Novel word learning deficits in infants at family risk for dyslexia

Short title: Word learning in infants at-risk for dyslexia

Marina Kalashnikova[1,2], Usha Goswami[3], Denis Burnham[2]

[1]BCBL. Basque Center on Cognition, Brain and Language, San Sebastian, Spain

[2]The MARCS Institute for Brain, Behaviour and Development, Western Sydney University, Penrith, Australia

[3]Centre for Neuroscience in Education, University of Cambridge, Cambridge, UK

Corresponding author: Marina Kalashnikova, BCBL. Basque Center on Cognition, Brain and Language, Paseo Mikeletegi 69, San Sebastian, Guipuzkoa, 20009, Spain; t: +34 943 309 300 (ext: 234), m.kalashnikova@bcbl.eu

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Children of reading age diagnosed with dyslexia show deficits in reading and spelling skills, but early markers of later dyslexia are already present in infancy in auditory processing and phonological domains. Deficits in lexical development are not typically associated with dyslexia. Nevertheless, it is possible that early auditory/phonological deficits would have detrimental effects on the encoding and storage of novel lexical items. Word-learning difficulties have been demonstrated in school-aged dyslexic children using paired associate learning tasks, but earlier manifestations in infants who are at family risk for dyslexia have not been investigated. This study assessed novel word learning in 19-month-old infants at-risk for dyslexia (by virtue of having one dyslexic parent) and infants not at-risk for any developmental disorder. Infants completed a word-learning task that required them to map two novel words to their corresponding novel referents. Not at-risk infants showed increased looking time to the novel referents at test compared to at-risk infants. These findings demonstrate, for the first time, that at-risk infants show differences in novel word-learning (fast-mapping) tasks compared to not at-risk infants. Our findings have implications for the development and consolidation of early lexical and phonological skills in infants at family risk of later dyslexia.

Keywords: paired associate learning; word learning; lexicon; infancy; family risk

Young infants are able to recognise the meanings of familiar words in their language before their first birthday (Bergelson & Swingley, 2012; Fenson et al., 1994). Even in constrained laboratory settings, toddlers successfully map novel word forms to their referents after only a brief exposure to the words and their corresponding referent objects (Schafer & Plunkett, 1998; Werker, Cohen, Lloyd, Casasola, & Stager, 1998; Yoshida, Fennell, Swingley, & Werker, 2009). It has been proposed that this early ability to learn new words encountered in their language input along with their acquisition of the phonological categories of their language (Pater, Stager, Werker, & District, 2004; Stager & Werker, 1997; Werker, Fennell, Corcoran, & Stager, 2002) equips infants with the fundamental skills for building a lexicon (Werker & Curtin, 2005). As a corollary, *deficits* in word-learning abilities and/or phonological categorisation may serve as an early indicator of later language delays. As discussed in our brief literature review below, research has already linked the latter, acoustic/phonological skills, with later language development. This study is concerned with the former, early word learning. Difficulties in learning novel words have been documented for children who already exhibit language problems such as late talking (Rescorla, Mirak, & Singh, 2000), children with developmental language disorders (Nation, 2014), and children with reading difficulties or dyslexia (Elbro & Jensen, 2005; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003). Nevertheless, it remains unknown whether such difficulties are also manifested in at-risk infants *before* there is any indication of a language disorder. In this study, we investigate this question by comparing early word-learning ability in infants who are at family risk for developmental dyslexia with infants who are not at-risk.

Dyslexia is a neurodevelopmental disorder of reading and spelling skills manifested independently of the child's general intellectual capacities and educational opportunities, and it affects approximately 7-10% of the world's population (Snowling, 2001). While dyslexia is defined primarily as a reading disorder, it is also characterised by phonological deficits, manifested in assessments of phonological awareness, phonological short term memory, and rapid retrieval of phonological forms (Noordenbos & Serniclaes, 2015; Snowling & Melby-Lervag, 2016). While dyslexia can only be diagnosed once reading begins, there is a genetic component to this disorder (Galaburda, LoTurco, Ramus, Fitch, & Rosen, 2006). Approximately 35-60% of infants born to a dyslexic parent also develop reading difficulties later in life (Pennington, 2006; Pennington & Lefly, 2001). Accordingly, the ability to identify young infants who are at family risk for developing dyslexia provides the opportunity to investigate early pre-linguistic and linguistic skills in this population, years before their reading abilities can be assessed (Lyytinen et al., 2001; Lyytinen et al., 2006).

Although the developmental origins of the phonological processing and later reading deficits in dyslexia continue to be debated (Goswami, 2015), evidence from electrophysiological and behavioural measures suggests that at-risk infants already exhibit deficits in the auditory processing of speech and non-speech sounds in their first year of life; deficits that could be expected to affect novel word learning. For instance, the detection of changes to the acoustic features of speech and non-speech sounds (e.g., F0 frequencies, vowel length, and consonant voice onset time) in newborns and two-month-olds is significantly worse in at-risk than in not at-risk infants, and there are also differences in their hemispherical distribution of the neural responses to these acoustic stimuli (Guttorm, Leppänen, Hämäläinen, Eklund, & Lyytinen, 2010; Guttorm et al., 2005; Leppänen et al., 2010; van Zuijen, Plakas, Maassen, Maurits, & van der Leij, 2013). Reporting on a sub-group of the infants participating in the current report, Kalashnikova, Goswami, and Burnham (2018) assessed at-risk and not at-risk infants' acoustic ability to discriminate amplitude envelope rise times. They found that at-risk infants showed significantly higher discrimination thresholds than not at-risk infants by 10 months of age, suggesting a degree of early auditory insensitivity. Infant acoustic discrimination of amplitude envelope rise time is known to be related to later vocabulary development, whether the infants are at-risk for dyslexia or not (Kalashnikova, Goswami, & Burnham, 2019a). Amplitude envelope rise time refers to the time period from the onset of an amplitude envelope to its point of maximum amplitude, and it plays a core role in neural speech encoding and in speech intelligibility (Di Liberto et al., 2018; Power, Mead, Barnes, & Goswami, 2012, 2013, 2016; Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995). This brief review suggests that infants at-risk for dyslexia already exhibit significant differences in early auditory and speech processing skills, which might be expected to affect their novel word learning abilities. It is therefore of interest to assess novel word learning abilities in at-risk infants using a fast-mapping paradigm, at an age before any formal diagnosis is possible.

Compared to other language processing skills, early lexical development has not been studied widely in infants at family risk for dyslexia. Indeed, deficits in lexical skills and verbal IQ are classically not considered to be part of the criteria used to identify and diagnose developmental dyslexia (see Snowling & Hulme, 2012 for a discussion). This has been confirmed by studies showing that school-aged children with dyslexia develop overall age-appropriate oral language skills (Nation & Snowling, 1998; Snowling, Bishop, & Stothard, 2000). Nonetheless, in pre-school children, a number of studies indicate differences in vocabulary size for children at-risk for dyslexia at different developmental time points (Chen, Wijnen, Koster, & Schnack, 2017; Koster, Been, & Diepstra, 2014; Lyytinen et al., 2004). For instance, Scarborough (1990) found that at-risk children did not differ in their vocabulary size from controls at 30 months of age, but they did have smaller vocabularies than controls at 36 and 42 months. Similarly, Lyytinen and colleagues (2004) reported no group differences in vocabulary size from 12 to 30 months, but lower vocabulary scores emerged in at-risk children compared with controls after the age of 30 months. However, more recently, studies examining parental reports of Dutch at-risk and not at-risk infants' early expressive vocabulary sizes have shown that reliable group differences can be found as early as at 17 months (Koster et al., 2014) and 19 months of age (Chen et al., 2017). These studies suggest that dyslexia may impact early vocabulary growth, but while fast-mapping skills and vocabulary size are related, they are considered to be independent factors in the infant literature on lexical development (Axelsson & Horst, 2013; Kucker, McMurray, & Samuelson, 2015).

Nevertheless, impaired fast-mapping abilities would be expected to impact vocabulary development. Being at-risk for dyslexia may have a direct effect on infants' vocabulary size as a result of early difficulties in auditory processing and speech perception intrinsic to the infant, such as the amplitude rise time deficits related to vocabulary development that we have documented (Kalashnikova et al., 2018, 2019a). These sensory differences may disrupt the process of establishing and retaining mappings between novel words and their referents, impairing fast mapping. Of course, it is still possible that lower vocabulary size in at-risk children may be an indirect product of dyslexia. That is, children may develop a smaller vocabulary size not as a result of their genetic predisposition for dyslexia, or its related auditory and phonological processing deficits, but due to environmental factors related to their experience of growing up in families with a history of dyslexia (Pennington, 2006). Factors that can have an impact on early vocabulary size include socio-economic status variables such as maternal education (Hoff, 2003; Fernald, Marchman, & Weisleder, 2013; Pan, Rowe, Singer, & Snow, 2005), and environmental factors such as early exposure to print materials (Montag, Jones, & Smith, 2015), maternal language behaviours (Tamis-LeMonda, Bornstein, & Baumwell, 2001), and the quality of maternal speech (Kalashnikova & Burnham, 2018), all of which have been shown to be affected if one or both of the child's parents have dyslexia (Kalashnikova et al., 2018;

Lyytinen, Eklund, & Lyytinen, 2003; Torppa, Eklund, Bergen, & Lyytinen, 2011; Torppa, Lyytinen, Erskine, Eklund, & Lyytinen, 2010).

To our knowledge, novel word learning has not yet been investigated experimentally in young infants at-risk for dyslexia, an omission that we remedy here by using a fast-mapping paradigm. However, novel word learning ability *has* been explored in pre-school and school-aged children using Paired Associate Learning (PAL) tasks. In these tasks, the child is required to learn an association between two representations, usually a novel spoken word and a visual referent (e.g., Aguiar & Brady, 1991; de Jong et al., 2000; Elbro & Jensen, 2005; Gathercole & Baddeley, 1990; Thomson & Goswami, 2010; Wimmer et al., 1998; Windfur & Snowling, 2001; Hulme, Goetz, Gooch, Adams, & Snowling, 2007). Studies across languages have found that children with dyslexia perform significantly worse than same-age typical reading controls in PAL tasks (e.g., Elbro & Jensen, 2005; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003; Vellutino et al., 1995). The source of these PAL deficits has been debated, but it has been shown that it is unlikely that PAL deficits are related to difficulties in establishing word-referent associations *per se*; instead, dyslexic children experience difficulties in encoding detailed phonological representations of novel words and retrieving them specifically for production purposes (Clayton, Sears, Davis, & Hulme, 2018; Litt, de Jong, van Bergen, & Nation, 2013; Litt & Nation, 2014). For instance, Kalashnikova and Burnham (2016) demonstrated that when children are required to recognise novel label-object associations in a comprehension version of the PAL task, dyslexic and control children perform similarly, but dyslexics do have difficulty when required to *produce* the same labels in response to seeing a target object.

Regarding potential links between novel word learning and auditory sensory processing, individual differences in amplitude rise time sensitivity have been shown to be related to individual differences in novel word learning in school-aged children with and without dyslexia (Thomson & Goswami, 2010). Thomson and Goswami's (2010) PAL study included the theoretically-important reading level match control group, a group of typically-developing children who were younger than the children with dyslexia, but who were equated for reading level to the children with dyslexia. Thomson and Goswami found that PAL of novel label-visual object associations was impaired in children with dyslexia compared to *both* age-matched and younger controls, suggesting that the PAL deficit in dyslexia is not driven by reading ability. Further, within the dyslexic group, children with poorer rise time discrimination showed significantly poorer PAL than children with better rise time discrimination. Therefore, in addition to the difficulties in retrieving novel words for production, a word-learning deficit in young infants at-risk for dyslexia could be expected on the basis of their early deficits in auditory processing (Guttorm et al., 2005; Kalashnikova et al., 2018; Plakas et al., 2013; van Zuijen et al., 2013), which may be reflected in their ability to encode novel lexical representations.

In order to assess this possibility, the present study investigated the ability to map two novel objects to their corresponding novel referents by 19-month-old infants who were or were not at family risk for dyslexia. At this age, infants who are not at risk for language delays usually undergo a significant growth in their expressive vocabulary (Fenson et al., 1994; Nazzi & Bertoncini, 2003) and demonstrate robust abilities in mapping words to their referents after brief exposure. We predicted that if infants at-risk for dyslexia experience difficulties in encoding novel phonological forms, then these infants should exhibit lower rates of learning the novel words in this fast-mapping paradigm than not at-risk infants.

Method

Participants

Thirty 19-month-old infants participated in this study: 15 were at-risk for dyslexia (AR; 8 female; *M* age = 86.0 weeks, *SD* = 2.6), and 15 were not at risk for any language disorders

(NAR; 8 female; *M* age = 85.5 weeks, *SD* = 1.5). All infants were acquiring English in a monolingual context, and had no reported risk for any additional cognitive or physical disorders. An additional 11 infants participated (6 NAR and 5 AR) but were excluded due to extreme fussiness (1 AR), failure to contribute sufficient gaze data for analyses (5 NAR, 3 AR, see Data coding below), or failure to reach the habituation criterion (1 NAR, 1 AR). Maternal education level was used as an index of families' Socio Economic Status. The education levels ranged from a high school diploma to a Master degree in the two groups (Median = university degree), and there were no significant differences between the groups, Kolmogorov-Smirnov $Z = .183$, $p = 1$.

To confirm infants' group assignment and parental diagnosis, parents of all at-risk infants completed a comprehensive battery of literacy-related skills and general language and cognitive tasks. Parents of control infants were not screened. The test battery included two reading tasks: word and non-word reading (Test of Word Reading Efficiency; Torgesen, Wagner & Rashotte, 1999), digit span (Wechsler Individual Achievement Test II, WIAT; Breaux, 2010), oral reading accuracy and fluency (WIAT), spelling (WIAT), and rapid picture naming (Woodcock-Johnson III; Schrank & McGrew, 2001). In addition, parents completed a measure of non-verbal IQ (Matrix Reasoning and Block Design sub-tests from the Wechsler Adult Intelligence Scale; Wechsler, 2014). An infant was assigned to the AR group, if at least one of their biological parents scored 1.5 SD or more below the standardised mean in (a) one of the reading tests and (b) three or more of the remaining screening tests, and (c) both parents obtained average non-verbal IQ scores. In the case of 5 infants, criteria (a) and (b) were not satisfied, but they were included in the at-risk group as one of their parents had a formal diagnosis of dyslexia. Appendix Table 1 presents individual screening scores and parental information for infants assigned to the AR group; note that Parent 1 had had a childhood diagnosis of dyslexia.

Word-Learning Task

This study used a fast-mapping task that consists of a combination of a habituation phase and a Looking While Listening (LWL) test phase. The design of the stimuli, procedure, and analyses steps were based on Yoshida et al. (2009) who provide a detailed description and rationale for this experimental procedure.

Stimuli and apparatus. The auditory stimuli consisted of the non-words "*lif*" and "*wug*". A female native speaker of Australian English was recorded producing these words in infant-directed speech. Recordings of each word were then concatenated to create two stimulus strings using Praat software (Boersma & Weenink, 2005). One string was used for habituation trials. It was 20 seconds long and consisted of repetitions of each word with an ISI of 500 msec. A second string was used for the preferential looking trials, which was 4 seconds long and included two phases: baseline and test. The baseline phase was 2000 msec in duration, and it consisted of 1630 msec of silence plus 370 msec of the first token of the target word (this is the time typically required for the infant to initiate a visual response to the target word; Fernald, Pinto, Swingley, Weinbergy, & McRoberts, 1998). The test phase was also 2000 msec in duration, and it consisted of 4 tokens of the target word presented with an ISI of 500 msec identical to the habituation trials (Yoshida et al., 2009). The distinction between the two phases was unnoticeable for the infants, but it was used for analysis purposes as described in Procedure below.

Images of two novel objects were selected from the 'Fribbles' set in the Tarr Lab Object Database (Yildirim & Jacobs, 2013) and were used as visual referents for the two novel words. For the habituation phase, the images were each embedded into a 20 second video clip in which the object was presented on a black background and moved on the video screen along the horizontal plane. The labels in the auditory string occurred asynchronously from the movements of the object. For the preferential looking trials, two static images of the objects depicted on a black background were used.

In addition to the auditory and visual test stimuli described above, the same speaker was recorded producing the phrases "*look at the ball*" and "*look at the cup*". These phrases were matched with static images of a ball, cup, shoe, and clock, which were embedded into 4-second trials, identical to the target label preferential looking trials. These filler trials were included to maintain infants' engagement throughout the task. Finally, a video of a moving water-wheel toy accompanied by an audio recording of the non-word "*pok*" was used for the attention trials that served to measure infants' engagement in the task before and after the presentation of the experimental stimuli.

Visual stimuli were presented on three 20 inch Dell monitors located side-by-side, and the auditory stimuli were presented over loudspeakers located behind the left and right monitors at a volume level that was comfortable for the child.

Procedure. During the task, the infant sat on their caregiver's lap approximately 60 cm away from the monitors and facing the centre monitor. The caregiver listened to masking sounds over noise-cancelling headphones and was instructed to remain silent and to avoid pointing to the screens during the task. An experimenter observed the infant's behavior via a CCTV camera in an adjacent room and recorded the direction of the child's gaze by pressing the left, right, or centre arrows on a computer keyboard.

The task comprised a combination of habituation and preferential looking components. During habituation, infants were introduced to the novel label-novel object pairings, one pairing at a time. Habituation stimuli were presented on the center monitor. During the preferential looking trials, infants saw the two objects side-by-side and heard one of the test labels. These stimuli were presented on the left and right monitors. See Fig. 1 for a graphical representation of the task.

[insert Fig.1 about here]

At the start of the task and before each trial, infants were presented with an attention getter (a flashing red light) to direct their gaze to the centre screen. As soon as the infant fixated the centre screen for 1 second, they completed the first attention trial and proceeded to the habituation and preferential looking phases. After the final trial of the preferential looking phase, infants completed the second attention trial.

Habituation phase: Habituation trials were presented in up to 6 blocks of 4 trials each, two trials for one label and two trials for the other label, always presented in alternating order. The habituation phase terminated when infants reached the habituation criterion, i.e., when total looking time on a given block decreased to 65% of the total looking time on the previous block.

Preferential looking phase: The preferential looking phase consisted of 4 blocks of 4 trials each. In each block, two trials were target label trials (one trial for each novel label) and two filler trials. During the target label trials, infants heard 4 repetitions of one of the labels presented during habituation (e.g., *"lif, lif, lif, lif"*). During filler trials, infants heard a phrase asking them to look to one of the familiar objects (e.g., "*look at the ball!*"). The order of trials within a block was randomised across blocks. The target object appeared on the right screen on one target label trial of each block and on the left screen on the other trial.

Data coding. Infants' looking duration to each side was recorded in preferential looking trials, and the proportion of overall looking time in the baseline phase and the test phase was calculated for analyses. In order to ensure that our baseline measure was reliable, only trials in which the infant fixated both objects during the baseline phase for at least 100 msec were retained for analyses. Eight infants (5 NAR and 3 AR) were excluded from the study because they did not contribute any trials that satisfied this criterion, and therefore failed to contribute sufficient gaze data for analyses. Responses to the two target labels were collapsed for analyses. Responses to the filler trials were not included in the analyses.

Expressive Vocabulary

The OZI: Australian English Communicative Development Inventory (Kalashnikova, Schwarz, & Burnham, 2016), which is an adaptation of the MacArthur-Bates Communicative Development Inventory (Fenson et al., 1994), was used to assess infants' expressive vocabulary size. The OZI consists of a checklist containing 558 words that are likely to be familiar to young infants, and in which parents are asked to select the words that they have heard their infant use spontaneously. The total number of selected items is used as the individual expressive vocabulary score. Parents were provided with the OZI and asked to complete it at home within a week of completing the experiment and return it by mail. Nine families (4 NAR and 5 AR) failed to return their inventories resulting in missing data for the analyses reported here.

Results

First, infants' performance during habituation and the attention trials at the start and end of the experimental session was analysed. No significant differences were observed in the total duration of habituation trials, $t(28) = 1.563$, $p = .129$, $d = .591$, or the number of habituation trials, $t(28) = .800$, $p = .430$, $d = .302$, completed by the AR (*M* duration = 104.83, *SD* = 45.37, *M* number = 11.47, *SD* = 3.96) and NAR infants (*M* duration = 81.28, *SD* = 36.72, *M* number = 10.40, *SD* = 3.31). Therefore, infants in the two groups required a similar amount of exposure to the audio-visual stimuli prior to reaching the habituation criterion and proceeding to the next phase. Next, a 2 (trial: attention trial 1, attention trial 2) × 2 (group: NAR, AR) ANOVA showed no effect of trial, $F<1$, group, $F(1, 28) = 1.013$, $p = .323$, $\eta^2 = .035$, and no trial by group interaction, $F(1, 28) = 1.218$, $p = .279$, $\eta^2 = .042$. Children's attention to the task did not wane during the experiment (NAR attention trial 1 *M*

= 17.67, *SD* = 3.74; attention trial 2 *M* = 16.94, *SD* = 5.27; AR attention trial 1 *M* = 14.81, *SD* = 5.70; attention trial 2 *M* = 16.87, *SD* = 6.11).

The proportion of looking time directed to the target object during the baseline and test phase of each preferential looking trial was calculated, and each child's performance in the test phase of each trial was analysed in relation to this trial's baseline phase. Infants' looking duration to the two objects was expected to be similar during baseline, but was expected to increase in the test phase if they recognised the referent of the target label, the classic measure of 'fast-mapping' used in the infant literature.

[insert Fig. 2 about here]

AR and NAR infants' performance in the test trials is depicted in Fig. 2. A 2 (segment: baseline, test) × 2 (group: NAR, AR) ANOVA yielded no significant main effects of segment, $F<1$, or group, $F<1$. However, there was a significant segment by group interaction, $F(1, 28) = 5.363$, $p = .028$, $\eta^2 = .161$. To investigate the source of the interaction, infants' performance in each segment was compared between the two groups. AR and NAR infants did not differ in the proportion of looking duration to the target in the baseline segment, $t(28) = 1.421$, $p = .166$, $d = .521$. That is, AR and NAR infants did not differ in the amount of attention that they directed to each object before hearing a label. However, NAR infants directed a significantly greater proportion of looking time to the target object in the test segment than the AR infants, $t(28) = 2.090$, $p = .046$, $d = .762$, indicative of fast mapping. That is, after hearing its label, NAR infants were more likely to direct their gaze to the target object than were the AR infants, who in fact were less likely to direct their gaze to the target object.

Follow up *t*-test analyses confirmed this interpretation of the interaction. There were no significant differences between the test and baseline looking proportion to the target in the NAR group, $t(14) = 1.507$, $p = .154$, $d = .601$, or in the AR group, $t(14) = 1.776$, $p = .098$, $d =$

.703. Proportion of looking to target in the test segment also was not different from chance (.5) in the NAR group (*M* = .548, *SD* = .151, $t(14) = 1.238$, $p = .236$, $d = .318$) or in the AR group (*M* = .406, *SD* = .215, $t(14) = 1.684$, $p = .114$, $d = .437$). These two post-hoc tests confirm that the source of the interaction was that for the proportion looking to the target as (i) there was no difference between groups at baseline, and (ii) there was a difference at test. The post-hoc analyses do not support the alternative possibility that NAR and AR infants showed opposite performance patterns in our task (looking to the target versus looking to the distracter in the test phase), as these baseline versus test comparisons were not significant for either group. Further, analysis of individual response patterns showed that 11 out of 15 NAR infants either maintained or increased their proportion of looking time to the target after hearing its label, consistent with a novel word learning interpretation of our data. In contrast, only 3 out of 15 AR infants showed this response pattern, with 12 AR infants decreasing their looking to target during test compared to baseline (Exact Binomial Test $p = .035$).

As a further check on our novel word learning interpretation of the data, infants' performance in the word-learning task was analysed in relation to their individual vocabulary size. NAR infants were reported to produce an average of 55.63 (*SD* = 55.56, *range* 9-191) words, and AR infants 54.10 words (*SD* = 60.63, *range* 4-189), and there was no statistical difference between the two groups' scores, $t(19) = .061$, $p = .952$, $d = .028$. Correlational analyses were then conducted between infants' vocabulary scores and their word-learning scores. Test-baseline difference scores were used as indices of word learning whereby a larger positive score denoted an infant's greater tendency to look at the target after hearing its label (see Byers-Heinlein & Werker, 2013; Kalashnikova, Mattock, & Monaghan, 2016; Kalashnikova, Escudero, & Kidd, 2018 for use of difference scores in similar analyses). This analysis revealed a significant correlation, $r(21) = .466$, $p = .033$, demonstrating that even though it was not the case that AR infants had smaller expressive vocabularies as a group, infants with larger vocabulary sizes were significantly more likely to look at the labelled target in the test phase of our word-learning task, indicative of greater learning. However, the variability within each groups' scores is noteworthy, and calls for caution in the interpretation of these data, particularly given that vocabulary data were missing for 9 infants in our sample.

Discussion

Infants at family risk for dyslexia have been shown to experience auditory processing and phonological deficits years before any delays in reading or spelling skills are observed (Kalashnikova et al., 2018; Lyytinen et al., 2004, 2006; van Der Leij et al., 2013). This study demonstrates that the ability to map novel words to their referents is another of the developing abilities already affected in at-risk infants at 19 months of age. This finding suggests that the propensity for general auditory and language processing deficits in infants at-risk for dyslexia can affect the development of early word learning and vocabulary development in the first years of at-risk children's lives. While we interpret the group-level differences observed here as related to the AR group being at-risk for dyslexia, it is also possible that that AR infants' performance may reflect risk for a general developmental language disorder (DLD) in addition to or instead of risk for dyslexia. There is extensive evidence that these developmental disorders are comorbid, and that some children at family risk for dyslexia develop general oral deficits characteristic of DLD (Snowling & Melby-Lervag, 2016). In support of our preferred interpretation, we note that the word-learning difficulty reported in our AR group is consistent with previous effects of family risk of dyslexia on skills related to lexical competence in our sample, including familiar word recognition (Kalashnikova, Goswami, & Burnham, 2019b) and auditory rise time discrimination (Kalashnikova et al., 2018).

While fast-mapping ability relies heavily on speech perception and lexical skills (Werker et al., 1998; Werker & Tees, 2005), it is a complex task that requires children to attend to the auditory and visual stimuli, establish associations between them, store them in short-term memory, and retrieve these associations at test. Hence, in addition to speech perception and phonological abilities, it is plausible that other deficits identified in individuals with dyslexia may account for or at least contribute to at-risk infants' diminished performance in this task, including difficulties with selective attention, visuo-spatial processing, and associative learning (Alt et al., 2017). It is not possible to discard all these possibilities based on our findings, as we did not include an associative learning control task. However, we believe that it is unlikely that infants' performance here was due to deficits in attention, since between-group performance only differed in the post-naming phase and not in any other phase of the task. If the infants at-risk for dyslexia required greater exposure to the labels and visual referents in the task, they would have been expected to require a greater number of habituation trials, a greater total duration of habituation, or even to fail to habituate altogether. None of these were the case. Similarly, there was no evidence that at-risk infants were inattentive overall or less engaged in the task, as they showed similar looking patterns to control infants in habituation, baseline segments, as well as the attention trials.

Research with school-aged children with dyslexia has also concluded that it is unlikely that word-learning difficulties in dyslexia are due to a general deficit in associative learning (Litt & Nation, 2014). The key evidence is that dyslexic children are successful at learning visual-visual and verbal-visual associations, but that they perform worse than same-age controls and younger controls in tasks in which they must retrieve newly-learned labels for production (Kalashnikova & Burnham, 2016; Litt et al., 2013; Thomson & Goswami, 2010). The fact that children's difficulty is restricted to visual-verbal PAL points to a lack of specificity in developing novel phonological representations rather than a general learning deficit. Further support for this explanation comes from evidence that children's difficulties in word-learning tasks are further exacerbated if the task involves multisyllabic lexical items (Alt et al., 2017), or items that are stored in high density lexical neighbourhoods (Thomson & Goswami, 2010), both of which increase the phonological learning load.

An alternative account for the present findings is that NAR and AR infants were able to establish the novel mappings to a similar extent, but that recognition of the mapping at test was manifested differently in the two groups. That is, the majority of infants in the AR group decreased their looking time to the target object after hearing its label, which was opposite to the response pattern observed in the NAR group. Similar preferential looking paradigms have been used extensively to assess infants' recognition of familiar or novel labels, and they tend to elicit recognition rather than novelty response patterns in infants and toddlers (Fernald, Zangl, Portillo, & Marchman, 2008). However, it is possible that AR infants interpreted the demands of this task differently as similar inconsistencies in familiarity and novelty responses have been documented across development and across task contexts for other paradigms used in infancy research (Houston-Price & Nakai, 2004; Liao, Yeh, & Shimojo, 2011). It is also noteworthy that responses in visual preference paradigms are time sensitive, so it is possible that the response pattern observed here reflects AR infants' need for additional processing time in this task. When infants see two familiar referents and hear one of their labels, their lexical processing efficiency is indexed by the time it takes them to re-direct their gaze from the distracter object to the target after the onset of the target's label. These latencies decrease as a function of age and increasing vocabulary size (Fernald & Marchman, 2012; Fernald, Perfos, & Marchman, 2006; Fernald et al., 1998). Additionally, when infants are uncertain about the label-object mapping such as in cases where they must infer the referent of an unfamiliar label (Halberda, 2003) or when the label has been mispronounced (Swingley & Aslin, 2000), they tend to fixate the distracter prior to redirecting their gaze to the target object. Therefore, it is possible that AR infants were able to recognise the target for the labels in this task, but this recognition was manifested in increased looks to the distracter. This could reflect their reduced efficiency in lexical access, which may be confirmed by our finding of the correlation between vocabulary scores and word-learning performance since infants with smaller vocabularies tend to show reduced lexical processing efficiency. It could also be due to uncertainty in label recognition related to lower specificity in the mapping or in the phonological representation of the novel word as observed in school-aged dyslexic children's performance in paired associative learning tasks (Kalashnikova & Burnham, 2016; Litt & Nation, 2014). Future studies may be able to use eye tracking technology to differentiate between these possibilities.

Previous research has demonstrated that young infants at family risk for dyslexia have smaller vocabulary sizes around the age of the vocabulary spurt (Koster et al., 2014). However, it appears that this deficit does not persist, as Scarborough et al. (1990) reported that pre-school children at risk for dyslexia had similar vocabulary sizes to their not at-risk peers at age 30 months, although the at-risk children did have smaller vocabularies than their controls at 36 and 42 months. Other studies suggest that this dissociation may occur even later, around six years of age (Caglar-Ryeng, Eklund, & Nergard-Nissen, 2019). The developmental trajectory of the vocabulary skills in at-risk infants remains to be defined as these findings can be due to differences in the samples included in each study. For instance, the comparison of AR and NAR infants' expressive vocabulary size in this study did not yield significant group differences, but it indicated a large amount of individual variability, which is characteristic of infant vocabulary size data (Fenson et al., 1994), and that could have also affected group-level comparisons in the above-mentioned previous studies. However, this does allow for the possibility that, while children at-risk for dyslexia may experience difficulties with learning new words during their first years of life, they may overcome these difficulties as they develop more advanced linguistic competence. Furthermore, at-risk infants' fast-mapping performance, even at ages younger than 30 months as in this study, may be facilitated by additional referential and contextual cues. Supporting information such as pre-exposure to the novel words or novel objects and the use of carrier phrases in word-learning tasks have been demonstrated to foster typically-developing infants' performance in challenging word-learning situations by reducing the cognitive load of experimental tasks and thus allowing infants to allocate more attentional resources to the phonetic detail of the novel words (Fennell & Waxman, 2010).

This study assessed the ability to map a novel label to a novel referent in infants who were at familial risk for dyslexia by virtue of having one dyslexic parent. At-risk infants were significantly less successful in learning new words than same-age infants who were not at-risk for any developmental language disorder. Similar difficulties in establishing and retrieving novel word forms have been identified in school- and pre-school-aged children with language and reading difficulties, and have been attributed to a lack of specificity in the phonological representations stored in the lexicon. Our findings demonstrate that these difficulties can already be identified in at-risk infants before their second birthday, suggesting that being at risk for dyslexia impacts not only early phonological skills but also early lexical skills, thus affecting at-risk children's general language abilities years before they start learning to read.

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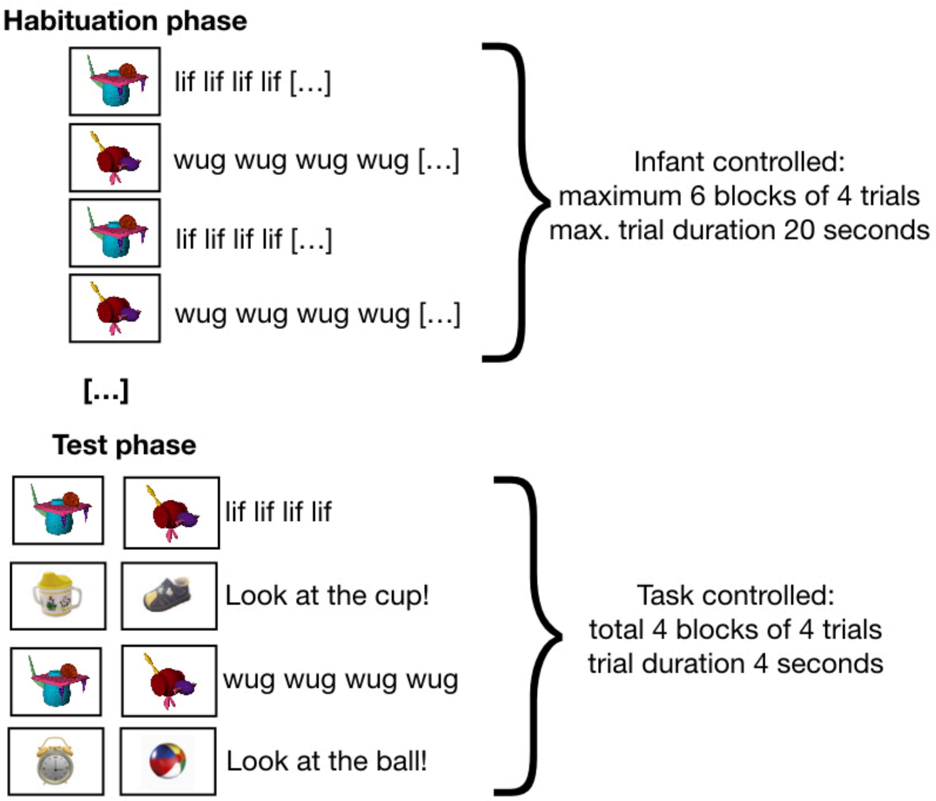
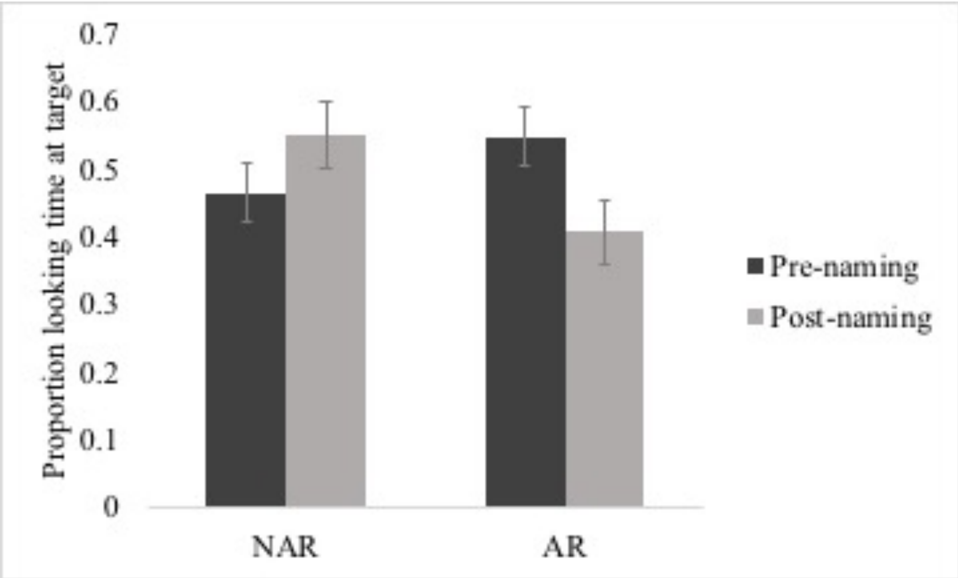
List of figures

Fig. 1. Graphical representation of the (A) habituation blocks, (B) preferential looking blocks, and (C) structure of the preferential looking trials included in the word-learning paradigm.

Fig. 2. Proportion of looking time to the target in the baseline and test phases by NAR and AR infants.


Habituation phase
lif lif lif lif […]
wug wug wug wug […]
lif lif lif lif […]
wug wug wug wug […]
Infant controlled:
maximum 6 blocks of 4 trials
max. trial duration 20 seconds
[…]
Test phase
lif lif lif lif
Look at the cup!
wug wug wug wug
Look at the ball!
Task controlled:
total 4 blocks of 4 trials
trial duration 4 seconds


Proportion looking time at target
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
NAR
AR
Pre-naming
Post-naming

Appendix

Table 1. *Individual parental screening scores for infants assigned to the at-risk (AR) group.*

	Parent	Word reading (WIAT III)[1]	Non-word reading (WIAT III)[1]	Sight word efficiency (TOWRE)[1]	Phonetic decoding efficiency (TOWRE)[1]	Spelling (WIAT III)[1]	Oral reading fluency (WIAT III)[1]	Oral reading accuracy (WIAT III)[1]	Oral reading rate (WIAT III)[1]	Rapid Automated Naming (Woodcock-Johnson)[1]	Digit span (WAIS)[2]	Non-verbal IQ (WAIS)[3]
1	Father	98	101	94	98	89	101	118	98	89	10	13
2	Mother	77	73	90	76	86	94	122	95	122	8	10.5
3	Mother	60	40	81	63	55	73	67	72	87	4	12
4	Father	105	108	83	90	98	74	82	73	89	15	14
5	Father	57	66	83	71	60	73	66	76	97	8	9.5
6	Mother*	89	70	99	80	90	108	40	60	94	8	11.5
7	Mother*	107	112	94	95	82	46	42	113	94	9	9
8	Father	69	66	80	73	56	73	63	76	101	7	12
9	Father*	84	69	75	72	85	81	80	86	96	8	9.5
10	Mother*	63	70	71	0	74	91	87	89	116	5	12.5
11	Father*	107	89	95	104	106	97	96	95	92	12	13
12	Father	105	108	83	90	98	74	82	73	89	15	14
13	Mother*	107	96	99	100	106	101	102	104	102	6	11
14	Father*	94	82	103	90	95	106	89	106	114	5	11
15	Father*	98	106	96	95	101	93	81	97	99	11	14.5
16	Father*	94	88	97	100	98	97	76	100	104	11	10.5
	M	88.375	84	88.9375	81.0625	86.1875	86.375	80.8125	88.3125	99.0625	8.875	11.71875
	SD	17.88808	20.36337	9.553141	24.94118	16.85316	16.59669	22.78953	15.07633	10.44649	3.304038	1.702633

*Inclusion based on formal diagnosis of dyslexia

[1]Standardised score $M = 100$, $SD = 15$

[2]Standardised score $M = 10$, $SD = 3$

[3]Average scaled score for Matrix Reasoning and Block Design subtests $M = 10$, $SD = 3$