Rhythmic and Morphosyntactic Predictions: The Anticipation Abilities of Italian Children with Developmental Dyslexia

Valentina Persici, Natale Stucchi, and Fabrizio Arosio

1. Introduction

The ability to read and extract meaning from a text is of great importance and heavily affects scholastic performance and later success in life. However, from 3% to 17% of the children reading is a complex task (rates depend on different definitions of reading disorder and on the language considered in the study; see for instance Lindgren, De Renzi, and Richman, 1985). These children suffer from Developmental Dyslexia (DD), a disorder characterized by difficulties with reading and writing despite age appropriate non verbal cognitive abilities, absence of neurological damage, or adequate educational opportunities. Although DD was once thought to be linked to phonological deficits only, more recent research has shown a more varied set of deficient areas.

In fact, children with DD not only show difficulties with morphosyntactic processing (Cantiani, Lorusso, Perego, Molteni, & Guasti, 2015; Rispens & Been, 2007), but also deficits in rhythmic perception and synchronization. Strong associations have been found between auditory rhythm sensitivity and literacy skills across the lifespan: in children (Flaugnacco et al., 2014; Overy, Nicolson, Fawcett, & Clarke, 2003; Thomson & Goswami, 2008), adolescents (Wolff, 2002), as well as in adults (Thomson, Fryer, Maltby, & Goswami, 2006). Moreover, a growing body of research, both with typical and atypical populations, has shown how timing is pivotal in language development and is related to both speech perception (Huss, Verney, Fosker, Mead, & Goswami, 2011) and grammar (Gordon, Jacobs, Schuele, & Mcauley, 2015).

The underlying cognitive mechanisms, nor the neurobiological basis, of the literacy-rhythm association are yet clear. One recent hypothesis was put forward by Guasti, Pagliarini, and Stucchi (2017), who proposed that anticipation mechanisms might be involved. In fact, the ability to temporally predict what will follow is required both in reading and rhythmic tapping.

* Valentina Persici, University of Milano – Bicocca, v.persici@campus.unimib.it; Natale Stucchi, University of Milano – Bicocca, natale.stucchi@unimib.it; Fabrizio Arosio, University of Milano – Bicocca, fabrizio.arosio@unimib.it.

 Proceedings of the 43rd Boston University Conference on Language Development, ed. Megan M. Brown and Brady Dailey, 537-548. Somerville, MA: Cascadilla Press.

While reading, we access abstract orthographic representations of words and morphemes we are presented with; these representations can be used to predict the ending of the words themselves and the words that will come subsequently in the sentence. Eye-tracking research supports these claims by showing how readers do not need to fixate on every small unit of a word and how most of it is actually skipped through rapid eye movements (Rayner, 1998), especially in the case of very high-frequency or of highly predictable words (Rayner, Binder, Ashby, & Pollatsek, 2001). Moreover, since eye movements are thought to reflect the underlying cognitive processes that take place (Rayner, 1998), detecting slower or different patterns of eye movements could help identify a greater cognitive load or a less efficient mechanism to cope with it. Interestingly, eye movement patterns differ between children with DD and their typically developing peers: children with DD fixate on words more frequently and for a longer time and make shorter eye movements between fixations (Rayner, 1998), even more so in the case of languages with a greater grapheme-phoneme inconsistency (see for example Landerl, Wimmer, & Frith, 1997). These results support the hypothesis that children with DD might not only have a difficulty in learning and processing the grapheme-phoneme associations (Ziegler & Goswami, 2005), but might also be provided with a less efficient ability to predict incoming input.

The ability to anticipate is pivotal not only in reading, but in rhythmic tapping tasks as well. In fact, we would not be able to tap in time with a rhythmic stimulus, if we did not anticipate when the next beat would be and plan our movements so as to be in time with it (see Miyake, Onishi, & Pöppel, 2004).

Since children with DD show lower performance in both reading and rhythm, and both tasks require the use of anticipation processes, it is possible that the lower performance of the DD children in these tasks may be due to an 'impairment' in their anticipation mechanisms.

2. The present study

The present study aimed at investigating and comparing the anticipation abilities of children with DD and of their typically developing (TD) peers, on the basis of the assumption that deficiencies in reading and rhythmic processing might point to a core deficit in prediction-making mechanisms. More precisely, we tested whether children with DD exhibited less efficient structure-based processes of prediction-making in morphosyntactic and rhythmic processing as compared to the TD group. Structure-based predictions are those types of predictions that do not follow from learning event associations as part of our world knowledge, but that are made based on the analysis of a structure that contains combinatory features and on the automatic and compulsory activation of integration processes. These predictions are used both in language and music to efficiently anticipate incoming input.

In language, for example, such predictions are used to anticipate the future occurrence of nouns based on the features of the preceding linguistic elements.

In languages such as Italian, in which determiners and pronouns are marked with gender features, the presence of a preceding element marked as feminine – rather than masculine – automatically triggers the expectation to encounter a feminine noun later in the sentence (see (1a) and (1b) for example sentences with a determiner and a clitic pronoun with a right dislocated antecedent, respectively).

1. a. Paolo mangia la mela
   Paolo eat-3PRS.SG. the.SG.F. apple.SG.F.
   'Paolo is eating the apple.'

   b. Paolo la mangia, la mela
   Paolo the.SG.F. eat-3PRS.SG. the.SG.F. apple.SG.F.
   'Paolo is eating the apple'

In rhythmic processing, an analogous prediction process might be involved while inferring the future occurrence of beats (Fraisse & Repp, 2012; Miyake et al., 2004). By analyzing the temporal structure of a rhythmic sequence of beats, we are able not only to predict when the next beat will be, but also to synchronize ourselves with the stimulus and plan an action so as to be in time with it. If children with DD are less able than their TD peers to anticipate incoming input, as hypothesized, this deficit should become evident in both domains.

3. Methods
3.1. Participants

Fifteen Italian monolingual children with a diagnosis of DD (mean age: 10.1, SD = 1.2 years) and 15 age-matched controls (mean age: 10;1, SD = 1.1 years) participated in the study. Children with DD were recruited from public schools in the Milan (Italy) metropolitan area. They were diagnosed as having DD on standard inclusion and exclusion criteria by certified expert clinicians (ICD-10; World Health Organization, 2004) in clinical centers where they were receiving clinical services during our study. Children with DD had low accuracy scores and slow reading times in word and pseudoword at the standardized reading test DDE-2 (Sartori, Job, & Tressoldi, 2007). All participants had no diagnosed or reported speech problems, nor hearing deficits, they all had normal or corrected-to-normal vision and an age appropriate nonverbal IQ.

Table 1. Participants' characteristics

	Children with developmental dyslexia	*Typically developing children*
N	15	15
Mean age (years)	10.1 (1.2)	10.1 (1.1)
Word reading (z-scores):		
Accuracy	-4.63 (3.72)	-0.10 (0.72)
Speed	-1.41 (0.82)	-0.75 (0.52)
Pseudoword reading (z-scores):		
Accuracy	-3.17 (1.13)	-0.35 (0.64)
Speed	-1.07 (0.81)	-0.78 (0.49)

Note. Standard deviations are given between parentheses. Z-scores are calculated in reference to normative data (Sartori, Job, & Tressoldi, 2007). Negative values indicate lower performance than standard in both accuracy and response times (RTs) data.

3.2. Materials

3.2.1. Determiner Processing Task

In the determiner processing task participants were presented with two pictures on a computer screen, one representing the referent of a noun of masculine gender, the other of feminine gender. Immediately after the presentation of the pictures, participants were played a sentence in which they were told about a character touching one of the two objects represented in the pictures. In each sentence, the noun was preceded by a determiner (morphologically marked with the same gender features) and by an opaque adjective (see (2) for an example sentence with a feminine noun).

2.	Pinky	tocca	la	grande	foglia
	Pinky	touche-3PRS.SG.	the.SG.F	big	leaf.SG.F.
	'Pinky will quickly touch the big leaf'				

The protypical nouns associated with the items represented in the target and competitor pictures were matched in number, syllable length, and animacy category (human vs. inanimate) and had comparable frequency.

Item pairs were assigned to one of three conditions, according to the type and number of gender cues available to the participant upon the activation of the noun referent represented in the pictures. Condition 1 (Grammar, G) included nouns in which only the grammatical lexical information of gender was available (e.g., nouns ending in –e that are phonologically opaque with respect to the gender information). Condition 2 (Grammar-Phonology, GP) included nouns ending in –o or –a (usually signaling masculine and feminine gender, respectively, in Italian). Finally, Condition 3 (Grammar-Phonology-Semantics, GPS) included phonologically marked nouns denoting a human character with an associated prototypical biological gender (e.g. the noun *regina* 'queen', ending in -a and denoting an individual with feminine gender). Participants saw a total of 18 items, six for condition. All items in the list had the same onset time.

3.2.2. Clitic Processing Task

The clitic processing task was the same used in Persici, Stucchi, and Arosio (2019). As in the determiner processing task, participants were presented with two pictures while listening to one sentence containing a gender marked direct object clitic pronoun. The auditorily-presented sentences were created following Léger, Prévost, and Tuller (2015). In each of them, a third-person singular clitic pronoun preceded an agreeing right-dislocated postverbal Determiner Phrase (DP). Clitic and noun, both marked for number and gender, were separated by a verb and an adverb. The latter was included to provide participants with more time to converge on the target noun. See (3) for an example sentence with a noun marked as masculine.

3. Pinky	lo	tocca	velocemente,	il	fungo
Pinky	CL.SG.M	touch-3PRS.SG.	quickly,	the.SG.M	mushroom.SG.M

'Pinky will quickly touch the mushroom'

Target and competitor pictures were matched and assigned a condition as in the determiner processing task. Again, a total of 18 items were presented, six for each condition, and all items had the same onset time.

3.2.3. Tapping Task

The participants' rhythmic abilities were tested in a warning-imperative task (WIT; Pagliarini, Maffioli, Molteni, & Stucchi, 2016). In this task, children listened to regular rhythmic sequences of sounds played with a frequency of 440 Hz at 80 beats per minute (bpm). After an initial habituation phase and at a random point along the sequence, participants heard a *warning sound*. This sound, created by adding a harmonic to the basic sounds, was meant to alert them to tap in time with the following beat, i.e., the *imperative stimulus*. Sequences were assigned to one of two conditions: (i) a spondee condition, in which all sounds had the duration of 150 milliseconds (ms) or (ii) a trochee condition, in which two durations alternated: the first sound always had a duration of 150 ms, the second of 100 ms. Each condition was presented ten times, for a total of 20 trials.

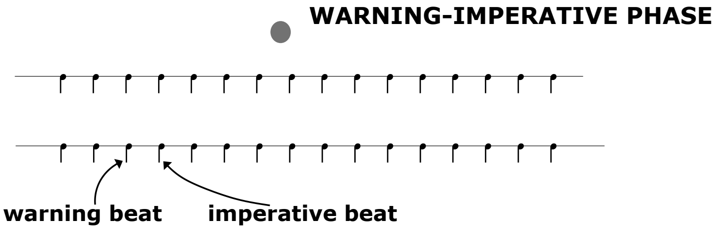

Fig. 1. Warning imperative task. Participants were asked to tap in time with the imperative beat. Adapted from Pagliarini et al., 2016.

4. Procedure

4.1. Determiner and Clitic Processing Tasks

During the sessions, each participant sat in front of a computer screen. In both the determiner and the clitic processing tasks participants saw two pictures (of objects with nouns of different gender) appearing on a computer screen and, one second later, listened to a sentence. All children were instructed to try and identify as quickly and as accurately as possible which of the two pictures the sentence was about. In order to choose one of the two pictures, participants had to click either L or S on the computer keyboard, respectively. Accuracy and response times were recorded and later analyzed and compared.

4.2. Tapping Task

During the WIT each participant sat in front of a computer screen and heard the sequences of sounds through headphones. The offbeat delay (i.e., the milliseconds interspersed between the beat and the participant's tap or vice versa) in each trial were recorded and analyzed.

5. Data analysis and results

5.1. Determiner Processing Task

Response times in the determiner processing task were analyzed using Linear Mixed-Effects Models (LMMs) in R (R Development Core Team, 2016; lmer function in package "lme4", Bates, Mächler, Bolker, & Walker, 2015). A likelihood ratio test showed that adding Condition - but not Group - as fixed effect significantly improved the goodness-of-fit of the model ($\chi^2_{(2)} = 6.170$ $p = .046$). Adding Age as covariate improved it further ($\chi^2_{(1)} = 4.015$, $p = .045$). Following analyses on the participants' response times were thus run by using a Mixed Model ANOVA with Condition as fixed effect, Subject and Item and random effects, and Age as covariate. Results showed only a marginally significant effect of Condition ($F(2, 14.988) = 3.259$, $p = .067$).

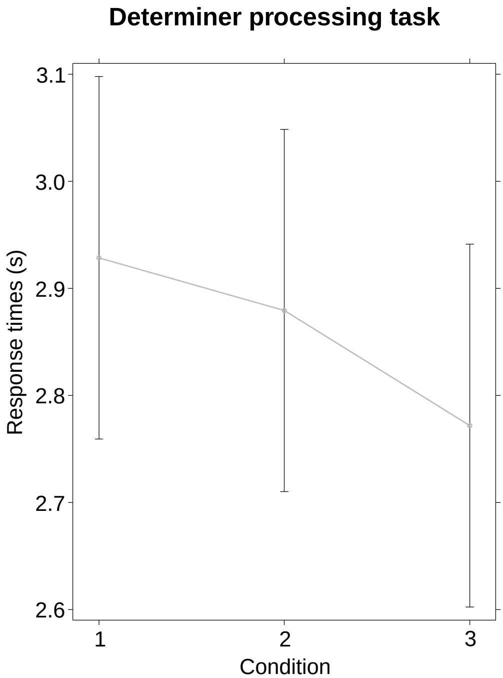

Fig. 2. Determiner processing task: participants' mean response times in the three conditions (1: Grammar, G; 2: Grammar-Phonology, GP; 3: Grammar-Phonology-Semantics, GPS).

5.2. Clitic Processing Task

LMMs were also run on the response times in the clitic processing task. The full model, including RTs as the dependent variable, Condition and Group as fixed effects, Subject and Item as random effects, and Age as covariate, provided the best fit to our data, both in comparison to the null model with a random intercept as predictor, as shown by a likelihood ratio test ($\chi^2 = 25.86$, $p < .001$), and on the basis of stepwise selection (function "step" in package "lmerTest"; Kuznetsova, Brockhoff, & Christensen, 2017). The full model run on our data yielded a significant main effect of Group ($F(1, 27.05) = 4.782$, $p = .038$) and a significant interaction between Condition and Group ($F(2, 448.39) = 5.936$, $p = .003$). Pairwise comparisons run through the function "testInteractions" in package "phia" (De Rosario-Martinez, 2015) revealed significant differences between the TD and DD groups in Condition 1 ($\chi^2_{(1)} = 9.076$, $p = .003$) and 2 ($\chi^2_{(1)} = 5.001$, $p = .025$), but not in Condition 3 ($\chi^2_{(1)} = 0.579$, $p = .446$). Pairwise comparisons also showed significant differences between Condition 1 and 3 ($\chi^2_{(1)} = 12.284$, $p < .001$) and between Condition 2 and 3 ($\chi^2_{(1)} = 6.077$, $p = .014$) in the DD group; no significant differences were found across conditions in the TD group (see Fig. 3).

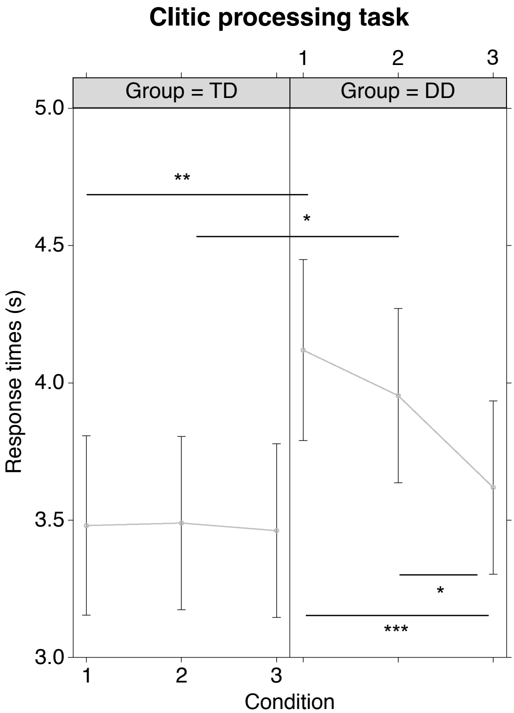

Fig. 3. Clitic processing task: participants' mean response times in the three conditions (1: Grammar, G; 2: Grammar-Phonology, GP; 3: Grammar-Phonology-Semantics, GPS).

***Note.* * *p* < .05, ** *p* < .01, *** *p* < .001.**

5.3. Tapping Task

The absolute values of the offbeat delay as shown by our participants in the tapping task were analyzed using LLMs. A likelihood ratio test showed that adding Group and Condition as fixed effects, Subject and Item as random effects, and Age as covariate did not improve the goodness-of-fit of the model ($\chi^2_{(4)} = 8.469$, $p = .08$). Stepwise selection showed that the best model only included Group as fixed effect and Subject as random effect. The absolute values of our participants' offbeat delays were thus analyzed in a Mixed Model ANOVA with Group as fixed effect and Subject as random effect. Results showed a significant main effect of Group ($F(1, 29.319) = 7.545$, $p = .01$), with the DD children being significantly less accurate than the TD children (see Fig. 4).

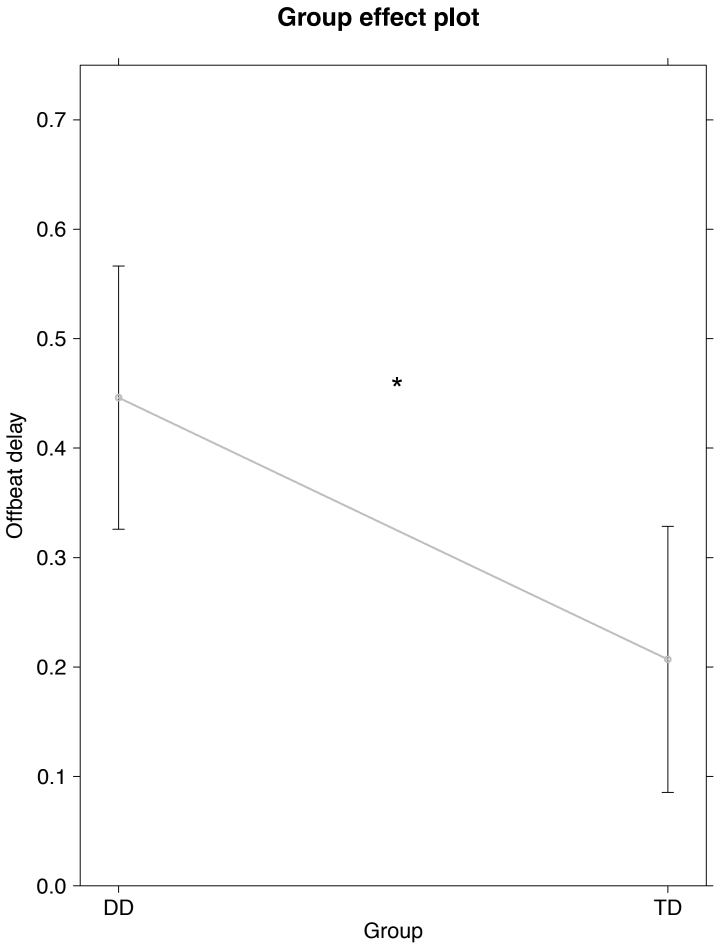

Fig. 4. Offbeat delay in the DD and TD groups in the warning imperative task.

***Note.* * $p < .05$, ** $p < .01$, *** $p < .001$.**

6. Discussion

This study examined whether children with DD exhibited less efficient mechanisms of structure-based prediction-making in morphosyntactic and rhythmic processing, as compared to their TD peers. As hypothesized, children with DD showed lower performance in both domains.

In language, how well children made structural morphosyntactic predictions with clitics was affected not only by their literacy skills (in the distinction between the two groups) but also by the type of gender information that was available to them. TD children and children with DD were similarly able to anticipate incoming input when the gender information provided by the preceding linguistic element was characterized semantically, but no more so when only the phonological and/or grammatical information was available. In fact, in that case, children with DD demonstrated to need significantly more time than their age-matched TD peers to identify the correct incoming noun. Interestingly, this difference was not evident in the determiner processing task. These results further corroborate the idea that dyslexia is not only associated with impaired phonology, but also with some deficit in morphosyntactic processing. This deficit might be usually well compensated and less visible in behavioral tasks, especially in the case of linguistic elements with a simpler hierarchical organization (as it was here in our determiner processing task), but might become more evident through the use of other techniques (e.g., with event related potentials (ERPs), see Cantiani et al., 2015) or more complex linguistic structures (e.g., gender agreement between nouns and clitic pronouns).

In rhythm, DD children also had more difficulties using anticipation mechanisms. In fact, they showed less accurate taps to the target beats as compared to the TD group in our warning imperative task. These results confirm previous research studies showing how individuals with DD find it more difficult to perceive and synchronize themselves with a rhythmic stimulus.

These findings, together with our morphosyntactic processing tasks results, seem to suggest that children with DD might be provided with a less efficient anticipation mechanism when the use of structure-based predictions is required. However, further research will have to establish whether their abilities are impaired similarly across the two domains and investigate whether this anticipation deficit has a neural correlate.

References

Bates, Douglas, Mächler, Martin, Bolker, Ben, & Walker, Steve (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Cantiani, Chiara, Lorusso, Maria Luisa, Perego, Paolo, Molteni, Massimo, & Guasti, Maria Teresa (2015). Developmental Dyslexia With and Without Language Impairment: ERPs Reveal Qualitative Differences in Morphosyntactic Processing. *Developmental Neuropsychology*, *40*(5), 291–312. https://doi.org/10.1080/87565641.2015.1072536

De Rosario-Martinez, Helios (2015). phia: Post-Hoc Interaction Analysis. R package version 0.2-1. Retrieved from https://cran.r-project.org/package=phia

Flaugnacco, Elena, Lopez, Luisa, Terribili, Chiara, Zoia, Stefania, Buda, Sonia, Tilli, Sara, … Schön, Daniele (2014). Rhythm perception and production predict reading abilities in developmental dyslexia. *Frontiers in Human Neuroscience*, *8*, 392. https://doi.org/10.3389/fnhum.2014.00392

Fraisse, Paul, & Repp, Bruno H. (2012). Anticipation of rhythmic stimuli: Speed of establishment and precision of synchronization (1966). *Psychomusicology: Music, Mind, and Brain*, *22*(1), 84–93. https://doi.org/10.1037/a0028758

Gordon, Reyna L., Jacobs, Magdalene S., Schuele, C. Melanie, & Mcauley, J. Devin (2015). Perspectives on the rhythm-grammar link and its implications for typical and atypical language development. *Annals of the New York Academy of Sciences*, *1337*(1), 16–25. https://doi.org/10.1111/nyas.12683

Guasti, Maria Teresa, Pagliarini, Elena, & Stucchi, Natale (2017). Language, reading and motor control: Get rhythm! *Biolinguistics*, *11*(1), 1–12.

Huss, Martina, Verney, John P., Fosker, Tim, Mead, Natasha, & Goswami, Usha (2011). Music, rhythm, rise time perception and developmental dyslexia: Perception of musical meter predicts reading and phonology. *Cortex*, *47*(6), 674–689. https://doi.org/10.1016/J.CORTEX.2010.07.010

Kuznetsova, Alexandra, Brockhoff, Per B., & Christensen, Rune H. B. (2017). lmerTest Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software*, *82*(13), 1–26. https://doi.org/10.18637/jss.v082.i13

Landerl, Karin, Wimmer, Heinz, & Frith, Uta (1997). The impact of orthographic consistency on dyslexia: A German-English comparison. *Cognition*, *63*(3), 315–334. https://doi.org/10.1016/S0010-0277(97)00005-X

Léger, Elodie, Prévost, Philippe, Tuller, Laurice, Haiden, Martin, Martineau, Joëlle, & Aguillon-Hernandez, Nadia (2015). The development of object clitics in French: A comparative study between production and real-time interpretation via eye-tracking while listening. In C. Hamann & E. Ruigendijk (Eds.), *Language acquisition and development: Proceedings of GALA 2013* (pp. 232–258). Newcastle upon Tyne: Cambridge Scholars Publishing.

Lindgren, Scott D., De Renzi, Ennio, & Richman, Lynn C. (1985). Cross-national comparisons of developmental dyslexia in Italy and the United States. *Child Development*, *56*(6), 1404–1417.

Miyake, Yoshihiro, Onishi, Yohei, & Pöppel, Ernst (2004). Two types of anticipation in synchronization tapping. *Acta Neurobiologiae Experimentalis*, *64*(3), 415–426. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15283483

Overy, Katie, Nicolson, Roderick I., Fawcett, Angela J., & Clarke, Eric F. (2003). Dyslexia and music: measuring musical timing skills. *Dyslexia*, *9*(1), 18–36. https://doi.org/10.1002/dys.233

Pagliarini, Elena, Maffioli, Giorgia, Molteni, Bruna, & Stucchi, Natale (2016). Predictive timing in Developmental Dyslexia.

Persici, Valentina, Stucchi, Natale, & Arosio, Fabrizio (2019). Predicting the future in rhythm and language: The anticipation abilities of a group of Italian-speaking preschoolers. In P. Guijarro-Fuentes & C. Suárez-Gómez (Eds.), *Proceedings of GALA 2017: Language acquisition and development* (pp. 451–468). Newcastle upon Tyne: Cambridge Scholars Publishing.

R Development Core Team. (2016). R: A Language and Environment for Statistical Computing. Retrieved from https://www.researchgate.net/publication/312455832_R_A_Language_and_Environment_for_Statistical_Computing

Rayner, Keith (1998). *Eye Movements in Reading and Information Processing: 20 Years of Research*. *Psychological Bulletin* (Vol. 124). Retrieved from https://search-proquest-com.proxy.library.vanderbilt.edu/docview/614338602/fulltextPDF/DAACFA0C9B9840A0PQ/1?accountid=14816

Rayner, Keith, Binder, Katherine S., Ashby, Jane, & Pollatsek, Alexander (2001). Eye movement control in reading: word predictability has little influence on initial landing positions in words. *Vision Research*, *41*(7), 943–954. https://doi.org/10.1016/S0042-6989(00)00310-2

Rispens, Judith, & Been, Pieter (2007). Subject–verb agreement and phonological processing in developmental dyslexia and specific language impairment (SLI): a closer look. *International Journal of Language & Communication Disorders*, *42*(3), 293–305. https://doi.org/10.1080/13682820600988777

Sartori, Giuseppe, Job, Remo, & Tressoldi, Patrizio E. (2007). *DDE-2: Batteria per la valutazione della dislessia e della disortografia evolutiva-2*. Firenze, Italia: O.S. Giunti.

Thomson, Jennifer M., Fryer, Ben, Maltby, James, & Goswami, Usha (2006). Auditory and motor rhythm awareness in adults with dyslexia. *Journal of Research in Reading*, *29*(3), 334–348. https://doi.org/10.1111/j.1467-9817.2006.00312.x

Thomson, Jennifer M., & Goswami, Usha (2008). Rhythmic processing in children with developmental dyslexia: Auditory and motor rhythms link to reading and spelling. *Journal of Physiology-Paris*, *102*(1–3), 120–129. https://doi.org/10.1016/J.JPHYSPARIS.2008.03.007

Wolff, Peter H. (2002). *Timing precision and rhythm in developmental dyslexia*. *Reading and Writing: An Interdisciplinary Journal* (Vol. 15). Retrieved from https://link.springer.com/content/pdf/10.1023%2FA%3A1013880723925.pdf

World Health Organization. (2004). *International Statistical Classification of Diseases and Health Related Problems (ICD-10)* (Second Ed.). Genève: WHO Press.

Ziegler, Johannes C., & Goswami, Usha (2005). Reading Acquisition, Developmental Dyslexia, and Skilled Reading Across Languages: A Psycholinguistic Grain Size Theory. *Psychological Bulletin*, *131*(1), 3–29. https://doi.org/10.1037/0033-2909.131.1.3

Proceedings of the 43rd annual Boston University Conference on Language Development

edited by Megan M. Brown
and Brady Dailey

Cascadilla Press Somerville, MA 2019

Copyright information

ISSN 1080-692X
ISBN 978-1-57473-096-8 (2 volume set, paperback)

Ordering information

To order a copy of the proceedings or to place a standing order, contact:

Cascadilla Press, P.O. Box 440355, Somerville, MA 02144, USA
phone: 1-617-776-2370, sales@cascadilla.com, www.cascadilla.com