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# The roles of family history of dyslexia, language, speech production and phonological processing in predicting literacy progress

Julia M. Carroll[1]

Ian R. Mundy[2]

Anna J. Cunningham[3]

[1]University of Warwick, UK

[2]Coventry University, UK

[3]Aston University, UK

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Abstract

It is well established that speech, language, and phonological skills are closely associated with literacy, and that children with a family risk of dyslexia (FRD) tend to show deficits in each of these areas in the preschool years. This paper examines what the relationships are between FRD and these skills, and whether deficits in speech, language and phonological processing fully account for the increased risk of dyslexia in children with FRD.

153 4-6 year old children, 44 of whom had an FRD, completed a battery of speech, language, phonology, and literacy tasks. Word reading and spelling were retested six months later, and text reading accuracy and reading comprehension were tested three years later. The children with FRD were at increased risk of developing difficulties in reading accuracy, but not reading comprehension. Four groups were compared: good and poor readers with and without an FRD. In most cases good readers outperformed poor readers regardless of family history, but there was an effect of family history on naming and nonword repetition regardless of literacy outcome, suggesting a role for speech production skills as an endophenotype of dyslexia.

Phonological processing predicted spelling, while language predicted text reading accuracy and comprehension. FRD was a significant additional predictor of reading and spelling after controlling for speech production, language and phonological processing, suggesting that children with FRD show additional difficulties in literacy that cannot be fully explained in terms of their language and phonological skills.

# The roles of family history of dyslexia, language and phonological processing in predicting literacy progress

Since the first study of children with a family history of dyslexia (FRD) twenty years ago (CELFScarborough, 1990), it has become well established that a significant proportion (around 40%) of children in this group will show literacy difficulties, and that these children are at increased risk of preschool speech and language difficulties. Children with FRD are usually defined as any child with a first degree relative (sibling or parent) who has been officially diagnosed as dyslexic. Examining the patterns of oral and written language difficulties shown in these children provides a fruitful way of establishing the relationships between these different skills in typically and atypically developing children. However, previous studies have not addressed the issue of whether poor readers with and without FRD show similar patterns of development, and whether the risk of FRD on later literacy is fully explained in terms of the early oral language difficulties that children in this group show. This study aims to address these questions.

Studies of children with FRD show that children who go on to become dyslexic show weaknesses in a range of areas, including speech production (Elbro, Borstrom, & Peterson, 1998; Scarborough, 1990); speech perception (H. Lyytinen et al., 2005; van Leeuwen et al., 2008), phonological processing (Elbro et al, 1998; Snowling, Gallagher & Frith, 2003) and receptive and expressive language (Scarborough, 1990; Snowling et al., 2003). Of course, demonstrating these deficits does not necessarily indicate that these deficits are causally implicated in dyslexia. However, additional studies have indicated that these difficulties are associated with prereading skills (Boets, Ghesquiere, van Wieringen, & Wouters, 2007; Boets et al., 2011; Guttorm, Leppanen, Hamalainen, Eklund, & Lyytinen, 2010).

A series of more complex questions about the nature of genetic risk and the cognitive markers of risk were addressed in some of the later studies of FRD children. For example, it is now generally agreed that risk of dyslexia is continuous, rather than discrete, with the ‘at-risk unimpaired’ children tending to show mild literacy impairments (Boets et al., 2010; Pennington & Lefly, 2001; van Bergen et al., 2011). However, the nature of this risk in cognitive terms seems to vary between studies. Both Pennington and Lefly (2001) and van Bergen, De Jong, Plakas, Maassen, and van der Leij (2012) found that at risk impaired children showed impairments in both phonological awareness and rapid naming, while at-risk unimpaired children tended to show weaknesses only in phonological awareness. These findings have interesting parallels with the patterns shown in language impaired children with and without literacy impairments (Bishop, McDonald, Bird, & Hayiou-Thomas, 2009; Brizzolara et al., 2006; Vandewalle, Boets, Ghesquiere, & Zink, 2012).

Other studies have identified a crucial role for broader oral language skills in the development of dyslexia in at-risk children. Snowling and colleagues followed a group of children with a FRD from three to thirteen years old (Gallagher, Frith, & Snowling, 2000; Snowling, Gallagher, & Frith, 2003; Snowling, Muter, & Carroll, 2007). The literacy-impaired and unimpaired children with FRD were both equally impaired in their phonics skills (phoneme awareness, letter knowledge and nonword reading) at six years old, but those who went on to be dyslexic showed additional broader language impairments. Snowling et al argue that good oral language acts as a protective factor in helping the high risk unimpaired children develop good literacy.

A related question is the extent to which the deficits shown in children with FRD mirror those shown in children with dyslexia who have no FRD. Possibly the most extensive and best-documented study of children with FRD is the Jyväskylä project (H. Lyytinen et al., 2001; Puolakanaho et al., 2007; Torppa, Lyytinen, Erskine, Eklund, & Lyytinen, 2010). In this project, approximately 100 children with a family history of dyslexia and 100 typically developing children were studied. Lyytinen and colleagues (Lyytinen, Eklund, & Lyytinen, 2005; Lyytinen, Poikkeus, Laakso, Eklund, & Lyytinen, 2001) argue that the oral language difficulties shown in FRD children may differ in qualitative ways from those shown by non FRD children. In their research, while late talkers are relatively common in both the familial risk and control groups, late talkers in the family risk group are more likely to have impairments in both receptive and expressive language, and (independently of this) are more likely to show persistent language difficulties. Hence, children with FRD are less likely to be able to overcome early oral language difficulties.

Typically, most at-risk studies have contrasted three groups: typical control children, FRD impaired readers and FRD unimpaired readers. In most studies, the small number of control children with reading impairment precluded statistical analysis of this group. For example, there were four ‘control-impaired’ children in Snowling et al., 2003, three in Pennington and Lefly, 2001 and two in van Bergen et al, 2012. While this group is analysed by Elbro et al. (1998), there were only five participants in the group, limiting statistical power. Excluding control impaired readers assumes that FRD impaired readers are representative of all impaired readers, an assumption that may well not be justified given the findings described above. A more appropriate approach is to use a comparison group that includes the full range of ability, and compare four different groups: poor readers and good readers with and without FRD. This is the approach taken in the current study. This will help to elucidate whether FRD status acts as an additional risk factor for dyslexia over and above measured variables. For example, Puolakanaho et al. (2007) finds that, in common with much other research, phonological awareness, rapid naming and letter knowledge were the most important cognitive predictors of literacy. However, familial risk status added further predictive power on top of these cognitive variables, indicating that familial risk cannot be fully explained in terms of poorer phonological awareness, letter knowledge or rapid naming.

Overall, therefore, while we can be confident that oral language and phonological skills are key factors in the development of children who go on to be dyslexic, the way in which these different factors are associated with one another and are moderated by family risk is not yet clear. Snowling et al (2003) indicate that both oral language and phonological difficulties are required for dyslexia, while Pennington and Lefly (2001) and van Bergen et al (2011) argue for a combination of phonological and orthographic difficulties. Lyytinen et al (2005) argue that the nature and persistence of the oral language difficulties shown in family risk children differs from that shown in typical children, and Puolakanaho et al (2007) find that family risk cannot be fully explained in terms of phonological awareness, letter knowledge and rapid naming.

This study also provides a useful opportunity to search for endophenotypes of developmental dyslexia. Endophenotypes are traits which are associated with a given disorder and can be thought of as intermediate between the genetics of a disorder and its behavioural manifestation (Bearden & Freimer, 2006). Using endophenotypes is a way of increasing the reliability of heritability estimates of psychological disorders. Endophenotypes are associated with risk for a particular disorder, and deficits are shown in unaffected family members at a rate higher than in the general population (Tierney, Gabard-Durnam, Vogel-Farley, Tager-Flusberg, & Nelson, 2012). It is important that the trait used as an endophenotype can be reliably and quantitatively measured, ideally showing a normal distribution. The longitudinal nature of this study, together with the broad ranging comparison group, allows us to search for endophenotypes.

*The role of Phonological Processing and language skills on literacy progress*

Traditionally, it has been argued that the main cause of dyslexia is a problem in phonological processing (Stanovich, 1988). However, partly as a result of the studies of children with FRD described above, researchers have emphasised the role of multiple interacting deficits. Bishop and Snowling (2004) contrast phonological deficits with non-phonological language deficits, and argue that dyslexic children show phonological deficits with normal broader language, while children with language impairments have difficulties in both areas. However, there is growing evidence that on an individual level, not all children with dyslexia show deficits in any given area (White et al., 2006). Pennington (2006) argues that dyslexia is best characterised as being caused by interacting multiple deficits (for example, a combination of a deficit in phonological processing with a deficit in processing speed). If one took a traditional, phonological deficit view of dyslexia, one would expect that thorough measurement of phonological skills would allow accurate prediction of dyslexia, while Pennington's view allows a role for additional, unmeasured factors.

*The measurement of PP and language*

Both language and phonological processing are umbrella terms covering a wide range of skills. Despite this, relatively few at-risk studies have used measures of phonological processing beyond standard measures of nonword repetition and phonological awareness (though see Pennington and Lefly, 2001 for a study that does include a range of these measures). It is now well established that both nonword repetition and phonological awareness are influenced by existing levels of literacy and letter knowledge (Castles & Coltheart, 2004; Nation & Hulme, 2011). Therefore poor readers may show low scores on these measures as a consequence, rather than a cause of their literacy difficulties. Moreover, phonological processing skills are assumed to form a 'bridge' between basic speech and language processing and later meta-phonological awareness (Fowler, 1991; Morais, Cary, Alegria, & Bertelson, 1979; Rvachew, 2006; Rvachew, Ohberg, Grawburg, & Heyding, 2003). Therefore, it is important to use a range of phonological processing measures which tap skills that precede reading acquisition such as implicit phonological sensitivity (Carroll, Snowling, Hulme, & Stevenson, 2003; Morton & Frith, 1993) and nonword learning (Hulme, Goetz, Gooch, Adams, & Snowling, 2007). These measures tend to involve multiple skills (including speech production, speech perception and short term memory, for example). However, use of latent variables allows us to extract the common variance across these measures (namely, the role of phonological processes).

Measurement of broader oral language is similarly complex, encompassing receptive and expressive vocabulary, use and understanding of grammatical and morphological forms, as well as the understanding and production of complex sentences (Stackhouse & Wells, 1997). Several studies use vocabulary measures as a proxy for general language development (e.g. Dickinson, McCabe, Anastasopoulos, Peisner-Feinberg, & Poe, 2003; van Bergen et al., 2011), but some research suggests that both vocabulary and overall language skills predict independent variance in both phonological sensitivity and reading (NICHD, 2005). Therefore, it is important to use a range of measures that tap all of the above skills and to use latent variable modelling to extract the common variance. This is the approach taken in the current study.

*The role of speech production skills on literacy progress*

In comparison to the relatively large literature investigating language and phonological processing, only a few studies have focused on the links between speech, phonological processing, and literacy. Intuitively, speech perception and production would seem to be fundamentally related to phonological skills (Carroll & Snowling, 2004). However, there is a certain amount of evidence showing that speech skills (in particular, speech production skills) are surprisingly weak predictors of literacy progress (e.g. Nathan, Stackhouse, Goulandris, & Snowling, 2004; Snowling et al., 2003). In order to investigate this in the current study, speech production measures are taken in addition to the more complex phonological processing tasks.

Relatively few studies have directly investigated the possibility that the associations between speech, language, phonological processing and literacy may differ between typically and atypically developing samples. For example, the associations between speech perception, vocabulary and phonological awareness observed in speech-impaired children (Rvachew & Grawburg, 2006), may not be reflected in typically developing children, who show generally good speech perception skills, with relatively little individual variation. In other words, speech perception skills may only have substantial consequences for phonological and literacy development when they fall outside of the normal range. For example, some recent research has indicated that early speech perception skills predict later literacy independently of phonological processing and letter knowledge in a sample of children at high risk of dyslexia (Boets et al., 2011).

A related argument is that deficits in one area may act as barriers to progress in another area. For example, Chiat (2001) argues that difficulties in speech perception and phonological processing will limit a child's ability to acquire certain linguistic constructions, particularly certain affixes that are brief and difficult to hear. However, when phonological processing skills are within the normal range, they have little influence on language acquisition. Hence, one might expect skills to be more highly correlated in samples including many children with difficulties.

*The current study*

The current study extends the existing literature by examining the links between speech production, language, literacy and phonological processing in children with and without FRD in two ways. Firstly, the study utilises a wider range of measures than existing at-risk studies. Secondly, the design includes a comparison group with a full range of abilities which will allow the comparison of poor readers with and without FRD, thus shedding light on the independent contribution of FRD to literacy beyond the skills measured. A large sample of children was tested during the first two years of school and followed-up six months and three years later.

The study has three aims. The first is to establish the links between speech production, language, phonological processing and literacy, and whether these vary according to FRD status. The second is to find out what skills differ between good and poor readers and whether this differs by risk status. In common with Carroll & Snowling (2004), it is predicted that children with FRD will show poorer speech production skills than the comparison group. In line with this study, it is possible that speech production skills may be a useful endophenotype for developmental dyslexia. Finally we predict reading accuracy and comprehension using speech production, language and Phonological Processing, and examine whether this relationship differs according to FRD status. In common with previous research, it is predicted that children who go on to be poor readers will show poorer language and phonological processing at Time 1, but it is hypothesised that language and phonological processing levels will not completely explain the poorer progress shown in children with FRD. Additionally, given the increased role for language described by Puolakanaho et al. (2007), it is predicted that language will have a larger role in predicting literacy outcome in the FRD group rather than the comparison group.

In order to investigate these questions, we carry out three sets of analyses. First, correlations are compared in FRD children versus the comparison group. Second, we compare good and poor readers with and without FRD to establish patterns of strengths and weaknesses at the group level. Finally, risk status is included as an independent variable in the multiple regressions predicting growth in literacy.

## Method

### *Participants*

One hundred and sixty-three children in the first two years of formal schooling were recruited (Carroll & Myers, 2010)[1]. Five children had some hearing loss due to glue ear, and five children spoke English as an additional language, and were excluded from these analyses, leaving a sample of 153. The comparison group (*n* = 109) had no known risk factors for reading disability. Questionnaires were given to the parents of these children to confirm that none of them had a history of hearing loss or speech/language therapy, any suggestion of a developmental disorder or any first or second degree relatives with dyslexia. Children were included in the FRD group (*n* = 44) if they had a first degree relative with an official diagnosis of dyslexia. To verify, parents were asked when and by whom the relative was tested. Only families with diagnoses from suitably qualified professionals (i.e. Educational Psychologists or Specialist Teachers) were included. Seventeen of the 44 children with FRD had received speech and language therapy input at some point.

Children were tested at three time points over a period of three years. The mean age at time 1 was 5;6 years, with a range from 4;5 years to 7;0 years. Time 2 occurred approximately six months later (mean age 6;0), and time 3 approximately 3 years after time 1 when the children were in their fourth and fifth years of school (mean age 8;6). Fifty-one percent of the sample was male. The children were recruited through screening in mainstream classes and general advertising. One child left the study before Time 2, and a further 18 (14 typical children and 4 FRD children) left the study before Time 3, giving an overall attrition rate of 13.3%. This left a sample size of 134 for the longitudinal analyses (94 typical and 40 FRD children).

## *Tasks*

All children completed the same tasks, regardless of age. The tasks used were selected to be sensitive across the age range tested.

### *Language*

Four subtests of the Clinical Evaluation of Language Fundamentals Preschool 2nd UK edition (CELF: Wiig, Secord, & Semel, 2006) were used: *Sentence Structure, Word Structure, Expressive Vocabulary* and *Recalling Sentences. Sentence Structure* is a sentence comprehension task in which children have to point to a picture that depicts a spoken sentence. *Word Structure* is an expressive morphological task in which children have to correctly alter a word (e.g. when a child hears ‘Here is a girl. Here are two _’, they are expected to respond ‘girls’). *Expressive Vocabulary* is a task in which children have to name pictures correctly, and in *Recalling Sentences* a child is asked to repeat increasingly complex sentences. *Recalling Sentences* was repeated at each time point, while the other three tasks were administered only at Time 1.

*Speech production*

Two measures of speech production were used in the current study. The *Diagnostic Evaluation of Articulation and Phonology* (DEAP: Dodd, Hua, Crosbie, Holm, & Ozanne, 2002) served as a standardised measure of speech production The DEAP has a brief screening measure in which children are asked to name ten pictures twice, and asked to produce in isolation any sound they pronounce incorrectly (with the exception of age-appropriate errors, such as /f/ for /th/ in children under six). Further subtests are then conducted based on children's performance on the screener. However, only percentage consonants correct on the screener is used in the present study. In addition to the DEAP, *Picture Naming*, an experimental measure which included complex multi-syllabic words with unusual stress and consonant clusters (e.g. *squirrel* and *tomato*), provided a sensitive measure of minor residual speech errors. The dependent variable in this task was the percentage of consonants correctly articulated across all trials on which the child was able to identify the picture. Incorrectly named pictures were not included in the total. Inter-rater reliability was 97%. These two tasks were administered at Time 1 and Time 2.

*Literacy*

Two single word reading tasks were used: *British Abilities Scales II Word Reading* (Elliot, Murray, & Pearson, 1996) and *Reception Reading Words.* The *British Abilities Scales II Word Reading* is a task in which the words become increasingly difficult and the task is discontinued if children make eight or more errors in a block of ten. The *Reception Reading Words* task presents 45 of the earliest key sight words that are expected to be learnt by British children during the first year of formal schooling. This is therefore a sensitive measure for children at the earliest stages of reading. A total *Word Reading* measure was created by calculating the z-scores of both measures and adding them. These tasks were administered at Time 1 and repeated at Time 2.

In the *Spelling* task, children were shown eight pictures and asked to spell the words corresponding to each of them. They were encouraged to spell the words from their own pronunciation. The spellings were scored as conventionally correct, and also according to a phonetic spelling system described in Caravolas, Hulme, and Snowling (2001), which awards partial credit for phonemes similar to the target phoneme. A total spelling score was created by calculating the z-scores for the conventional score and for the phonetic score and adding them. This task was administered at Time 1 and repeated at Time 2.

*Letter Knowledge* was measured by showing children all of the 26 lower case letters and asking them to give their names and sounds. A total letter knowledge score was created by adding these two scores. This task was only presented at Time 1.

The *York Assessment of Reading Comprehension* (YARC: Snowling et al., 2011)) was administered at Time 3 and provided measures of word reading accuracy and text comprehension. During this task, children read 2 short text passages aloud. Decoding errors were noted by the experimenter as the children read and these formed the basis of the accuracy score. After completing each passage, children were asked to answer 8 comprehension questions of increasing difficulty in order to measure their understanding of the text.

*Phonological processing*

The children were asked to complete four tasks measuring phonological processing: *Nonword Repetition*, *Phonological Awareness, Mispronunciation Detection* and *Nonword Learning*[2]. The *Nonword Repetition* task contained 30 nonwords from two to five syllables in length. These words were taken from the Children's Nonword Repetition Test (Gathercole, Willis, Baddeley, & Emslie, 1994). The task was recorded and scored offline. Each word was given a single correct/incorrect score. Certain speech errors which were phonetically very close to the target sound were scored as correct (specifically ng-n, th-f, th-v and r-w). Inter-rater reliability was 86%. This task was repeated at each of the three time points.

The *Phonological Awareness* task was a two alternative initial sound matching task. For example, a child would be asked 'which word starts with the same sound as pig, is it bat or pool?'. The items were taken from Byrne and Fielding-Barnsley (1993) and were controlled for overall phonological similarity. This task was administered at Time 1 and Time 2.

The *Mispronunciation Detection* task assessed children's sensitivity to slightly mispronounced words. It was presented on a laptop using DirectRT (Jarvis, 2006). The child sees a picture and hears it named, either correctly or incorrectly. The child is asked to say whether or not the word was correctly pronounced. Feedback was provided on each trial. Sample specific reliability was high ($\alpha = 0.85$). This task was administered only at Time 1. While this task requires both speech perception and phonological processing skills, it is included as a phonological processing task in this battery, because it was felt that the speech perception element of the task was relatively straightforward (perceiving a single word in no noise with picture accompaniment), while the task of holding the word in mind and comparing it to the known phonological representation was more complex.

The *Nonword Learning* task was based on the paradigm used by Treiman and Breaux (1982) in which children and adults are asked to learn the names of animals and errors are recorded. The task is described in detail elsewhere (Carroll & Myers, 2011). Each child was asked to associate nine nonwords and toy animals (e.g. "the giraffe is called Mern"). Up to six trial sets were given, but the task was discontinued if the child completed two completely correct sets. A second testing session was carried out approximately twenty-four hours after the original learning session. No significant effects of testing session were found and so a single 'total correct' score was used which combines both test points. Sample specific reliability was high ($\alpha$ = 0.92). This task was administered only at Time 1.

## *Procedure*

All children completed the same tasks, regardless of age. The tasks used were selected to be sensitive across the age range tested. The children who were recruited through mainstream classrooms were assessed at school over a few weeks, completing a few short tasks each day. For the children recruited through other means it was not always possible to work in this way and some were tested at home. At Time 1, younger children completed four 30 minute sessions over two days, while older children were tested on one day for two 1 hour long sessions with a break in between. At Times 2 and 3, testing was normally completed in a one or two sessions. All children were tested individually by one of the authors or by a trained research assistant. Signed parental consent and verbal consent from the children was obtained in all cases.

### *Missing Data*

One child did not complete the *Word Structure* task from the CELF because of a request from their speech and language therapist, who was planning to do the task. Six children did not complete the *Nonword Learning* task and three did not complete the *Mispronunciation Detection* task due to technical difficulties. No group differences were found for those with missing data, and so they were included in the analyses when possible.

## Results

### *Age Effects and Data Preparation*

Given the relatively broad age range within the sample, it was important to consider the roles of age and schooling. Both age and school year correlated significantly with raw scores on many of the measures (shown in Table 1). Given the high correlation between age and school year ($r$ = .85), it was likely that they explained similar variance in the test variables. For this reason, standard scores were used if available (as for the CELF and YARC measures). For the other tasks, scores were residualised for age, then standardised against the comparison group such that the comparison group had a mean of 100 and a standard deviation of 15. *Picture Naming* and *DEAP* were retained as percentage consonants correct, as they showed ceiling effects in the comparison group, rendering standardisation unreliable.

Factor scores were created for Language (*Word Structure, Sentence Structure, Expressive Vocabulary* and *Recalling Sentences*), Phonological Processing (Phonological Processing: *Nonword Repetition, Phonological Awareness, Mispronunciation Detection* and *Nonword Learning*), Speech Production (*DEAP* and *Picture Naming*), and Literacy (*Word Reading, Letter Knowledge* and *Spelling*) by forcing a single factor solution for each set of variables using age standardised scores. The Language factor accounted for 62.4% of the total variance and showed good loadings from each measure (Sentence Structure: .704; Word Structure: .823; Expressive Vocabulary: .799; and Recalling Sentences: .826). The Phonological Processing factor accounted for 51.4% of the variance and showed adequate loadings from each measure (Nonword Repetition: .776; Phoneme Awareness: .747; Mispronunciation Detection: .592; Nonword Learning: .738). The Speech Production factor accounted for 93.27% of the variance, with high loadings from each of the two measures (.966 for both Picture Naming and DEAP). [3]The Literacy factor accounted for 80.8% of the variance, with high loadings from each of the measures (Word Reading: .934; Letter Knowledge: .858; Spelling: .903). One participant (a member of the FRD group) had an unusually low Speech Production factor score ($z$ = -9.27) and was excluded.

*Categorisation of good and poor readers.*

Children were designated poor word readers if they showed reading accuracy on the YARC at Time 3 more than 1 standard deviation below the mean for the comparison group. This proportion (i.e. 5 children in a typical class of 30) would be approximately the proportion that would be likely to receive some kind of extra literacy support in a classroom situation.

17% of the comparison group and 44.7% of the FRD group showed this pattern, meaning that poor reading accuracy was significantly more common in the FRD group ($\chi^2(1) = 13.66, p < .01$).

To further explore the effects of FRD status on Time 3 reading, children were designated Poor Comprehenders if they showed reading comprehension on the YARC at Time 3 more than 1 standard deviation below the comparison group mean (irrespective of their reading accuracy score). 19.3% of the comparison group and 18.2% of the FRD group showed this pattern, meaning that poor comprehension was not significantly more common in the FRD group ($\chi^2(1) = 0.02$, $p = .89$).

*What are the concurrent relationships between speech production, language, Phonological Processing and literacy, and do they vary according to FRD status?*

Correlations between the different factor scores are shown separately for the typical and FRD groups in Table 2. All correlations were significant apart from those between Speech Production and Language and Literacy in the comparison group. Statistical comparisons of the correlations in the typical and FRD groups revealed that after controlling for multiple comparisons, 1 out of 6 correlations differed significantly. In the FRD group, Phonological Processing was more highly associated with Speech Production than it was in the comparison group (p = .006). This provides tentative evidence for the hypothesis that difficulties in one area of spoken language may limit progress in other areas of spoken language.

Correlations between the individual measures are shown separately for the typical and FRD groups in Table 3. In general, each group of tasks showed moderate within group correlations – language tasks correlate with one another, the literacy tasks correlated with one another and the two speech tasks were highly correlated with each other, particularly in the FRD group. The phonological tasks show less consistent patterns of correlation, perhaps indicating that this factor is less tightly specified than the others measured.

Statistical comparisons of the correlations in the typical and FRD groups revealed that after controlling for multiple comparisons, only 2 out of 78 correlations differed significantly. In each case, correlations were higher in the FRD group. *Word*

*Structure* was more highly correlated with *Mispronunciation Detection* in the FRD group (p = .001) and the two speech production tasks were more highly correlated with one another in the FRD group (p < .001). Four further comparisons approached significance: *Nonword Repetition* correlated more highly with *Naming* (p = .003), *Phonological Awareness* (p = .003) and *DEAP* (p = .005) in the FRD group, and *Word Reading* appeared more highly correlated with *Word Structure* in the FRD group (p = .004).

To summarise, tasks involving accurate speech production (*Word Structure, Naming* and *Nonword Repetition*) were more highly correlated with each other and with *Phonological Awareness* in the FRD group. In addition, the task involving both phonological processing and speech perception (*Mispronunciation Detection*) was more highly correlated with a productive language measure in this group.

*What skills differ between good and poor readers? Does this differ by family risk status?*

Descriptive statistics for the four participant groups – comparison-average readers (*n* = 78), comparison-poor readers (*n* = 16), FRD-average readers (*n* = 21) and FRD-poor readers (*n* = 17) – are presented in Table 4. A series of reading group (average reader, poor reader) by FRD status (FRD, no FRD) two-way ANOVAs were conducted for the speech production, language, Phonological Processing and literacy variables. Significant effects of reader group indicate skills that were impaired in poor readers regardless of their FRD status. Significant effects of FRD status indicate skills that were impaired in children with FRD regardless of whether they go on to become poor readers. Significant interactions indicate different deficits across reader groups depending on the family history of the children. For example, they may indicate skills that are impaired only in poor readers with an additional FRD. In order to control for multiple comparisons, a linear step-up procedure (Benjamini, Krieger, & Yekutieli, 2006) was employed, which indicated that comparisons with $p<.018$ could be considered significant.

The results are relatively clear. On the Language measures, there was a significant effect of reading group on all of the measures except *Sentence Structure* at Time 1, and the effect of FRD group was significant only on the *Word Structure* measure. There were no significant interactions.

On the Speech Production measures, there were main effects of FRD group, but no effect of reading group, and no interactions. On the *Nonword Repetition* task, there were main effects of both reader group and FRD group at each of the three time points. The interaction was significant at Time 3 ($F(1,128) = 11.94$, $p < .01$, $\eta^2 = .09$), because the FRD-poor readers scored less well than the other three groups. On the other Phonological Processing measures, there were significant effects of reader group but no significant effects of FRD group. While the interaction between the two groups on *Nonword Learning* was nonsignificant, there was a suggestion it might have become significant in a larger sample ($F(1,121) = 4.93$, $p =.03$, $\eta^2 = .04$), because the comparison-poor readers achieved somewhat lower scores than the FRD poor readers. This is the only task on which this pattern was observed.

On the Literacy measures at Time 1 and 2, there was a significant main effect of reader group, as would be expected, but no effect of FRD group on the *Word Reading* and *Letter Knowledge* measures. The interaction of groups approached significance on *Spelling* at Time 2 ($F(1,127) = 5.44$, p = .046, $\eta^2 = .04$). At this time point, the FRD readers scored slightly less well than the non-FRD readers.

As the YARC had been used to identify children as good or poor readers, the effect of reader group on the YARC was not examined. There was no significant effect of FRD group on YARC reading accuracy scores ($F$ (1, 127) = 3.35, $p$ = .070, *ns*) or on YARC comprehension scores ($F$ (1, 127) = 1.60, $p$ = .21, *ns*). When YARC comprehension scores were residualised for accuracy and restandardised in order to control for differences in text reading accuracy between the FRD children and the controls, the effect of FRD status on comprehension ability was weaker still ($F < 1$). The interaction between reader group and FRD status was not significant in any of the analyses ($F < 1$ in all cases).

Overall, poor readers show poorer language, phonological processing and early literacy than the good readers, regardless of their FRD status. The children with FRD showed poorer speech production, nonword repetition and spelling, regardless of their reading outcome. The poor readers with FRD were poorer than the other three groups on *Nonword Repetition*, while the comparison group poor readers were marginally poorer than the other three groups on *Nonword Learning*. There are therefore some indications of differential patterns of impairments between these groups.

*What are the predictive effects of speech production, language and Phonological Processing on reading accuracy and comprehension, and does FRD status have an additional effect?*

For each dependent variable, three different regressions were carried out. These included the autoregressor at the first step, then the three Time 1 factors (Language, Speech Production and Phonological Processing) at step two and risk status at the third step (dummy coded with 0 = comparison group and 1 = FRD group), and at the final step, interaction terms were included assessing the association between risk status and language, Phonological Processing and speech production. These regressions are shown in Tables 5-8. In order to account for multiple calculations, the Benjamini two-step linear step up procedure for non-independent variables was used (Benjamini et al., 2006; Benjamini & Yekutieli, 2001). This indicated a p-value boundary at $p = .018$.

For the *Word Reading* and *Spelling* regressions at Time 2 (shown in Tables 5 and 6), a similar pattern was shown. The auto-regressor accounted for a large proportion of the variance (*Word Reading*: 76.6%; *Spelling*: 61.5%). In addition to this, Speech Production, Language and Phonological Processing entered simultaneously added a small but significant amount of additional variance (*Word Reading*: $R^2 = 2.4\%$; *Spelling*: $R^2 = 2.7\%$). In both cases Phonological Processing seemed to account for most of this variance, but it was a significant predictor only in the case of Spelling at Time 2. Language and Speech Production were not significant predictors. In the case of *Spelling*, FRD status accounted for further independent variance (B = -4.69, CI: -8.40 – -0.97, $p = .014$), while in the case of *Reading* this failed to reach significance (B = -2.71,CI: -5.46 – 0.04, $p = .053$). No significant interaction effects were found for either *Word Reading* or *Spelling*. The small contributions of the cognitive variables are likely due to the extremely large effect of the autoregressor, which itself is likely due to the small time lag of six months between T1 and T2.

A parallel set of regressions was carried out using the Time 3 *Reading Accuracy* and *Comprehension* measures. These regressions are shown in Tables 7 and 8. When predicting *Reading Accuracy*, as before, including Speech Production, Language and Phonological Processing explained a significantly larger percentage of the variance than the auto-regressor alone ($R^2$ = 12.3%). This was carried by Language. FRD status also explained significant further variance ($R^2$ = 3.1% B = -5.06, CI: -8.79 – -1.32, $p < .01$), and none of the interaction terms were significant.

In the regression predicting *Reading Comprehension*, *Word Reading* at Time 1 predicted a smaller percentage of the variance ($R^2$ = 22.2%) while the cognitive variables predicted a larger percentage ($R^2$ = 23.7 %). Language was a significant unique predictor ($\beta = .531$, $p < .01$), while Phonological Processing and Speech Production were not. FRD status did not add any further variance and none of the interaction terms were significant.

In other words, Phonological Processing contributed significantly to growth in early Spelling (and the contribution to Word Reading approached significance), but Language and Speech Production did not add further variance. When looking at later text reading accuracy and comprehension, Language was a significant independent predictor. After controlling for Speech Production, Language and Phonological Processing, FRD status added marginal further variance in predicting spelling and text reading accuracy, but not reading comprehension. The effect in word reading marginally failed to reach significance. The lack of any significant interactions between the FRD status and the cognitive variables indicated that these cognitive variables contribute to literacy in a similar way across both groups.

## Discussion

The study examined deficits in literacy, speech, language and phonological processing in children with and without FRD. The aims were to measure the concurrent and predictive relationships between speech production, language, phonological processing and literacy, and to assess whether the lower skills in these areas shown by children with FRD accounted for the literacy difficulties shown later.

*What are the concurrent relationships between speech production, language, Phonological Processing and literacy? Do they vary by risk group?*

The first part of the results section examined the relationships between the different variables, using correlations. In general, there were moderate correlations between the factors. Phonological Processing was more highly correlated with Speech Production in the FRD group. This is likely to be at least in part because of the higher variability within the FRD group. However, higher variability alone would not cause higher correlations. These correlations provide a suggestion of deficits in one skill limiting performance in another skill, as suggested by Chiat (2001), though the correlational nature of the data limits the conclusions that can be drawn.

After controlling for multiple comparisons, only two of the 78 correlations differed significantly between the groups, with the two speech tasks correlating more highly in the FRD group and the Word Structure and Mispronunciation Detection task correlating more highly in the FRD group. This may in part be due to ceiling effects in the speech production tasks, and to some extent in Mispronunciation Detection, in the comparison group.

*What skills differ between good and poor readers? Does this differ by family risk status?*

The FRD group showed an increased incidence of word reading deficits (45% of the group were poor word readers), but no increased incidence of reading comprehension deficits, indicating a relatively specific pattern of risk for these children. Poor word readers showed weaknesses in language, phonological processing and early literacy measures, but no weaknesses in speech production. In contrast, the

FRD group as a whole showed weaknesses in speech production and two tasks which place high demands on speech production, *Nonword Repetition* and *Word Structure*. In other words, these children are more likely to have speech production difficulties than the comparison group, but these are not necessarily associated with reading difficulties. Speech production difficulties may therefore be a useful endophenotype measure for assessing genetic contributions to developmental dyslexia.

There is some evidence of this pattern in previous research (Elbro et al, 1998). It is interesting to speculate why this might be. This deficit could be epiphenomenal: it could be an additional genetic risk associated with the genetic risk for dyslexia, but not causally implicated in the disorder. Alternatively, it may be that the difficulties in speech production indicate a slightly different type of phonological impairment shown in the children with FRD compared to comparison group poor readers, but that this impairment only causes difficulties when accompanied by additional weaknesses (Pennington, 2006). The poorer *Spelling* and *Nonword Repetition* shown in the FRD poor readers is in line with this interpretation.

The FRD good readers also showed weaker spelling at Time 2 and marginally weaker reading accuracy at Time 3 than the comparison good readers, in line with previous studies indicating mild literacy impairments in this group (Pennington & Lefly, 2001; Snowling et al., 2003). In these respects, our study has similarities with Snowling et al (2003), with the FRD poor readers showing generally low performance, and the FRD good readers showing weaknesses in early literacy, but relatively good language skills.

An innovative aspect to this research was the inclusion of poor readers with no FRD. There were few interactions between FRD group and reader group, indicating that generally poor readers showed similar patterns of impairments whether or not they had FRD. The exceptions to this pattern were the *Nonword Repetition* and *Spelling* tasks, in which the FRD poor readers scored particularly poorly, and the *Nonword Learning* task, in which the comparison poor readers scored unexpectedly poorly.

These results indicate perhaps that we should not consider Phonological Processing as a unitary factor. The FRD poor readers show particular deficits on one aspect of Phonological Processing, while the comparison poor readers show particular deficits in another area. The low performance of the FRD poor readers on the nonword repetition task cannot be explained by the poor speech production shown by the FRD group as a whole, as the interaction remained after controlling for speech production. Instead, it seems that these children are particularly likely to show impairments in short-term phonological memory.

The lower performance for the comparison poor readers on the *Nonword Learning* task in comparison to the other three groups is a particularly novel finding, partly of course because this group has rarely been studied before. While nonword learning is classified as a Phonological Processing task in this study, it clearly involves additional skills, including linking visual and verbal material in memory, and it is well established that this is a difficulty associated with reading difficulties (Hulme et al., 2007). It is also useful to consider the pattern of correlations shown in this task with the two groups, though these should be interpreted with caution as the differences do not achieve significance after controlling for multiple comparisons. In the comparison group, this task is moderately associated with all of the language, Phonological Processing and particularly literacy tasks. In contrast, in the FRD group, the task is not significantly associated with language or literacy, and the strongest association is with nonword repetition. This implies that in the FRD group, the task may be limited by weaknesses in phonological short-term memory, while in the comparison group, it is perhaps more associated with general learning ability, or with written word acquisition in general. Hence, perhaps the comparison poor readers are more likely to show general weaknesses in learning, while the FRD poor readers are more likely to show deficits in phonological short-term memory.

*Do language, speech production and Phonological Processing predict growth in literacy over time?*

Longitudinal regressions showed that phonological processing was a key predictor of growth in literacy, particularly in terms of spelling, with a marginal contribution of phonological processing to word reading accuracy at Time 2. On the text reading accuracy and comprehension measures at Time 3, language was the only significant predictor once early reading had been controlled. In line with previous studies (Nathan et al., 2004; Raitano, Pennington, Tunick, & Boada, 2004), speech production did not predict literacy progress over time once Language and Phonological Processing were controlled. The findings are in line with Dickinson's et al.'s (2003) comprehensive language view for reading comprehension, and the phonological sensitivity view for reading accuracy, as shown by Storch and Whitehurst (2002).

*Do the lower speech production, language and Phonological Processing skills shown by the children with FRD account for the increased risk of word reading difficulties?*

In line with results from the Jyväskylä studies (Puolakanaho et al., 2007), FRD status explained a small, but significant proportion of additional variance in spelling and text reading after accounting for prior ability, language, phonological processing and speech production skills. In other words, despite the fact that children with FRD often show lower language, speech production and phonological processing early in development, these difficulties do not provide a full explanation of the risks carried by a family history of dyslexia. However, there were no significant interaction terms with the FRD status variable, indicating that these variables did not predict differently across groups. It is possible that this dummy variable provides a proxy for another, unmeasured deficit (e.g. processing speech, rapid naming or home literacy environment; Pennington et al., 2011).

*Limitations*

As always, there are limitations to the data presented here. The unequal group sizes mean that group differences should be interpreted with caution, though in many cases these would decrease, rather than increase power. Direct assessment of family members in the FRD and comparison groups has not been carried out, meaning that some members of the FRD group may not have FRD, while some members of the comparison group may have had undiagnosed dyslexia in their family. This is a significant limitation: while we tried to establish familial dyslexia through our parental questionnaire, only direct testing could provide certainty in this area. Again however, this weakness makes the analyses more conservative. Overall, we feel that the strengths and novelty of these data outweigh these limitations. Furthermore, the demonstration that the FRD group were not more likely to show poor reading comprehension demonstrates that their word reading difficulties are relatively specific.

A further concern relates to the measurement of the different variables. As described above, there was some evidence that the phonological processing factor was less coherent than the language or speech production factors, with the FRD poor readers showing a different pattern of deficits across the tasks to the comparison poor readers. In addition, the mispronunciation detection task showed a relatively low loading from the phonological processing factor (.60). This probably reflects the increased variation in task demands in the phonological processing measures, which were selected to test a range of phonological skills. Using a latent variable reduces the issue of varied task demands affecting performance but in the future it may be worth considering the utility of considering phonological processing as a single underlying ability.

*Conclusions*

This study examined three key issues: the associations between speech production, language, phonological processing and literacy; the deficits shown by poor readers; and the additional role of FRD in the prediction of literacy progress. As a whole, children with FRD show mild weaknesses in phonological processing, language and literacy, and clear weaknesses in speech production at school entry. These difficulties in speech production could be thought of as an endophenotype for developmental dyslexia. Children who go on to have reading difficulties show deficits in language and phonological processing at school entry. Poor readers with and without FRD showed similar deficits, with the exception that poor readers with FRD showed weaker speech production and better visual-verbal learning than poor readers with no FRD. Perhaps most importantly, it was found that between-group differences in speech, language and phonological processing do not fully explain the deficits in literacy seen in the FRD group.

In addition to the theoretical implications discussed above, these findings also have practical implications. They indicate that in order to predict a child's literacy outcome, it can be useful to know a child's family history in addition to assessing their cognitive abilities. Even after accounting for these children's language and phonological abilities at Time 1, FRD still predicted further independent variance in literacy. Hence it would be useful for teachers to be aware of the family history of their child in addition to their current skill level. Children with a family history of dyslexia may benefit from extra support to prevent them falling behind, even if their early skills do not indicate this is necessary.

Author Note

Correspondence should be addressed to: Julia M. Carroll, Department of Psychology, University of Warwick, Coventry, UK, CV4 7AL. Email: J.M.Carroll@warwick.ac.uk.

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Footnotes

[1] As described in Carroll & Myers (2010), 210 children were originally recruited, but 12 completed only a subset of the measures, and 35 were recruited because of a history of speech and language difficulties, and are not included in this paper.

[2] Two additional tasks, priming and a word classification task were also included but are not reported here.

[3] Confirmatory factor analysis was also carried out using these three factors, and indicated a good fit to the data (CFI = .967, RMSEA = .058, $\chi^2 = 71.72$ , df = 48, p=.02, SRMR = .049)

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Tables and Figures

Table 1: Correlations with age and school year

| Task | Age (months) | School year (spearman rank correlations used) |
|---|---|---|
| School year | - | .848 (<.001) |
| Sent. Struct. | .285 (<.001) | .265 (.001) |
| Word Struct. | .215 (.008) | .225 (.006) |
| Exp. Vocab. | .209 (.010) | .280 (<.001) |
| Recall. Sent. | .138 (.09) | .230 (.004) |
| Naming | .249 (.002) | .140 (.086) |
| DEAP diagnostic | .083 (.176) | -.019 (.718) |
| Nonword Rep. | .117 (.150) | .123 (.131) |
| Pho. Aware. | .230 (.004) | .153 (.060) |
| Mispro. (prop. correct) | .250 (.002) | .283 (<.001) |
| NW learning | .245 (.003) | .275 (.001) |
| Total reading | .558 (<.001) | .583 (<.001) |
| Total spelling | .535 (<.001) | .513 (<.001) |
| Letter knowledge | .518 (<.001) | .608 (<.001) |
| T2 Total reading | .485(<.001) | .468 (<.001) |
| T2 Total spelling | .448(<.001) | .439 (<.001) |
| T3 Reading Accuracy | .160 (.066) | .151(.084) |
| T3 Reading Comprehension | .228 (.009) | .253 (.003) |

Table 2: Bivariate correlations between the Time 1 factor scores in the typically developing children (n = 109) and the children with FRD (n = 42)

| | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| 1. Language | - | .270 | .542 | .436 |
| | | .005 | <.001 | <.001 |
| 2. Speech Production | .336 | - | .281 | .150 |
| | .030 | | .004 | .120 |
| 3. Phonological Processing | .754 | .641 | - | .554 |
| | <.001 | <.001 | | <.001 |
| 4. Literacy | .632 | .381 | .528 | - |
| | <.001 | .012 | <.001 | |

Note: correlations in the typically developing group are shown above the diagonal. Correlations in the FRD group are shown below the diagonal.

p-values are shown under the correlation coefficient.

Table 3: Bivariate correlations between the scores for individual tasks in the typically developing children (n = 109) and the children with FRD (n = 42)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Sent. Struct. T1 | - | .383* | .506* | .388* | .025 | .250* | .207 | .313* | .005 | .283* | .181 | .155 | .216 |
| 2. Word Struct. T1 | .551* | - | .381* | .476* | .250* | .355* | .344* | .378* | .077 | .280* | .209 | .309* | .284* |
| 3. Exp. Voc. T1 | .453* | .575* | - | .469* | .155 | .210 | .308* | .334* | .194 | .320* | .418* | .407* | .444* |
| 4. Rec. Sent. T1 | .295 | .617* | .647* | - | -.040 | .103 | .348* | .297* | .024 | .254* | .285* | .238 | .413* |
| 5. Naming T1 | .199 | .297 | .245 | .233 | - | .453* | .197 | .129 | .246 | .235 | .036 | .131 | .001 |
| 6. DEAP T1 | .282 | .363 | .166 | .271 | .801* | - | .245 | .196 | .008 | .086 | .184 | .232 | .085 |
| 7. NWrep. T1 | .322 | .563* | .515* | .609* | .618* | .624* | - | .269* | .141 | .358* | .268* | .296* | .308* |
| 8. Pho Aware T1 | .474* | .491* | .584* | .582* | .482* | .424* | .664* | - | .053 | .336* | .458* | .549* | .443* |
| 9. Mispro T1 | .322 | .592* | .501* | .414* | .402* | .277 | .433* | .365 | - | .274* | .115 | .116 | .127 |
| 10. NW Learn. T1 | .145 | .224 | .113 | .263 | .285 | .355 | .419* | .305 | -.016 | - | .367* | .338* | .368* |
| 11. Reading T1 | .335 | .580* | .513* | .512* | .296 | .215 | .488* | .525* | .291 | .084 | - | .803* | .695* |
| 12. Spelling T1 | .453* | .600* | .464* | .536* | .420* | .415* | .601* | .554* | .382 | .196 | .765* | - | .676* |
| 13. LK T1 | .123 | .458* | .527* | .393* | .348 | .267 | .482* | .478* | .264 | .006 | .807* | .637* | - |

Note: correlations in the typically developing group are shown above the diagonal. Correlations in the FRD group are shown below the diagonal. Sent. Struct. = CELF Sentence Structure; Word Struct. = CELF Word Structure; Exp. Voc. = CELF Expressive Vocabulary; Rec. Sent. = Recalling Sentences; NWrep = Nonword Repetition; Pho. Aware = Phonological Awareness; Mispro. = Mispronunciation Detection; NW Learning = Nonword Learning; LK = Letter Knowledge. * indicates $p<.01$; † indicates $p<.05$

Table 4: Mean group differences and ANOVAs

| Task | Comparison-average readers (n = 78) | Comparison-poor readers (n = 16) | FRD-average readers (n = 21) | FRD-poor readers (n = 17) | FRD group effect size (p value) | Reader group effect size (p value) |
|---|---|---|---|---|---|---|
| Age (months) | 64.12 (6.18) | 68.19 (5.71) | 67.67 (9.12) | 69.88 (8.20) | -0.43 (.08) | -0.60 (.036) |
| Age range (months) | 53-84 | 55-77 | 55-83 | 53-81 | | |
| T1 Recalling Sentences [a] | 11.58 (2.19) | 9.75 (1.39) | 11.10 (2.64) | 8.47 (2.81) | 0.38 (.07) | 1.05 (<.001)* |
| T2 Recalling Sentences [a] | 11.37 (2.23) | 9.63 (1.31) | 10.81 (2.66) | 8.47 (2.35) | 0.49 (.07) | 1.00 (<.001)* |
| T3 Recalling Sentences [a] | 10.65 (2.29) | 8.63 (2.45) | 10.52 (2.84) | 7.06 (3.67) | 0.47 (.13) | 1.08 (<.001)* |
| T1 Sent. Struct.[a] | 9.85 (2.26) | 8.25 (1.65) | 8.81 (1.83) | 8.47 (3.26) | 0.24 (.41) | 0.56 (.05) |
| T1 Word Struct. [a] | 12.77(2.78) | 11.50 (2.63) | 11.48 (2.34) | 9.37 (3.01) | 0.59 (.004)* | 0.75 (.004)* |
| T1 Exp. Vocab. [a] | 11.95 (2.28) | 9.13 (2.16) | 11.10 (2.41) | 8.59 (3.30) | 0.45 (.18) | 1.21(<.001)* |
| T1 Naming [b] | 95.28 (3.62) | 95.29 (3.08) | 93.67 (7.51) | 89.64 (9.40) | 0.60(.002)* | 0.28 (.08) |
| T1 DEAP diagnostic [b] | 97.43 (2.64) | 97.65 (1.78) | 94.94 (4.08) | 93.59 (6.91) | 0.79 (.001)* | 0.35 (.31) |
| T1 Nonword Repetition [c] | 17.76 (3.52) | 16.38 (3.22) | 17.48 (5.40) | 13.06 (4.04) | 0.39 (.014)* | 0.77 (<.001)* |

| | | | | | | |
|---|---|---|---|---|---|---|
| T2 Nonword Repetition [c] | 20.00 (3.47) | 19.06 (3.13) | 19.29 (5.53) | 14.53 (4.38) | 0.56 (<.001)* | 0.77 (<.001)* |
| T3 Nonword Repetition [c] | 26.47 (2.59) | 25.75 (2.24) | 26.05 (3.22) | 21.12 (3.92) | 0.80 (<.001)* | 0.99 (<.001)* |
| T1 Phoneme Awareness (max = 10) | 8.96 (1.58) | 7.50 (1.75) | 8.76 (2.05) | 7.59 (1.94) | 0.20 (.45) | 0.80(<.001)* |
| T1 Mispronunciation Detection (prop. correct) | 0.91 (0.09) | 0.91 (0.06) | 0.93 (0.05) | 0.85 (0.17) | 0.20 (.20) | 0.45(.006)* |
| T1 NW learning (max = 117) | 98.04 (13.76) | 85.53 (18.63) | 94.63 (13.81) | 92.88 (9.49) | 0.14 (.77) | 0.58 (.007)* |
| T1 Reading[d] | 103.10 (14.58) | 85.89 (8.91) | 99.46 (15.87) | 86.22 (11.03) | 0.48 (.58) | 1.19 (<.001)* |
| T1 Spelling[d] | 104.15 (13.36) | 83.30 (11.64) | 96.39 (15.04) | 83.95 (16.80) | 0.58 (.23) | 1.35 (<.001)* |
| T1 Letter knowledge | 34.91 (11.99) | 28.25 (8.38) | 34.86 (11.93) | 28.76 (12.00) | 0.21 (.87) | 0.56 (<.001)* |
| T2 Reading[d] | 104.24 (12.95) | 82.89 (10.49) | 98.15 (14.06) | 82.35 (12.70) | 0.65 (.23) | 1.53(<.001)* |
| T2 Spelling[d] | 104.14 (12.40) | 82.46 (11.69) | 96.41 (13.53) | 78.63 (18.93) | 0.75 (.05) | 1.62 (<.001)* |
| T3 Reading Accuracy[e] | 107.68 (8.55) | 86.75 (4.64) | 103.48 (7.02) | 84.94 (4.64) | 0.80 (.07) | - |
| T3 Reading Comprehension[e] | 105.15 (8.49) | 96.25 (6.21) | 101.48 (9.17) | 95.29 (10.13) | 0.54 (.21) | - |

[a] Scale Score (m = 10, sd = 3). [b] Percentage consonants correct. [c] Maximum Score = 30. [d]Standard Score standardised on full comparison group (m=100, sd = 15). [e] Standard Score based on published test (m=100, sd = 15). * indicates $p<.018$; † indicates $p<.05$.

Table 5: Hierarchical multiple regression predicting reading outcome at Time 2

| Variable | B | SE B | β | Sig. | % $R^2$ Change |
|---|---|---|---|---|---|
| Dependent Variable: Total Reading | | | | | |
| **Step 1: T1 Total Reading** | **0.88** | **.041** | **.875** | **<.001** | 76.6 |
| Step 2 | | | | | 2.4 |
| Language | 0.95 | .782 | .061 | .310 | |
| Phonological Processing | 1.89 | .851 | .113 | .036 | |
| Speech Production | 1.63 | 1.38 | .051 | .360 | |
| Step 3: FRD status | -2.71 | 1.39 | -.081 | .053 | 0.6 |
| Step 4: FRD*Phonological Processing | .678 | 1.64 | .020 | .693 | <0.1 |
| Step 4: FRD*Language | .539 | 1.40 | .021 | .738 | <0.1 |
| Step 4: FRD*Speech Production | 3.08 | 2.61 | .068 | .298 | 0.2 |

Table 6: Hierarchical multiple regression predicting spelling outcome at Time 2

| Variable | B | SE B | β | Significance | % $R^2$ Change |
|---|---|---|---|---|---|
| Dependent Variable: Total Spelling | | | | | |
| **Step 1: T1 Total Spelling** | **.802** | **.054** | **.784** | **<.001** | 61.5 |
| Step 2 | | | | | 2.7 |
| Language | -.434 | 1.08 | -.026 | .501 | |
| **Phonological Processing** | **3.20** | **1.16** | **.182** | **.005** | |
| Speech Production | 1.61 | 1.91 | .048 | .630 | |
| **Step 3: FRD status** | **-4.69** | **1.88** | **-.133** | **.014** | 1.6 |
| Step 4: FRD*Phonological Processing | 2.25 | 2.22 | .063 | .357 | 0.3 |
| Step 4: FRD*Language | 1.05 | 1.77 | .039 | .625 | 0.1 |
| Step 4: FRD*Speech Production | .418 | 3.56 | .009 | .944 | <0.1 |

Table 7: Hierarchical multiple regression predicting reading accuracy outcome at Time 3

| Variable | B | SE B | β | Significance | % $R^2$ Change |
|---|---|---|---|---|---|
| Dependent Variable: Reading Accuracy (Time 3) | | | | | |
| Step 1: | | | | | 34.4 |
| **T1 Reading** | **.459** | **.058** | **.586** | **<.001** | |
| Step 2 | | | | | 12.3 |
| **Language** | **3.59** | **1.11** | **.294** | **.005** | |
| Speech Production | -0.82 | 1.89 | -.033 | .502 | |
| Phonological Processing | 2.33 | 1.18 | .180 | .030 | |
| **Step 3: FRD status** | **-5.06** | **1.89** | **-.191** | **.009** | 3.1 |
| Step 4: FRD*Language | 1.36 | 1.77 | .066 | .490 | 0.3 |
| Step 4: FRD*Speech Production | 2.30 | 3.55 | .067 | .668 | 0.2 |
| Step 4: FRD*Phonological Processing | 2.59 | 2.13 | .099 | .269 | 0.6 |

Table 8: Hierarchical multiple regression predicting reading comprehension outcome at Time 3

| Variable | B | SE B | β | significance | % $R^2$ Change |
|---|---|---|---|---|---|
| Dependent Variable: Reading Comprehension (Time 3) | | | | | |
| Step 1: | | | | | 22.2 |
| **T1 Reading** | **.294** | **.050** | **.471** | **<.001** | |
| Step 2 | | | | | 23.7 |
| **Language** | **5.17** | **.890** | **.531** | **<.001** | |
| Speech Production | .780 | 1.52 | .039 | .673 | |
| Phonological Processing | .188 | .947 | .018 | .660 | |
| Step 3: FRD status | -.193 | 1.56 | -.009 | .896 | <0.1 |
| Step 4: FRD*Language | 1.51 | 1.46 | .093 | .307 | 0.5 |
| Step 4: FRD*Speech Production | 5.54 | 2.90 | .201 | .063 | 1.7 |
| Step 4: FRD*Phonological Processing | 2.39 | 1.76 | .114 | .201 | 1.1 |