RHYTHM DEFICITS IN DEVELOPMENTAL DYSLEXIA: EVIDENCE FROM ITALIAN

Marina Rossi, Eline Smit, Tamara Rathcke

University of Konstanz
marina.rossi@uni-konstanz.de, eline.smit@uni-konstanz.de, tamara.rathcke@uni-konstanz.de

ABSTRACT

Rhythm deficit in developmental dyslexia has recently received much attention. Three major accounts consider it to be the key issue in dyslexia, though supporting evidence is somewhat conflicting. The present experiment investigated rhythm processing in Italian – a language with a comparably high number of dyslexia diagnoses. Adolescents with and without developmental dyslexia were asked to tap in synchrony with metronome and monosyllable sequences at a fast and a slow pace. The results revealed subtle differences in rhythmic performance at the group level, though limited to the slow-paced condition only. Synchronisation performance of dyslexic participants showed longer absolute asynchronies indicative of a larger synchronisation error as compared to asynchronies measured for typically developing adolescents. No differences were found for sensorimotor stability, signed asynchronies, and none could be uncovered by more fine-grained time-series analyses of rhythmic performance. We conclude that there may be a rhythmic processing deficit in developmental dyslexia, though it is rather subtle and cannot predict the range of issues associated with developmental dyslexia.

Keywords: rhythm, timing, developmental dyslexia, sensorimotor synchronisation, temporal processing, time-series analyses

1. INTRODUCTION

1.1. Timing and rhythm in developmental dyslexia

Developmental dyslexia (DD) refers to specific difficulties in learning to read, write and spell, which are not accompanied by intellectual disabilities [28]. Despite many years of extensive study, the underlying causes of DD are not fully understood [17]. Sometimes considered "a heterogeneous disorder” [28], a growing number of proposals has been put forward to explain DD as a temporal processing deficit [25], a rhythm impairment [11, 14], or a rhythmic prediction deficit [4, 5, 16].

The hypothesis of a rapid temporal auditory deficit [25] proposes that the key issue in DD is a deficit in processing short or fast-paced acoustic signals. Given that phoneme identification often relies on the ability to perceive formant transitions and other spectral changes on very short timescales [9], a rapid temporal auditory deficit would lead to issues in establishing adequate phonological representations and result in instable phoneme-to-grapheme mappings that are essential for reading.

An alternative account is presented by the temporal sampling framework [11]. This suggests that DD arises as a result of an auditory sensory deficit, where the underlying cause of the deficit is seen in altered brain activity involving neural oscillations specifically within the delta range (specifically 2-2.5 Hz, [12]). These brain oscillations are assumed to lock on to acoustic modulations of speech signals on similar timescales representative of syllable rates in speech signals [10]. According to this framework, DD is the result of a temporal misalignment between neural activity and syllabic rise-times during speech perception. Such misalignment impairs the extraction of linguistic information and leads to a poor encoding of syllables that then gives rise to a poor grapheme-to-phoneme mapping.

Most recently, an inefficient anticipation hypothesis [16, 24] has advanced the idea that DD may reflect a rhythm deficit that stems from an impaired ability to make profitable use of temporal structure in speech that guides anticipation of upcoming linguistic events [4]. Such predictive processes are known to facilitate speech and language processing [29]. Accordingly, DD is suggested to be a consequence of impaired predictive processes in auditory and visual modalities affecting word recognition in both speech [4] and reading [13].

1.2 Sensorimotor synchronisation in DD

Given that several accounts of DD suggest a rhythm deficit [14], empirical methods examining temporal aspects of auditory processing are key to capturing the underlying causes of DD. One of the frequently deployed methods is sensorimotor synchronisation (SMS) that studies rhythm perception and predictive processes often by means of finger tapping in time with a metronome [26]. The paradigm asks participants to synchronize taps of their dominant index finger with an auditory rhythm sequence, e.g. a metronome beat, and performance analysis shows that participants frequently tap ahead – i.e. anticipate – a metronome beat [22]. SMS thus offers a simple way of testing the predictions of all three accounts of DD outlined above.

Current evidence documenting clear SMS deficits in DD is somewhat conflicting. On the one hand, SMS with a metronome may show deviant patterns in DD, e.g. larger asynchronies or higher variability than in typically developing participants [26]. On the other hand, the timescales at which the group-level deficits are measurable vary across studies. For example, some research provides evidence for an impairment at timescales of 2-2.5 Hz (or 500-400 ms IOI) [26] whereas others at longer timescales of 1.3 Hz (or 750 ms IOI) [16]. However, other studies fail to establish any deviant metronome synchronisation performance in DD, at any timescale [19]. Overall, existing findings do not straightforwardly support the three accounts outlined above, though the conducted analyses of SMS behaviours in DD have also been quite limited in nature.

So far, only few studies investigated rhythmic processing in DD by means of SMS, focusing primarily on tapping variability and mean accuracy [5, 16]. Predictive processes as indicated by negative mean asynchronies as well as the time-course of synchronisation have also received little attention, though individuals are known vary in the ease with which they establish a rhythmic pattern and resume synchronisation [21]. The present study aimed to fill this gap by investigating potential group-level differences in (1) signed asynchronies as an indication of predictive processes [5, 21] and (2) the time-course of synchronisation (as an indication of the ease in establishing the temporal frame of synchronisation). Moreover, there is little evidence if an increased spectral complexity of the auditory prompt (such as spoken monosyllabic words as opposed to a metronome, cf. [20]) may pose more difficulties to individuals with DD.

The language of the present study is Italian which has a large number of school-age children being annually diagnosed with DD (3,5%, [2]), even though Italian has a more consistent phoneme-to-grapheme mapping than English [27].

2. METHOD

2.1. Participants

Seventy adolescent volunteers were recruited at a local high school in Greater Milan area. Forty adolescents (29 F) aged between 14 and 21 years (M= 16.6, SD =1.8) had a formal diagnosis of DD defined according the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM–V, [1]). Thirty typically developing adolescents (23 F) aged between 14 and 20 years (M 16.2, SD=1.5) took part as a control group. Attention was paid to (proportionally) matching age and gender across the two groups of participants. All participants were Italian monolinguals without any hearing impairments, mental health issues, cognitive or developmental comorbidities (though dyscalculia occurred in 60% of the adolescents with DD and was not considered an exclusion criterion).

2.2. Materials

The study's materials consisted of faster- vs. slower-paced metronome and syllable stimuli. The metronome stimuli contained short (50 ms) beats of a metronome, repeated at two IOI. The faster-paced metronome had IOI of 300 ms and the beat repeating 40 times while the slower-paced metronome had IOI of 800 ms and the beat repeating 20 times. The syllable stimuli contained an Italian monosyllable noun [re] (meaning: *king*), produced by a female speaker of Northern Italian. The monosyllabic word had a total duration of 250 ms and was repeated 25 times, with a shorter pause of 300 ms (resulting in a faster-paced sequence with 550 ms IOI) or a longer pause of 800 ms (resulting in a slower-paced sequence with 1050 ms IOI) between repetitions.

2.3. Procedure

Participants were first presented with the metronome and then with the verbal stimuli, slow-paced sequences preceded the faced-paced ones. The task was to listen to each sequence and to start synchronizing with the pacing sounds (i.e., the beats or the syllables) as soon as possible, by tapping with the index finger of the dominant hand on the KAT KTMP1 drum pad placed in front of the participants. At the start of a session, the experimenter (the first author) explained what tapping pressure was needed and which drum-pad area had to be used during the experiment to ensure that taps were recorded correctly.

The stimuli were played back via good-quality headphones (Sennheiser HD 380). Taps were collected using LogicPro [7] running on the MacBook Air 13 laptop. The set-up specific time delay consisted of 34 ms that were subtracted from the tapping data collected, prior to calculating asynchronies.

Participants were tested individually in a quiet room allocated to the experiment by the local school authorities. At the beginning of a session, participants were asked to self-report their previous musical training by filling in a questionnaire (cf.Rathcke and Lin [19]). The questionnaire collected information if participants ever had any musical training (coded 0 for "no", 1 for "yes"), if they were still actively practicing their hobby (again, coded 0 for "no", 1 for "yes"), at what age they started their training (coded 2 for under 10 y.o., 1 for over 10 y.o.), the number of years they engaged with the hobby and how many instruments they played. Musical training included not only playing an instrument, but also singing or dancing. An individual musicality score was a numerical composite of all questionnaire answers provided. Higher scores were indicative of a higher level of musical training and experience [19].

All participants and their guardians consented to their participation. The study received ethical approval from the Ethics Board of the University of Konstanz (IRB statement 05/2021).

2.4 Data preparation and analyses

Temporal onsets of the metronome and the syllable targets were extracted using Praat [6]. Subsequently, time delays between each metronome beat or syllable onset and the nearby tap were calculated[15], resulting in the following set of measures:

- *mean coefficient of variation (CV)* as an individual measure of SMS consistency, calculated as standard deviation of inter-tap intervals divided by the mean interval duration;
- *mean absolute asynchronies (AA)* as an individual measure of accuracy, reflecting the temporal distance between a target and a tap;
- *mean signed asynchronies (SA)* as an individual measure of predictive processes, or the distance from a tap to the preceding (negative values) or the following (positive values) target.

These measures are widely used in studies of clinical and non-clinical SMS-profiles[8, 20]. In addition, we examined signed asynchronies as time-series data for each participant and stimulus, focusing on potential group-level differences in the ease of establishing and maintaining the temporal frame of synchronization. These analyses provide additional evidence on potential anticipation issues that may be key to DD [14].

3. RESULTS

3.1 Mean-based measures of SMS performance

The best-fit models reported in this section were established using a backward-fitting procedure and estimated using REML and *nloptwrap* optimizer [3]. They included *participant* as random effect.

The best-fit linear mixed-effects regression with *CV* as the dependent variable did not include *group* either as a main effect or as an interaction, for either type of stimuli. *IOI* was the only significant predictor showing that tap consistency was higher for *the faster IOI* compared to the *slower IOI* across both groups and stimulus types (metronome: ß = 0.25, SE = 0.08, z = -2.86, p <.01; verbal: ß = 0.12, SE = 0.033, z = 3.64, p <.001).

The best-fit linear mixed-effects regression with *AA* as the dependent variable included *group* in interaction with *IOI* as a significant predictor, for both stimulus types. The dyslexic group had higher *AA* (indicative of lower accuracy) than the control group, but only in the *slower IOI* compared to the *faster IOI* (metronome: ß = 63.28, SE = 9.12, z = 6.93, p <.001; verbal: ß = 24.74, SE = 9.05, z = 2.73, p <.01, see Figure 1). There was no significant effect of musical training.

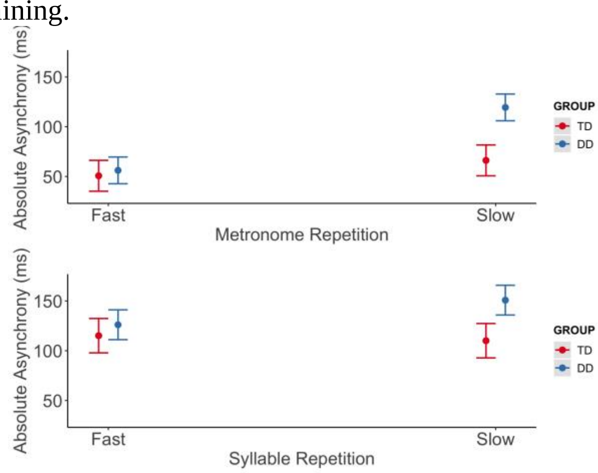

Figure 1: Group-level estimates of absolute asynchronies from best-fit models for synchronization with metronome (top panel) and syllable (bottom panel) sequencies.

The best-fit linear mixed-effects regression with *SA* as the dependent variable did not include *group* either as a main effect or as an interaction, for either type of stimuli. Only *IOI* was a significant predictor for verbal (but not metronome) stimuli, showing that all participants anticipated the upcoming target more in the *faster IOI* than the *slower IOI* condition (ß = 53.52, SE = 7.48, z = 7.15, p <.001).

3.2 Time-series measures of SMS performance

Generalised additive mixed models (GAMMs) were fit to the time-series data measuring *SA* with each synchronisation target. The models were estimated using ML and *outer newton* optimizer and included *participant* as random effect [23]. Best-fit GAMMs did not included *group* as the significant smoothing term at either fast pace (*300 ms IOI*: edf = 4.9, Ref. df = 5.6, F = 1.8, p = 0.2; *550 ms IOI*: edf = 1.06, Ref. df = 1.01, F = 0.24, p = 0.6) or slow pace (*800 ms IOI*: edf = 1, Ref. df = 1, F = 0.05, p = 0.8; *1050 ms IOI*:

edf = 1.1, Ref. df = 1.5, F = 0.02, p = 0.9; see Figures 2 and 3).

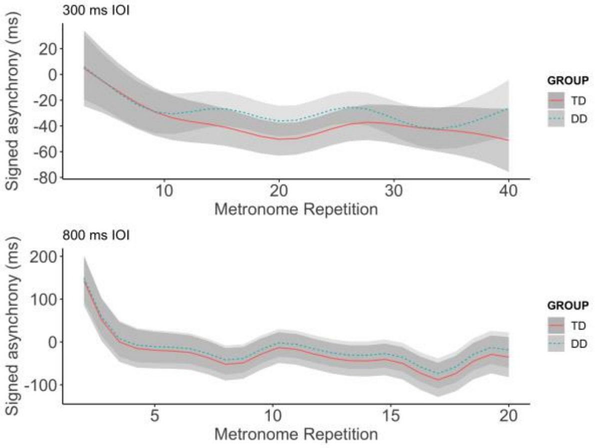

Figure 2: Best-fit GAMMs estimating SA in the *metronome* condition as a function of *group*.

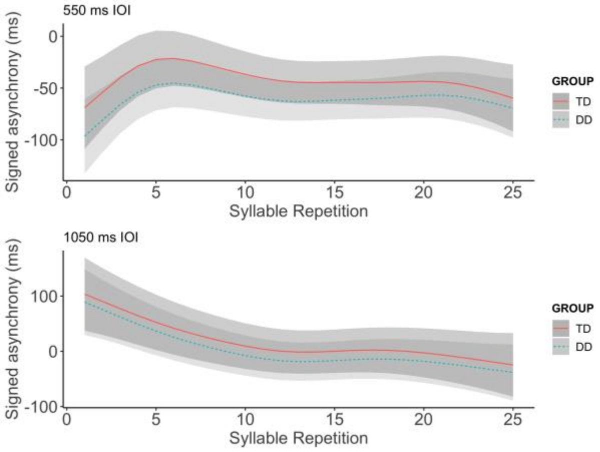

Figure 3: Best-fit GAMMs estimating SA in the *syllable* condition as a function of *group*.

Visual comparisons of the time-series data indicate that all participants experienced more difficulties with maintaining stable tapping when synchronizing with metronome than syllable sequencies and when synchronizing at slower than faster pace. Across all experimental conditions, dyslexic participants showed anticipatory tapping responses to a similar degree control participants did.

4. DISCUSSION

The purpose of the current study was to investigate rhythmic processing in Italian adolescents with and without developmental dyslexia. The method of the study involved a SMS paradigm used in previous research [19, 26]. Participants had to synchronize with slow and fast-paces stimuli containing either metronome beats or syllables [19]. Overall, our results support the idea of a rhythm impairment in DD [11, 24, 25], even though reliable group-level differences are very subtle and limited to slow-paced rhythmic prompts.

We observed significant group-level differences in synchronisation with both metronome and syllable sequences, but these differences were specific to the slow-paced stimuli. Time-series analyses did not help to capture these group-level differences, though here, we focused primarily on signed asynchronies to test the hypothesised anticipation issues in the dyslexic group[18]. Overall, sensorimotor performance of the two groups differed exclusively in their absolute mean asynchronies. No other measure of rhythmic synchronization showed a significant effect of group.

Current findings do not straightforwardly support existing accounts of DD. The rapid temporal auditory deficit hypothesis [25] predicts an impaired rhythmic performance primarily for fast-paced stimuli. However, we found the opposite pattern. The assumptions of the temporal sampling framework [11] are not supported for two reasons. First, the framework predicts main issues at 2-2.5 Hz (i.e., around 500-400 ms IOI), but not at slower tempi. However, the present study shows key differences between the groups at longer IOIs. Second, the framework suggests that rhythmic processing issues stem from an auditory issue with encoding complex amplitude modulations. Accordingly, tapping long with acoustically complex syllables should cause more difficulties for dyslexic participants than tapping with a metronome beat. The prediction was not borne out by the present study. Given that we tested a relatively large sample, it is rather unlikely that the lack of statistical evidence to support group-level differences is due to low power.

Finally, the inefficient anticipation hypothesis [16] would predict lack of anticipation of upcoming rhythmic events, with taps lagging behind targets during SMS [4]. The results of the present time-series analyses clearly show that Italian adolescents with DD can indeed tap *ahead* of rhythmic targets similar to typically developing control group. When synchronizing with slow-paced prompts, both groups lagged behind the first few targets but then started anticipating. When synchronizing with fast-paced prompts, all participants tended to anticipate from the onset of their tapping.

The study of developmental dyslexia has seen a number of controversial findings. A previous review of the literature concluded that disordered production and/or perception of prosodic phenomena in dyslexia has only been consistently attested in tasks involving metalinguistic judgements or other factors that increased processing difficulty (e.g., the presence of background noise, high short-term memory load, or time pressure on decision making) [18]. The results of the present study speak in support of the suggestion that a rhythmic impairment is unlikely to be the primary cause of the issues observed in dyslexia.

7. REFERENCES

[1] American, Psychiatric, and Association, 2013, Diagnostic and Statistical Manual of Mental Disorders. DSM-5, ed: American Psychiatric Publishing.

[2] Barbiero, C. *et al.*, 2019, The lost children: The underdiagnosis of dyslexia in Italy. A cross-sectional national study, *PLoS One*, vol. 14 no. 1 e0210448

[3] Bates, D., Mächler, M., Bolker, B., and Walker, S., 2015, Fitting Linear Mixed-Effects Models Using lme4, *Journal of Statistical Software*, vol. 67 no. 1 1 - 48

[4] Beach, S. *et al.*, 2022, The Neural Representation of a Repeated Standard Stimulus in Dyslexia, *Frontiers in Human Neuroscience*, vol. 16

[5] Bégel, V., Dalla Bella, S., Devignes, Q., Vandenbergue, M., Lemaître, M. P., and Dellacherie, D., 2022, Rhythm as an independent determinant of developmental dyslexia, *Dev Psychol*, vol. 58 no. 2 339-358

[6] *Boersma, P. and Weenink, D., 2007, PRAAT: Doing phonetics by computer (Version 5.3.51).*

[7] *Cousins, M. and Hepworth-Sawyer, R., 2014, Logic Pro X*. Oxon: Focal Press, Abingdon.

[8] Dalla Bella, S. *et al.*, 2017, BAASTA: Battery for the Assessment of Auditory Sensorimotor and Timing Abilities, *Behav Res Methods*, vol. 49 no. 3 1128-1145

[9] Dorman, M., Cutting, J., and Raphael, L., 1975, Perception of temporal order in vowel sequences with and without formant transitions, *J. of exp psychology. Human perc and performance*, vol. 104 2 147-153

[10] Flanagan, S. and Goswami, U., 2018, The role of phase synchronisation between low frequency amplitude modulations in child phonology and morphology speech tasks, *J of the Acoustic Soc of America*, vol. 143 no. 3 1366-1366

[11] Goswami, U., 2011, Temporal sampling framework for developmental dyslexia, *Trends in cognitive sciences*, vol. 15 3-10

[12] Keshavarzi, M. *et al.*, 2022, Atypical delta-band phase consistency and atypical preferred phase in children with dyslexia during neural entrainment to rhythmic audio-visual speech, *Neuroimage Clin*, vol. 35 103054

[13] Kirkby, J. A., Barrington, R. S., Drieghe, D., and Liversedge, S. P., 2022, Parafoveal processing and transposed-letter effects in dyslexic reading, *Dyslexia*, vol. 28 no. 3 359-374

[14] Ladányi, E., Persici, V., Fiveash, A., Tillmann, B., and Gordon, R. L., 2020, Is atypical rhythm a risk factor for developmental speech and language disorders?, *Wiley Interdiscip Rev Cogn Sci*, vol. 11 no. 5 e1528

[15] *Natick, 2022a, MATLAB*. Massachusetts: The MathWorks Inc.

[16] Pagliarini, E., Scocchia, L., Granocchio, E., Sarti, D., Stucchi, N., and Guasti, M. T., 2020, Timing anticipation in adults and children with Developmental Dyslexia: evidence of an inefficient mechanism, *Scientific Reports*, vol. 10 no. 1 17519

[17] Protopapas, A., 2014, From temporal processing to developmental language disorders: mind the gap, *Philos Trans R Soc Lond B Biol Sci*, vol. 369 no. 1634 20130090

[18] Ramus, F. and Ahissar, M., 2012, Developmental dyslexia: the difficulties of interpreting poor performance, and the importance of normal performance, *Cogn Neuropsychol*, vol. 29 no. 1-2 104-122

[19] Rathcke, T. and Lin, C.-Y., 2021, Towards a Comprehensive Account of Rhythm Processing Issues in Developmental Dyslexia, *Brain Sci*, vol. 11 no. 10 1303

[20] Rathcke, T., Lin, C.-Y., Falk, S., and Dalla Bella, S., 2019, When language hits the beat: Synchronising movement to simple tonal and verbal stimuli, presented at the International Congress of Phonetic Sciences, Melbourne, Australia.

[21] Rathcke, T., Lin, C.-Y., Falk, S., and Dalla Bella, S., 2021, Tapping into linguistic rhythm, *Laboratory Phonology: Journal of the Association for Laboratory Phonology*, vol. 12(1):11 1-32

[22] Repp, B. H. and Su, Y.-H., 2013, Sensorimotor synchronization: A review of recent research (2006–2012), *Psychonomic Bulletin & Review*, vol. 20 no. 3 403-452

[23] Sóskuthy, M., 2017, Generalised additive mixed models for dynamic analysis in linguistics: a practical introduction,

[24] Taha, J., Stucchi, N., Pagliarini, E., and Guasti, M. T., 2022, *What is wrong with rhythm in Developmental Dyslexia? The inefficient anticipation hypothesis*.

[25] Tallal, P., 1980, Auditory temporal perception, phonics, and reading disabilities in children, *Brain Lang*, vol. 9 no. 2 182-198

[26] Thomson, J. M. and Goswami, U., 2008, Rhythmic processing in children with developmental dyslexia: auditory and motor rhythms link to reading and spelling, *J Physiol Paris*, vol. 102 no. 1-3 120-129

[27] Traficante, D. and Burani, C., 2014, List context effects in languages with opaque and transparent orthographies: a challenge for models of reading, *Front Psychol*, vol. 5 1023

[28] van Bergen, E., van der Leij, A., and de Jong, P. F., 2014, The intergenerational multiple deficit model and the case of dyslexia, *Front Hum Neurosci*, vol. 8 346

[29] Zettersten, M., 2019, Learning by predicting: How predictive processing informs language development, in *Patterns in Language and Linguistics*, Busse and Moehlig-Falke Eds. Berlin, Boston: De Gruyter Mouton, 255-288