., “Can you find the deev?”). The child’s task was to find the correct object by pressing the left or right buttons on a response box as quickly as possible.

DMDX software (Forster & Forster, 2003) was used to present the task. The experimenter controlled the start of each trial from a second computer located outside of the child’s field of view, and the response box was connected to the computer as an input device. Two handprints were placed to the sides of the response box. Children were asked to place their hands on the prints to indicate that they were ready. Each trial only commenced when the child had placed both hands on the handprints and was facing the monitor. After the child pressed the response button, a black screen was presented until the next trial began. Children completed two types of comprehension trials depicted in Figure 1:

(a) Reinforcement trials. Children completed 16 reinforcement trials. In these trials, the child saw one of the four test objects paired with a familiar object on the screen and heard the voice requesting the novel object (e.g. “Find the deev!”). The purpose of these trials was to reinforce the learned associations instead of testing comprehension since children could infer the correct referent by relying on the disambiguation word-learning strategy (Merriman & Bowman, 1989). Performance on these trials was not included in the final analyses.

(b) Retention trials. Children completed 20 retention trials. These were the critical comprehension trials. Only the test objects were presented in pairs on the screen, and the voice requested the child to find one of the objects. Each response was scored as correct or incorrect, so children’s scores could range from 0 to 20.

Reinforcement and retention trials were presented in blocks of four trials. Each test object–label pair was the target once in each block. The paradigm included four reinforcement and five retention blocks presented in the following fixed order: retention-reinforcement-retention-reinforcement-retention-reinforcement- retention-reinforcement-retention, but the order of blocks of each type and order of trials within a block were randomized across participants. The position of the target object was also counterbalanced within blocks (half the time it appeared on the right and half the time on the left).

Verbal retrieval phase. Immediately after the comprehension phase, the child proceeded to the verbal retrieval phase. The experimenter showed the images of each novel object to the child one by one and asked them to name the object. Children saw each object twice and were not provided any feedback from the experimenter in this phase. Each response was scored as correct or incorrect, so children's scores could range from 0 to 8.

Nonword repetition. Children completed this task at 3.5 years of age. This is an experimental measure of early phonological sensitivity that has been demonstrated to relate to children's auditory processing and linguistic abilities (Kalashnikova, Goswami, & Burnham, 2019a, b). In this task, children are introduced to a puppet of an alien and told that they would learn new words from an alien language. The nonwords were pre-recorded and played over loudspeakers, while the experimenter manipulated the puppet and scored children's responses as correct or incorrect. The task consisted of four practice items, and 16 test items (see Supplementary Materials for a complete list of items). Only identical repetitions were coded as correct. The number of correct repetitions and total items attempted were computed. The proportion of correct responses out of the total attempted responses was used for analyses.

Letter knowledge. Children completed this task at 4 and 4.5 years of age. The letter knowledge section from the Early Reading Skills subtest of the Wechsler Individual Achievement Test, WIAT III (Wechsler, 2009) was used. In this test, children saw a booklet depicting letters from the alphabet and were asked to name some letters and find some letters named by the experimenter. Each child completed 13 test items and received a score of 1 for a correct response on each item, so the total scores could range from 0 to 13.

Vocabulary. Children completed this task at 4 years of age. The Knowledge Vocabulary sub-test in the Routing-Verbal Domain of the Stanford-Binet Intelligence Scales-5th Edition (Roid, 2003) was used. A single scaled score (M = 10; SD = 3) based on the combination of receptive and expressive vocabulary test items was calculated for each child and used for analyses.

Non-verbal IQ. Children completed this task at 3 years of age. The Fluid Reasoning Object Series/Matrices sub-test in the Routing Non-Verbal Domain of the Stanford-Binet Intelligence Scales-5th Edition (Roid, 2003) was used. A single scaled score (M = 10; SD = 3) was used for analyses.

Results

Language and Reading-related Measures

Independent-sample *t*-test analyses were conducted to compare NAR and AR performance on all the language and reading-related measures in this study (see Table 1 for the descriptive statistics and *t*-test results). One-tailed tests were used since NAR children were expected to outperform AR children with the exception of non-verbal IQ for which a two-tailed test was used (due to a lack of *a priori* predictions about the direction of the effect). NAR children outperformed AR children in all measures. It should be noted that NAR children obtained higher non-verbal IQ scores than AR children, but importantly, the two groups' scores were within the normal range.

[insert Table 1 here]

Paired Associate Learning

Children's accuracy scores in the comprehension and retrieval phases of the PAL task are shown in Figure 2. For this task, 23 NAR and 24 AR children contributed data at 4 years and 24 NAR and 21 AR at 4.5 years.

To assess performance across the groups and the two ages, two Generalized Linear Mixed Effects (GLME) models were used, one for comprehension and one for verbal retrieval. GLME analyses were used in this case as they do not require exclusion of participants with partially missing data (i.e., for one of the timepoints) or imputation for missing data (Cunnings & Finlayson, 2015). Analyses were conducted using the lmer function (Bates, 2005) in R (R Core Team, 2013). Since initial data inspection showed that PAL scores were not normally distributed, these models were fitted using a Poisson distribution. Models were specified with either comprehension or verbal retrieval accuracy scores as the dependent variable, Group (NAR, AR; contrast-coded as 0.5 and -0.5 respectively) and Age (4, 4.5 years) as the independent factors, and random intercepts for participants.

Model results are presented in Table 2. We expected a Group effect for the verbal retrieval task, but not for the comprehension task. However, Age was the only significant predictor in both models. Older children showed better comprehension scores and greater verbal retrieval accuracy. There was no significant effect of Group, nor significant Group by Age interaction in either analysis, although the Group effect for the verbal retrieval task approached significance (p = .078).

[insert Table 2 here]

As can be seen, the GLME models did not provide evidence for an effect of Group on children's PAL performance. Follow-up Bayesian independent-samples *t*-test analyses were consistent with the GLME models in showing that comprehension and verbal retrieval performance in each age group was comparable. The *t*-tests yield a Bayes factor, the values of which represent the likelihood of the null and experimental hypotheses for the experimental data (Jarosz & Wiley, 2014). In this case, a BF_{10} value of 1 indicates equal evidence for the null and alternative hypotheses, values above 1 indicate support for the alternative hypothesis, and values below 1 indicate support for the null. For the comprehension task, the *t*-test provided moderate evidence for the null hypothesis at 4 years (BF_{10} = .304) and anecdotal evidence at 4.5 years (BF_{10} = .511). For the verbal retrieval task, the *t*-test provided moderate evidence for the null hypothesis at both 4 (BF_{10} = .300) and 4.5 years (BF_{10} = .296).

These BF results are below 1, but the finding of anecdotal evidence at 4.5 years suggests that the conclusion that the AR group did not have difficulties with learning visual-verbal paired associates compared to their NAR peers may not be secure. A more sensitive measure of potential PAL difficulties for the AR group in the comprehension test may be gained by analysing performance in the first retention block only, before any reinforcement of learning was given. Accordingly, a further model was constructed to assess children's performance in the first retention block of the comprehension task. A GLME model was specified with Group (NAR, AR; contrast-coded as 0.5 and -0.5 respectively) and Age (4, 4.5 years) as the independent factors and random intercepts for participants. In order to match the earlier models, the dependent variable was the number of correct comprehension trials (out of a maximum of 4). The model yielded no main effect of Age, $\beta = .217$, $SE = .124$, $Z = 1.73$, $p = .080$, Group, $\beta = -.012$, $SE = .184$, $Z = -0.064$, $p = .949$, nor Age by Group interaction, $\beta = -.099$, $SE = .247$, $Z = -0.401$, $p = .688$. Follow up Bayesian independent-samples *t*-tests provided moderate evidence for the null hypothesis at 4 years (BF_{10} = .302) and anecdotal evidence at 4.5 years (BF_{10} = .489). The BF data suggest that as the children age, the null finding for PAL becomes less secure.

PAL, Language, and Reading-related Measures

Our analyses of AR and NAR children's PAL comprehension and verbal retrieval performance indicated that the AR children did not show significant impairments in PAL in the current paradigm. Nevertheless, PAL may be related to early literacy skills in the sample as a whole irrespective of group membership. To test this possibility, we assessed the relation between children's PAL accuracy scores and their performance in the nonword repetition, vocabulary, and letter knowledge tasks, using Spearman correlation analyses (see Table 3). Inspection of Table 3 shows that children's PAL comprehension scores at 4- and 4.5-years were significantly correlated, and that comprehension and retrieval scores were also significantly correlated at both ages. Both the comprehension and verbal retrieval measures of PAL also showed large and significant time-lagged correlations with earlier nonword repetition. The PAL verbal retrieval scores were significantly correlated with concurrent letter knowledge both at 4 and 4.5 years. Regarding time-lagged correlations, *both* PAL comprehension and retrieval scores at 4 years showed significant relations to letter knowledge at 4.5 years. As nonword repetition at 3.5 years also showed significant time-lagged correlations with letter knowledge at both 4 and 4.5 years, these time-lagged correlations by themselves do not indicate an independent contribution for PAL to reading development. Children's vocabulary scores did not show correlations with either measure of PAL.

[insert Table 3 here]

Next, two hierarchical regression analyses were conducted to assess whether PAL verbal retrieval and early phonological processing were independent predictors of children's concurrent and future letter knowledge scores. In order to account for missing data across tasks, listwise exclusions were applied. Model 1 assessed the concurrent relation between the variables and included letter knowledge scores at 4 years as the outcome variable. Here the control measures non-verbal IQ and vocabulary size were entered in Step 1, non-word repetition in Step 2, and PAL verbal retrieval scores at 4 years in Step 3. Model 2 assessed the longitudinal relation, so it included letter knowledge scores at 4.5 years as the outcome variable. To explore whether predictive relations between the variables and letter knowledge would be present even when letter knowledge earlier in development (the autoregressor) was controlled, the first step of Model 2[1] controlled for the autoregressor, letter knowledge at 4 years. Next, we included the control measures non-verbal IQ and vocabulary size in Step 2, non-word repetition in Step 3, and PAL verbal retrieval at 4 years in Step 4.

Model results are shown in Tables 4 and 5. As can be seen, the two models yielded similar results with respect to our theoretical questions. Firstly, PAL performance as measured by the verbal retrieval assessment did not predict either concurrent or future letter knowledge scores. Secondly, nonword repetition, a measure of novel phonological form learning, was a significant predictor of letter knowledge, even when including stringent controls for prior letter knowledge via the autoregressor.

[insert Table 4 here]

[insert Table 5 here]

Discussion

This study is unique in assessing early visual-verbal PAL ability in pre-school children at-risk (AR) and not at family risk (NAR) for dyslexia. Our longitudinal approach enabled a robust test of whether visual-verbal PAL abilities and phonological abilities are independent predictors of literacy development (the independent account, first proposed by Hulme et al., 2007), or whether visual-verbal PAL is associated with literacy development

[1] A post-hoc power analysis was conducted using GPower (Faul, Erdfelder, Buchner, & Lang, 2009). The resulting power was 1 indicating that our sample size was suitable for this hierarchical regression model with five predictors.

because of the demands that it places on children's auditory and phonological processing abilities (the verbal account, first proposed by de Jong, 2000). The data show clearly that phonological skills (as measured by a nonword repetition task) rather than visual-verbal PAL skills (as measured by both comprehension and verbal retrieval measures of PAL) predict letter knowledge in our sample of four-year-old children. The predictive relations between nonword repetition and letter knowledge remained robust even when letter knowledge at Time 1 (the autoregressor, letter knowledge at 4 years) was controlled. Accordingly, these longitudinal data support the verbal account of the relationship between PAL and reading (de Jong, 2000; Litt et al., 2013).

Further, and contrary to expectation, PAL did not significantly discriminate children's risk for dyslexia status in this sample. When PAL was assessed in a comprehension task that required recognition of the novel labels that had been learned, AR and NAR children performed equally well, even on the initial retention trials. When PAL was assessed in a verbal retrieval task requiring production of the novel labels, AR and NAR children's performance was again comparable. It should be noted, however, that for the 4.5 year olds, Bayes Factor analyses suggested anecdotal evidence for a null effect rather than moderate evidence. Hence while the failure of the PAL task to discriminate our groups is consistent with the verbal/phonological account of the relationship between PAL and reading, the PAL task may prove more discriminative as the children get older.

Already in their first months of life, children at-risk for dyslexia show deficits in early auditory processing abilities and in general language development compared to not at-risk children (Guttorm et al., 2005; Leppänen et al., 2010; Lyytinen et al., 2001; van Zuijen, Plakas, Maassen, Maurits, & van der Leij, 2013). Previous studies of sub-groups of children from the "Seeds of Literacy" cohort are consistent with this broader developmental literature of prior auditory and linguistic processing deficits. Our assessments have provided evidence for deficits in the discrimination of amplitude envelope rise time by 10 months (Kalashnikova, Goswami, & Burnham, 2018), and deficits in novel word learning and word recognition tasks at 19 months of age (Kalashnikova, Goswami, & Burnham, 2019b, 2020). Notably in these prior studies, individual differences in rise time processing in early infancy significantly predicted vocabulary size two years later (Kalashnikova, Goswami, & Burnham, 2019b), suggesting a continuous interaction between auditory and linguistic abilities. Yet despite their documented earlier auditory and linguistic deficits, the at-risk children's PAL performance in the current study was comparable to their not at-risk peers. Therefore, our data suggest that PAL difficulties are likely to develop as a *consequence* of the phonological deficits associated with dyslexia. Children with developmental dyslexia have less practice in recoding words from print to sound, because they are poor at reading. Over development, this can translate into reduced experience in recoding hundreds of thousands of items to sound, with cognitive consequences for tasks such as PAL, and for other cognitive tasks such as visual-spatial attention (Goswami, 2015a). Together with this body of literature, the current findings support the view that PAL abilities *per se* are not a precursor of individual differences in the ability to learn letter-sound associations early in childhood. Rather, these difficulties in letter-sound learning are a direct result of the verbal/phonological deficit in developmental dyslexia.

Furthermore, as the current study used a variation of a PAL task that differentiated children's general associative learning ability from their ability to retrieve novel labels for verbal production, it is noteworthy that no reliable group difference in either measure was detected here at four years of age. This is further evidence for the view that the visual-verbal PAL deficits observed in dyslexia are not due to decreased general associative learning ability, but rather to difficulties in phonological processing (Litt & Nation, 2014). Indeed, it could be argued that visual-verbal PAL makes similar cognitive demands to associative word-learning tasks in infancy, which are often assessed using "fast-mapping" visual fixation paradigms (Werker, Cohen, Lloyd, Casasola, & Stager, 1998). In fast-mapping tasks, infants are typically taught novel labels for novel visual stimuli by observing the repeated pairing of the labels with the visual forms. Infants must thus attend to the auditory and visual stimuli, establish the associations between them, store them in memory, and retrieve these associations at test. Fast mapping is thought to rely heavily on auditory speech perception and lexical skills (Stager & Werker, 1997). A sub-set of the children in the current study were given a fast-mapping task when they were aged 19 months (Kalashnikova, Goswami, & Burnham, 2020). In that fast-mapping task, the AR group did show a deficit, yet later at four years of age, the AR group did not show a PAL deficit. Further, PAL and vocabulary scores were not related in the current study. Accordingly, the data suggest that even though PAL appears to resemble the process of fast-mapping, successful performance in visual-verbal PAL tasks relies on children's ability to encode and retrieve detailed representations of novel phonological forms, not on their general lexical skills of establishing mappings between novel word forms and their meanings.

Alternatively, it could be suggested that phonological memory demands may play a role in individual differences in PAL (Clayton et al., 2018). Phonological memory is involved in both the PAL comprehension and retrieval assessments used here, since phonological storage skills are required for children to learn and encode novel word forms (Gathercole, 2006). This study did not include a measure of phonological memory to test this possibility directly, but we consider this explanation unlikely given our results in the comprehension and verbal retrieval phases of the PAL task. The comprehension and retrieval assessments used here differ in their demands for phonological specificity of the newly stored word forms: successful comprehension performance can be achieved even if only a partially-specified phonological form of the word has been encoded, but successful retrieval performance can only be achieved by accessing, retrieving, and producing the *exact* representation of each newly learned word. The finding that the AR and NAR groups did not differ in the comprehension assessment of PAL here, even when only the initial retention trials were compared (similar to previous findings with school-aged children with and without dyslexia, Kalashnikova & Burnham, 2016), suggests that phonological memory demands *per se* are unlikely to be a definitive factor in visual-verbal PAL deficits.

The present findings suggest that verbal retrieval measures of visual-verbal PAL do not discriminate between children at-risk and not at-risk for dyslexia at 4 and 4.5 years of age. Nevertheless, these measures may discriminate between children who do and do not develop dyslexia as the children get older. Of the AR group studied here, not all will develop dyslexia, as typically only 40 – 60% of children at family risk of dyslexia later receive a diagnosis. There are many studies showing that visual-verbal PAL is poorer in older children with dyslexia compared to normal reading controls (Elbro & Jensen, 2005; Kalashnikova & Burnham, 2016; Litt & Nation, 2014; Litt et al., 2019; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003), so it is possible that the visual-verbal PAL task used here may eventually identify those children in the AR group who do meet criteria for dyslexia. It is also plausible that any later emergence could reflect the reduced practice in articulating the verbal labels (spoken words) that match visual patterns (letter strings) that is an inevitable consequence of having dyslexia. These two possibilities can be investigated using retrospective analyses when the cohort become older. An alternative, but not mutually exclusive possibility, is that PAL skills are linked to children's developing ability to establish connections between visual and orthographic word forms, which are developed as children consolidate their sight word reading skills (Ehri, 2014; Wang et al., 2017). In fact, more experienced readers may employ the strategy of imagining the spelling form of a novel word, which is known to facilitate the word's memory and retrieval (Ehri & Wilce, 1979).

It is also possible that the lack of significant group differences in PAL performance here were due to several methodological aspects of our study. First, it is noteworthy that this study included a conservative sample size, which could not be increased given that participants were pooled from a carefully selected longitudinal cohort. Second, our Bayes Factor analyses indicated moderate to anecdotal evidence for the null hypothesis, which calls for a replication of these findings in a larger sample. Third, it must be considered that identical versions of the PAL tasks were used for the 4- and 4.5-year assessments. Young children tend to rapidly forget novel words learned in fast-mapping tasks (Vlach & Sanhofer, 2012), so it is unlikely that children in this study retained the word-object mappings over a period of six months. However, we cannot fully discard the possibility that our longitudinal analyses may have been affected by children's retention of the information learned in the task during the first lab visit or by their overall familiarity with task procedures. It is also plausible that the task of learning and retrieving novel labels was too cognitively demanding for children of this young age, which may have masked potential group differences. However, data from the comprehension phase of this study does not support this explanation as NAR and AR children showed high rates of recognition of the novel labels (correct responses on 70-85% of the trials). Considering these possibilities, we propose that further longitudinal investigations of the development of PAL abilities in relation to lexical, phonological, reading, and orthographic development in larger samples of children at family risk for dyslexia are required to shed light on the discrepancies between the present results and previously reported PAL deficits in school-aged children with reading difficulties.

Individual differences in early literacy acquisition were assessed here by measuring letter knowledge. It is worth noting that the AR children here show the same type of delays in early letter knowledge reported in other longitudinal studies of the precursors of dyslexia (Gallagher et al., 2000; Snowling et al., 2003; van Bergen et al., 2011). Early letter knowledge is one of the most robust predictors of later literacy skills in young children (Byrne, 1998; de Jong & van der Leij, 1999; Hulme et al., 2007; Lervåg et al., 2009; Schatschneider et al., 2004). The children in the current study have not yet begun formal reading instruction and are yet to receive formal diagnostic tests for dyslexia, but already at 4.5 years of age they demonstrate significantly poorer letter knowledge compared to their not at-risk peers. Our current findings indicate that this early deficit is not the result of intrinsic difficulties in establishing associations between the particular phonemes and graphemes of their native language grounded in a discrete inability to form arbitrary connections between letters and sounds (Hulme et al., 2007). Rather, difficulties in acquiring letter-sound correspondences arise from pre-existing phonological processing difficulties (de Jong, 2000), previously demonstrated for this cohort beginning with auditory processing difficulties detected in the first months of life (Kalashnikova, Goswami, & Burnham, 2018, 2019 a, b, 2020).

PAL has received attention in the literature as a potentially simple indicator for reading difficulties and dyslexia (Ho, 2014; Mourgues et al., 2016). Our current data suggest that this hope may be misplaced. Here PAL was assessed prior to the onset of reading instruction in a sample of four-year-old children. While PAL performance significantly correlated with reading-related skills, it did not reliably discriminate children who are at-risk for developmental reading disorders by virtue of a family history of reading disability.

Acknowledgements: The authors declare no conflict of interest related to this work. This research was supported by the Australian Research Council grant DP110105123, ‘The Seeds of Literacy’, to the 2nd and 3rd authors. The first author’s work is supported by the Basque Government through the BERC 2018-2021 program and by the Spanish Ministry of Science and Innovation through the Ramon y Cajal Research Fellowship, PID2019-105528GA-I00.

We thank Maria Cristou-Ergos, Scott O'Loughlin, and Hana Zjakic for their assistance with participant recruitment, data collection, and data analyses. We also thank all the children and their parents for their valuable time and interest in this research.

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Table 1. *Mean (SD) and results of independent-samples t-tests comparing NAR and AR children's performance in the measures of nonword repetition, vocabulary, letter knowledge, and non-verbal IQ.*

	NAR			AR					
	M	*SD*	*N*	*M*	*SD*	*N*	t^2	*p*	*Cohen's d*
Nonword repetition[1] (3.5 years)	58.25	22.3	25	47.15	22.57	27	1.78	.040	0.495
Vocabulary (4 years)	11.38	2.26	26	9.65	2.59	26	2.56	.007	0.711
Letter knowledge (4 years)	6.08	3.79	24	3.96	3.98	26	1.96	.028	0.544
Letter knowledge (4.5 years)	8	4.34	26	5.23	3.95	26	2.36	.011	0.668
Non-verbal IQ (3 years)	11.54	2.47	26	10.15	1.75	27	2.37	.011	0.652

[1]Non word repetition: percent correct responses (0-100); Letter knowledge: number of correct responses (0-14); Verbal and Non-verbal IQ: standardized score (standardized *M* = 10, *SD* = 3).
[2] One-tailed *t*-tests for non-word repetition, letter knowledge, and vocabulary, and two-tailed *t*-test for non-verbal IQ.

Table 2. *Results of GLME models assessing the effects of group (NAR, AR) and age (4, 4.5 years) on children's comprehension and verbal retrieval in the PAL task.*

Comprehension				
	ß	*SE*	*Z*	*p*
(Intercept)	2.658	0.042	62.966	<.001
Group	0.007	0.084	0.082	.935
Age [4.5 years]	0.172	0.056	3.091	.002
Group × Age [4.5 years]	-0.026	0.111	-0.230	.818
Verbal Retrieval				
	ß	*SE*	*Z*	*p*
(Intercept)	0.521	0.137	3.819	<.001
Group	0.464	0.263	1.764	.078
Age [4.5 years]	0.515	0.144	3.575	<.001
Group × Age [4.5 years]	-0.244	0.288	-0.849	.396

Table 3. *Spearman correlation coefficients for NAR and AR scores in PAL comprehension and verbal retrieval, nonword repetition, vocabulary, and letter knowledge (partial correlations controlling for non-verbal IQ in parentheses) (**p <.01, *p <.05).*

	PAL retrieval 4.5 yr	PAL comp. 4 yr	PAL comp. 4.5 yr	Nonword rep. 3.5 yr	Vocab. 4 yr	Letter know. 4 yr	Letter know. 4.5 yr
PAL retrieval 4 yr	.359*	.476***	-.313	.468**	.406**	.452**	.429**
	(.297)	(.521**)	(.168)	(.508**)	(.212)	(.442**)	(.478**)
PAL retrieval 4.5 yr		.397*	.452**	.499	-.028	.446**	.498**
		(-.397*)	(.353*)	(.605**)	(-.062)	(.453**)	(.472**)
PAL comp. 4 yr			.654**	.631**	.151	.390**	.456**
			(.669**)	(-.628**)	(.036)	(.284)	(.421*)
PAL comp. 4.5 yr				.237	-.054	.209	.347*
				(.376*)	(-.208)	(.080)	(.252)
Nonword rep. 3.5 yr					.340*	.429**	.486**
					(.233)	(.500**)	(.594**)
Vocabulary 4 yr						.380**	.311*
						(.295)	(.292)

Letter know. 4 yr	.892**
	(.886**)

Table 4. *Hierarchical regression model with letter knowledge at 4 years as the dependent variable and non-verbal IQ, verbal IQ, nonword repetition, and PAL verbal retrieval scores at 4 years as predictor variables.*

Step 1: *Adj* R^2 = 0.143, $F(2, 44) = 4.834$, $p = .013$				
	ß	*SE*	*t*	*p*
Non-verbal IQ	.317	.247	2.322	.025
Vocabulary	.285	.233	2.091	.042
Step 2: *Adj* R^2 = 0.261, *RΔ* = 0.129, $F(1, 43) = 8.005$, $p = .007$				
	ß	*SE*	*t*	*p*
Non-verbal IQ	.182	.245	1.343	.186
Vocabulary	.132	.235	.961	.342
Nonword repetition	.412	.026	2.829	.007
Step 3: *Adj* R^2 = 0.257, *RΔ* = 0.013, $F(1, 42) = 0.815$, $p = .372$				
	ß	*SE*	*t*	*p*
Non-verbal IQ	.184	.246	1.354	.183
Vocabulary	.104	.242	.732	.468
Nonword repetition	.366	.027	2.362	.023
PAL verbal retrieval 4 yr.	.131	.355	.903	.372

Table 5. *Hierarchical regression model with letter knowledge at 4.5 years as the dependent variable and letter knowledge at 4 years, non-verbal IQ, verbal IQ, nonword repetition, and PAL verbal retrieval scores at 4 years as predictor variables.*

Step 1: *Adj* R^2 = 0.776, $F(1, 42) = 149.816$, $p < .001$				
	ß	*SE*	*t*	*p*
Letter knowledge 4 yr.	.884	.075	12.240	.001
Step 2: *Adj* R^2 = 767, $R\Delta$ = 0.002, $F(2, 40) = .219$, $p = .804$				
	ß	*SE*	*t*	*p*
Letter knowledge 4 yr.	.897	.087	10.669	.001
Non-verbal IQ	-.048	.155	-.598	.553
Vocabulary	.011	.157	.135	.894
Step 3: *Adj* R^2 = 0.810, $R\Delta$ = 0.044, $F(1, 39) = 10.006$, $p = .003$				
	ß	*SE*	*t*	*p*
Letter knowledge 4 yr.	.787	.086	9.430	.001
Non-verbal IQ	-.093	.142	-1.262	.214
Vocabulary	-.063	.145	-.439	.663
Nonword repetition	.257	.015	3.163	.003
Step 3: *Adj* R^2 = 0.807, $R\Delta$ = 0.002, $F(1, 38) = 0.391$, $p = .535$				
	ß	*SE*	*t*	*p*
Letter knowledge 4 yr.	.779	.088	9.144	.001
Non-verbal IQ	-.091	.144	-1.213	.233
Vocabulary	-.039	.147	-.525	.603
Nonword repetition	.244	.016	2.892	.006
PAL verbal retrieval 4 yr.	.047	.196	.626	.535

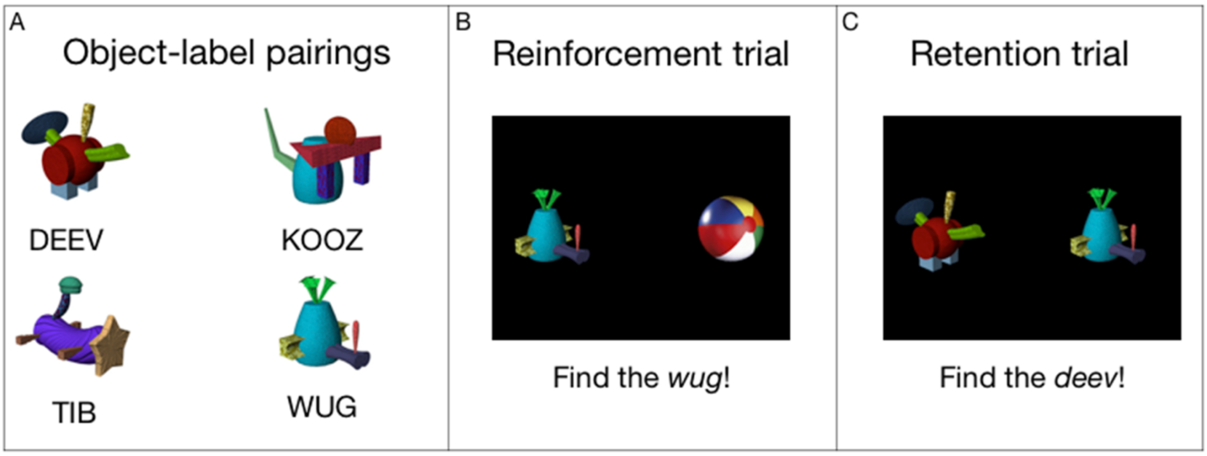

Figure 1. Materials used in the paired-associate learning task: object label pairings used in the learning and verbal retrieval phases (A), sample reinforcement trial (B), and a sample retention trial (C) of the comprehension phase.

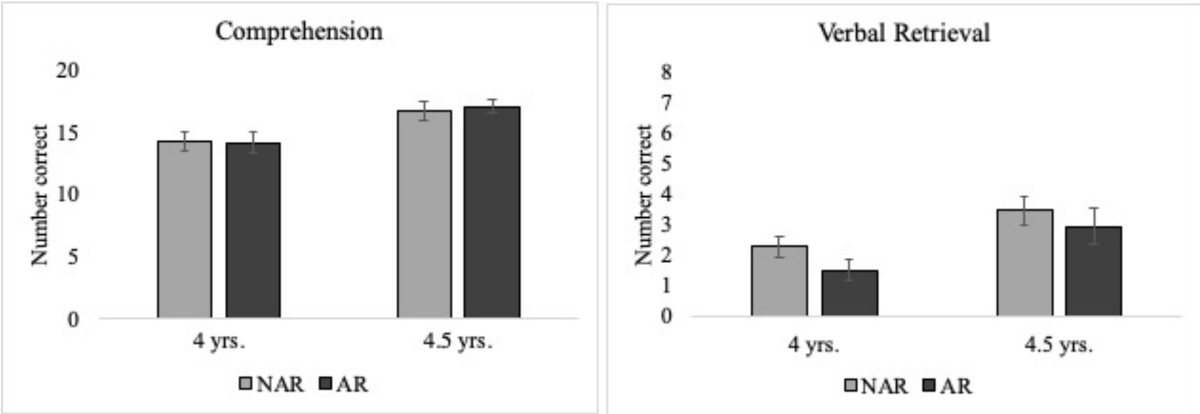

Figure 2. NAR and AR children's accuracy in the comprehension (number of errors out of 20) and verbal retrieval (number of correctly produced words out of 8) phases of the PAL task at 4 and 4.5 years of age (horizontal lines represent the median, boxes represent the standard error of the mean, and whiskers extend to the confidence interval percentiles).