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The Statistics of Subtypes: A Proposed Study Investigating Statistical Learning Across Subtypes of Dyslexia

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Introduction

What is Dyslexia?

Dyslexia is a learning disorder that negatively impacts an individual’s ability to read, despite having normal intelligence (Gabay, Thiessen & Holt, 2015; Ramus et al., 2003; Singh, Walk & Conway, 2018; Vicari et al., 2005; Vicari, Marottaa, Menghinia, Molinarib & Petrosini, 2003). Generally, individuals with dyslexia have difficulty reading but process other information, such as numbers and verbal information, in a typical manner (Gabay et al., 2015; Singh et al., 2018). The complex interactions between both genetic and environmental factors are considered to be the cause of dyselxia. (Peterson & Pennington, 2015). Previous literature has shown an association between dyslexia and a deficit in the phonological components of language (i.e., rhyme, letter-sound patterns, and speech-sound segmentation) (Pavlidou, Kelly & Williams, 2009; Pavlidou & Williams 2010; Wiseheart, Altmann, Park & Lombardino, 2009). Specifically, children with dyslexia appear to have difficulties accurately representing sound patterns in their language (Thomson & Goswami, 2010). These deficits are predicted to lead to later difficulties in learning to read (Pavlidou et al., 2009).

Research in the field of dyslexia is inconsistent. There is an on-going debate in terms of what causes dyslexia and what impairments are characteristic of people with dyslexia. A proportion of the literature focuses on sentence comprehension in individuals with dyslexia (Leiken & Assayag-Bouskil, 2004; Robertson & Joanisse, 2010; Wiseheart et al., 2009; Wiseheart & Altmann, 2017). These studies propose that syntactic processing deficits (e.g., word reading ability, sentence comprehension, and grammar) are characteristic of dyslexia (Wiseheart, Altmann, Park

& Lombardino, 2009). Their research has shown that dyslexics show a profound impairment in working memory and word reading ability (Wiseheart et al., 2009; Wiseheart & Altmann, 2017).

Many studies have shown that children with dyslexia display general implicit learning impairments, such as deficits in pattern recognition, visual regularity detection, and linguistic regularity awareness (Nigro, Fernandez, Simpson, & Defior, 2015; Pavlidou et al., 2009; Pavlidou & Williams, 2010; Vicari et al., 2003; Vicari et al., 2005). These studies have concluded that a lack of implicit learning ability explains a large part of the reading difficulties experienced by children with dyslexia (Pavlidou, Kelly & Williams, 2010).

Similarly, it has been suggested that individuals with dyslexia display a phonological deficit (Gabay, et al., 2015; Hakvoort et al., 2016; Pavlidou & Williams 2010; Pavlidou et al., 2009; Singh et al., 2018; Thomson & Goswami, 2010; Vicari et al., 2003; Vicari et al., 2005; Wiseheart et al., 2009; Ziegler et al., 2008). It has been shown that a phonological deficit associated with dyslexia can lead to impairments in phonological awareness, which is the ability to analyze sound structures within words (Thomson & Goswami, 2010). Smaller vocabularies, and difficulty learning to read have also been shown to be associated with a phonological deficit (Gabay et al., 2015; Singh et al., 2018).

Previous research suggests a divergent understanding and lack of conformity about the distinct causes of dyslexia. However, the phonological deficits associated with dyslexia are a good point to start at for the purpose of this study.

Subtypes of Dyslexia

Although there are some discrepancies regarding how many varieties, and what those varieties are, there are three specific subtypes of dyslexia that have been largely studied and examined. The first subtype, phonological dyslexia, is characterized by poor non-word reading (i.e., the reading of words that obey the linguistic rules of a language, but are not real words in that language), mediocre regular word reading, and an inability to manipulate the basic sounds of language (Castles & Coltheart, 1993; Wybrow & Hanley, 2015). The second subtype, surface dyslexia, involves poor irregular word reading (i.e., a word in a language that does not follow the phonetic rules of that language) with intact regular word and non-word reading (Castles & Coltheart, 1993; Friedmann & Lukov, 2008; Wybrow & Hanley, 2015). The final subtype being discussed is deep dyslexia and is characterized by semantic reading errors (i.e. reading the word “heart” as “blood”), difficulty reading non-words, and difficulty recognizing words as a whole (Lukov et al., 2015).

Past literature surrounding subtypes of dyslexia is limited, likely due to the uncertainty in defining a set of subtypes. However, a review of the existing literature yields a focus on explored verbal memory tasks (Van Strein, 1999), reading ability across subtypes (Coltheart, 2015; Ziegler et al., 2008), and prevalence of specific subtypes (Lukov et al., 2015; Wolff, 2009; Wybrow & Hanley, 2015). Van Strein (1999) found that there are meaningful differences across subtypes for memory focused tasks. This study also revealed differences in verbal word learning and recall across two subtypes of dyslexia (i.e., P-dyslexia and L-dyslexia; which are part of a previous subtype classification system). Coltheart (2015) concluded that cognitive and reading abilities differed across several subgroups of dyslexics. In terms of prevalence, previous literature shows a difference in deficiency between phonological dyslexia and surface dyslexia (Wolff, 2009; Wybrow & Hanley, 2015; Ziegler et al., 2008). That being said, both phonological dyslexia and surface dyslexia show a phonological deficit (Ziegler et al., 2008).

In previous research, several attempts have been made to classify children with dyslexia into distinct subgroups (Wolff, 2009). Previous findings have suggested that there is a heterogeneity across children with dyslexia (Castles & Coltheart, 1993; Ziegler et al., 2008). However, it is debated whether dyslexia should be considered one disorder with several outcomes, or a collection of disorders with similar outcomes (Tamboer, Vorst & Oort, 2016). Assuming that there are distinct subgroups of dyslexia (e.g., phonological dyslexia, surface dyslexia, and deep dyslexia), children with dyslexia would benefit from treatments that are tailored to a specific subtype rather than a single treatment for dyslexia in general. Specific treatments tailored to individual sequences of impairments would likely allow for more effective treatment methods. Additionally, making distinctions between these subtypes allows for further research regarding specific causes of different varieties of dyslexia, risk factors for the development of dyslexia, and preventative measures.

Statistical Learning

In written language, word boundaries are clearly indicated by physical spaces separating words. In spoken language, these boundaries are less obvious and only represented periodically by acoustic cues (Saffran, Aslin & Newport, 1996). As a result, it can be difficult for children to determine where one word ends and the next begins (Saffran, 2003). Evidence suggests that children can use the statistical regularities present in language to discover the structure of a linguistic input (Saffran, 2003). Statistical learning refers to the ability to detect statistical patterns in the order of syllables in a stream of sound (Batterink, Reber, Neville, & Paller, 2015; Saffran et al., 1996). It has been suggested that statistical learning is automatic in typically developing individuals and occurs in the absence of conscious effort (Saffran et al., 1997). In other words, statistical learning is an implicit skill that is present and functional in typically developing individuals.

It has been proposed that a deficit in statistical learning plays an important role in dyslexia (Gabay et al., 2015; Pavlidou et al., 2009; Pavlidou & Williams 2010; Singh et al., 2018; Vicari et al., 2005; Vicari et al., 2003). Singh et al. (2018) concluded that children with dyslexia were slower to learn statistical regularities and showed an atypical learning process of statistical patterns. Similarly, Gabay et al. (2015) found that participants with dyslexia were worse than typical readers at identifying statistical regularities in speech. In another study conducted by Pavlidou et al. (2009), children with dyslexia failed to exhibit adequate implicit learning in an artificial grammar learning task, which has been confirmed in another study by Pavlidou and Williams (2010). Thus far, the research suggests that children with dyslexia show an overall impairment in statistical learning ability when compared to typically developing peers. However, there is an argument stating that poor performance on statistical learning and other implicit learning tasks as being caused by a lack of attention (Schmalz, Altoc & Mulatti, 2017). Further research is necessary to address the relationship between statistical learning and dyslexia in order to directly define a relationship.

As previously noted, dyslexia is generally associated with an impairment in reading ability (Gabay et al., 2015; Singh et al., 2018). It has been demonstrated in the literature that there is a direct link between implicit learning and reading (Gabay et al., 2015). More specifically, it has been shown that statistical learning is directly related to reading ability (Archiuli & Simpson, 2012). Although the magnitude of the relationship is not fully understood, Gabay et al. (2015) suggest that impaired statistical learning might influence learning to read by reducing sensitivity to the statistical regularities that exist among letters and phonemes. This reduced sensitivity comes from a reduced accuracy for encoding phonological input (Gabay et al., 2015; Ramus et al., 2003) and an impairment in extracting statistical input from speech streams (Gabay et al., 2015). It is also suggested that these inefficiencies in statistical learning may result in smaller vocabularies, which could affect the resolution of phonological representations, and in turn, reading ability (Gabay et al., 2015). Overall, findings indicate that impaired statistical learning may cause the deficits that appear in dyslexic individuals.

The Current Study

The purpose of the proposed study is to investigate if there are differences in statistical learning ability across three subtypes of dyslexia (i.e., phonological dyslexia, surface dyslexia, and deep dyslexia). Based on a review of the literature, it is predicted that the participants with a dyslexia diagnosis of any subtype will be worse at using statistics to find word boundaries than control participants. As previously noted, individuals with dyslexia struggle with implicit learning and statistical learning, which inhibits their ability to find word boundaries statistically.

Additionally, it is predicted that participants with surface dyslexia will express the highest capacity for statistical learning among the three subtypes. Individuals that have been diagnosed with surface dyslexia tend to have a greater ability for manipulating language sounds than members of the other subtypes (Wybrow & Hanley, 2015). Although this ability is impaired compared to typical readers, surface dyslexics are predicted to be better at statistical learning as result.

Finally, it is hypothesized that participants belonging to the deep dyslexia subgroup will express the lowest capacity for statistical learning. Individuals diagnosed with deep dyslexia show a profound impairment in both non-word reading and regular word reading. The nature of the impairments have been shown to be more detrimental to reading ability than other forms of dyslexia (Lukov et al., 2015). It is predicted that the complexity of impairments associated with deep dyslexia will have the greatest impact on statistical learning among the subtypes.

Method

Participants

A total of 64-80 participants, aged 8-12, will be included in the study. It should be noted that finding a large enough sample, given the specific criteria, may pose a challenge. All participants will be native English speakers and enrolled in elementary schools across Ontario. Among participants, socioeconomic status will be taken into consideration and an equal number of males and females will be included in the study. These restrictions attempt to limit any confounds resulting from socioeconomic status or sex. Participants will have to obtain parental permission and consent before participating in the study and will receive compensation.

All participants in the control group will be recruited from elementary schools in London, ON. Similarly, dyslexic children will be recruited from elementary schools as well as a centre for children with learning disabilities in London, ON. All control participants will be chosen based on the following inclusion criteria: native English speakers who are judged to be typically developing by their classroom teacher and have no learning, language, hearing, or speech impairments. All dyslexic participants will be selected based on the following inclusion criteria: a well-documented history of one type of dyslexia. Children experiencing multiple learning disabilities concurrently, more than one subtype of dyslexia, or history of neurological problems will be excluded from the study. Inclusion and exclusion criteria discussed were taken from previous studies involving children with dyslexia (Archiuli & Simpson, 2012; Batterink et al., 2015; Gabay et al., 2015).

Stimuli

Stimuli and experimental parameters will be modelled after those used in previous statistical learning studies (Batterink et al., 2015; Saffran et al., 1997; Saffran, 2003). The stimulus set will consist of 11 syllables combined to form six trisyllabic nonsense words (babupu, bupada, dutaba, patubi, pidabu, tutibu). A speech synthesizer will be used to generate a continuous speech stream composed of the six nonsense words at a rate of approximately 208 syllables per minute. The rate is based on previous auditory statistical learning experiments conducted in adults (Batterink et al., 2015; Saffran et al., 1997; Saffran, 2003). Each nonsense word will be repeated 300 times in random order, with the restriction that the same word never occurs twice in a row. The speech synthesizer will produce no pauses or acoustic cues of word onsets. The only indication of word boundaries will be statistical in nature. Six non-word combinations will be generated (batabu, bipabu, butipa, dupitu, pubada, tubuda) to test participants' ability to decipher between words and nonwords.

Procedure

The procedure is modelled after a similar study by Batterink et al. (2015). Participants from each of the four treatments (i.e., phonological dyslexia, surface dyslexia, deep dyslexia, and control) will be exposed to the same auditory stream. Participants will be informed that they will be listening to a "nonsense" language that contains words, but no meaning or grammar. Participants will not be given any information about the length or structure of the non-words or how many words the language contains. All auditory stimuli will be played at a comfortable level from speakers mounted on either side of the participant.

After finishing the listening phase, all participants will complete a forced-choice recognition task. The task will be to indicate which of the two sound strings sounds most like a word from the nonsense language. Each trial will include a word and a nonword. Each of the six words and six nonwords will be paired exhaustively for a total of 36 trials. In half of the trials the “real word” will be presented first while in the other half the non-word will be presented first. The entire procedure should take approximately one hour.

Anticipated Results

A one-way analysis of variance (ANOVA) will be conducted to analyze the mean accuracy scores across the four treatment groups. Based on a thorough review of the literature, it is predicted that participants with a dyslexia diagnosis of any subtype will be worse at using statistics to find word boundaries than control participants. Additionally, it is predicted that participants with surface dyslexia will express the highest capacity for statistical learning among the three subtypes. Finally, it is predicted that participants belonging to the deep dyslexia subgroup will express the lowest capacity for statistical learning

Previous research has indicated that there is a difference between participants with dyslexia and those without dyslexia on tasks which measure statistical learning ability (Gabay et al., 2015; Schmalz et al., 2016; Singh et al., 2018). Figure 1, taken from Gabay et al. (2015) displays the difference in accuracy between controls and dyslexics on a statistical learning task. Results of the proposed study are expected to follow this general trend (i.e., dyslexics performing more poorly on statistical learning tasks than typically developing controls). Similarly, studies by Nigro et al. (2015), Vicari et al. (2005), and Pavlidou and Williams (2010) have indicated that there is an overall impairment in implicit learning in children with dyslexia. However, there is literature that suggests that children with dyslexia show the same degree of implicit learning as typical readers (Roodenrys & Dunn, 2008). Additionally, Ramus et al. (2003) conclude that children with dyslexia display deficits in phonological learning highlighted across several tasks. Table 1, taken from Ramus et al. (2003), illustrates these findings. It is expected that the results of the proposed study will follow a similar pattern.

There are two main results that are possible in this study. First, there are differences in statistical learning ability between different subtypes of dyslexia, and second, there are no differences in statistical learning ability between subtypes of dyslexia. The former of the two results is most supported by previous literature and would suggest that not all cases of dyslexia are equal. Rather, individuals with dyslexia differ in their statistical learning ability, and potentially, other cognitive abilities. Table 2, taken from Ziegler et al. (2008), displays scores on several tasks contrasting phonological and surface dyslexia. From this table, it can be predicted that phonological and surface dyslexics may also display a difference in scores on statistical learning tasks. The purpose of the proposed study is to quantify this difference as well as increase its extent by comparing the scores of participants with deep dyslexia as well. Further research would be necessary to predict any other cognitive differences among subtypes. The latter result would suggest that the majority of individuals with a dyslexia diagnosis experience the same statistical learning impairment. From this, treatments and interventions can be generalized to all dyslexia cases, and the role of other cognitive deficits among subtypes can be explored.

Results from the proposed study can potentially be used to design treatments for dyslexia. As stated in Schmalz et al. (2017), it is unlikely that all children with dyslexia display the same underlying cognitive deficits. If the results of this study show that there are differences in statistical learning ability between different subtypes of dyslexia, treatments and interventions can be tailored more appropriately to individuals belonging to each subtype. Although further analysis at the individual level will be needed to construct the most effective interventions, this possibility gets us closer to identifying the most efficient treatments.

Statistically significant findings from the proposed study may be useful for understanding reading impairments. Differences in statistical learning among groups, if found, can potentially lead to links between statistical learning and other cognitive skills (i.e., working memory, processing speed, and logical reasoning). Further research in this area will be necessary to indicate specific relationships between statistical learning and these cognitive skills.

Finally, if a significant difference in statistical learning is found between groups, it will be possible to highlight early risk factors that can help with early identification of dyslexia in children. As a screening mechanism, children at risk, or children who display a reading impairment, can receive earlier intervention. Earlier identification is important for preventative measures and treatment methods that promote reading development.

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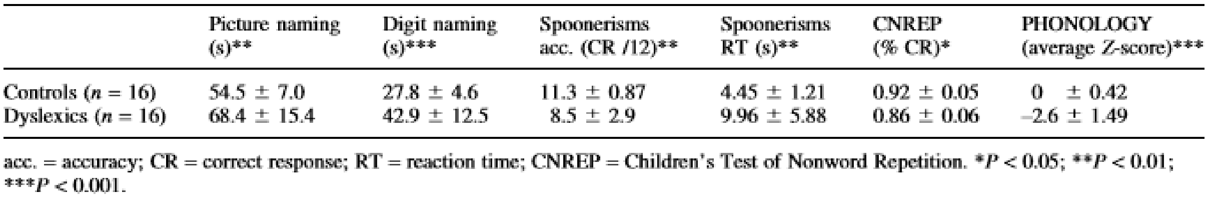
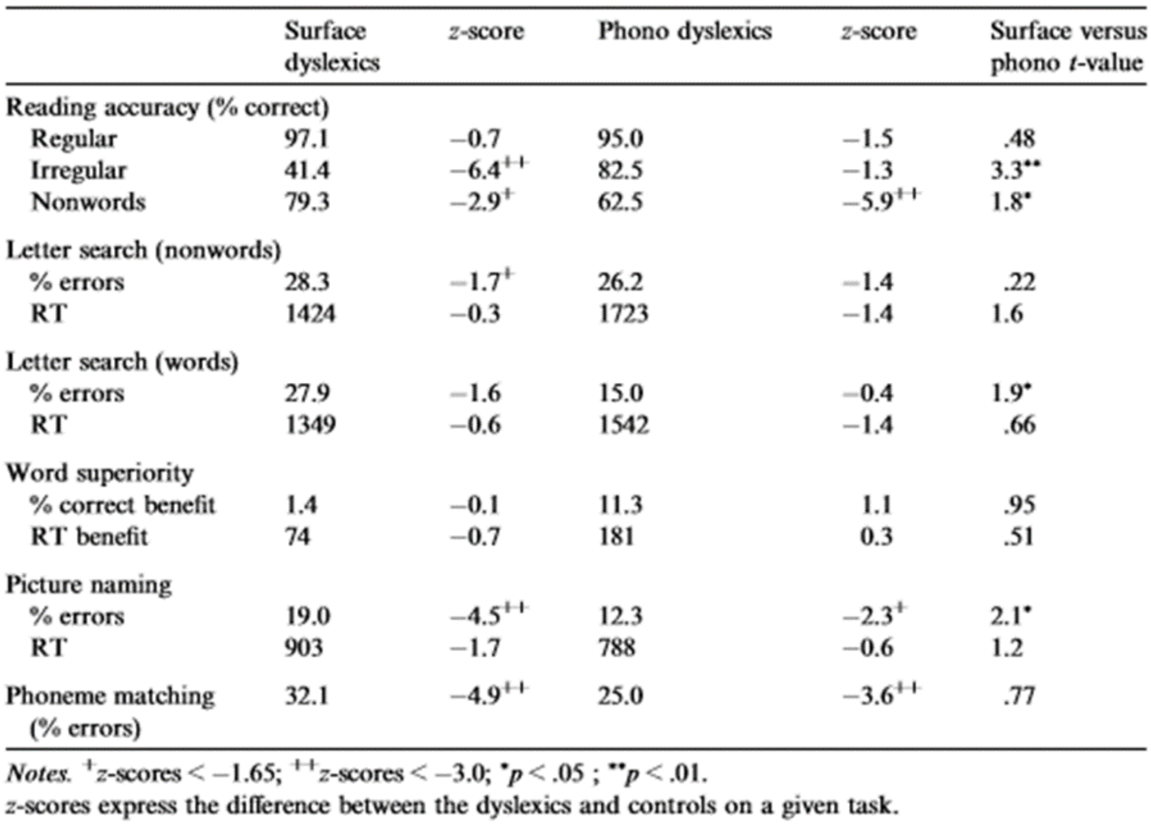


	Picture naming (s)**	Digit naming (s)***	Spoonerisms acc. (CR /12)**	Spoonerisms RT (s)**	CNREP (% CR)*	PHONOLOGY (average *Z*-score)***
Controls (*n* = 16)	54.5 ± 7.0	27.8 ± 4.6	11.3 ± 0.87	4.45 ± 1.21	0.92 ± 0.05	0 ± 0.42
Dyslexics (*n* = 16)	68.4 ± 15.4	42.9 ± 12.5	8.5 ± 2.9	9.96 ± 5.88	0.86 ± 0.06	–2.6 ± 1.49

acc. = accuracy; CR = correct response; RT = reaction time; CNREP = Children's Test of Nonword Repetition. $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

Table 1. Comparison of dyslexic individuals with control individuals on various phonological tasks. Take from Ramus et al. (2003).



	Surface dyslexics	*z*-score	Phono dyslexics	*z*-score	Surface versus phono *t*-value
Reading accuracy (% correct)					
Regular	97.1	−0.7	95.0	−1.5	.48
Irregular	41.4	-6.4^{++}	82.5	−1.3	3.3^{**}
Nonwords	79.3	-2.9^{+}	62.5	-5.9^{++}	1.8^{*}
Letter search (nonwords)					
% errors	28.3	-1.7^{+}	26.2	−1.4	.22
RT	1424	−0.3	1723	−1.4	1.6
Letter search (words)					
% errors	27.9	−1.6	15.0	−0.4	1.9^{*}
RT	1349	−0.6	1542	−1.4	.66
Word superiority					
% correct benefit	1.4	−0.1	11.3	1.1	.95
RT benefit	74	−0.7	181	0.3	.51
Picture naming					
% errors	19.0	-4.5^{++}	12.3	-2.3^{+}	2.1^{*}
RT	903	−1.7	788	−0.6	1.2
Phoneme matching (% errors)	32.1	-4.9^{++}	25.0	-3.6^{++}	.77

Notes. ^{+}z-scores < -1.65; ^{++}z-scores < -3.0; $^{*}p < .05$; $^{**}p < .01$.
z-scores express the difference between the dyslexics and controls on a given task.

Table 2. Performance of the surface and phonological dyslexics on the reading and DRC component tasks. Taken from Ziegler et al. (2008).

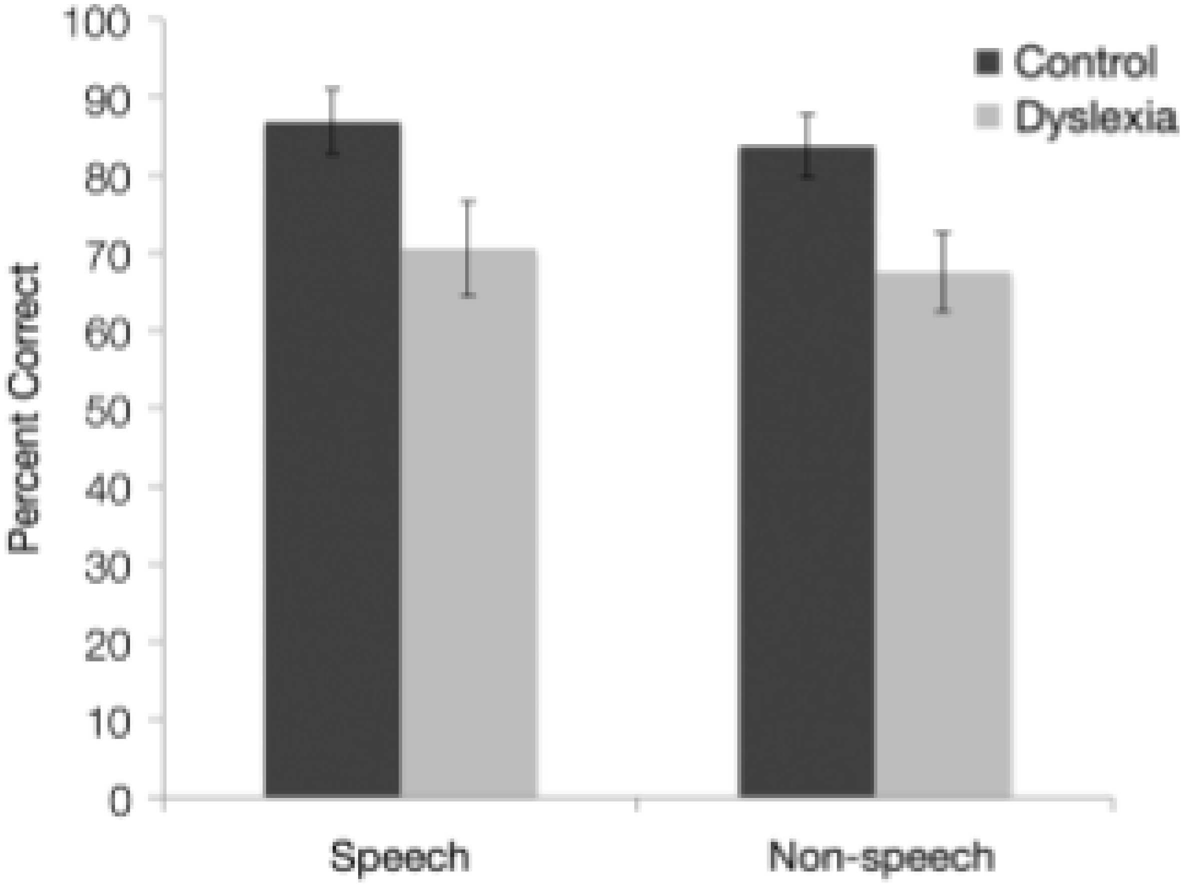


Figure 1. Average test trial accuracy of DD and control groups after familiarization with speech and nonspeech sequences. Error bars represent standard errors. Taken from Gabay, Thiessen & Holt (2015).