Rhythm and Reading Abilities: Adult Readers, Rhythm Perception and the Role of Memory and Sensory Motor Engagement

J. Riikka Ahokas, Ariane Tretow,
Petri Toiviainen, Paavo Leppänen,
& Suvi Saarikallio
University of Jyväskylä, Jyväskylä, Finland

This study was conducted to investigate the previously indicated causal relationship between reading impairment and difficulties in rhythm perception in an adult sample. In our study the comparison was made between the family risk for dyslexia and the no-risk for dyslexia groups to assess the possibility of shared risk factors. We hypothesized that a relationship exists between reading deficits and lower performance in rhythm perception within the family risk for dyslexia participant group. The participants were young adults ($N = 119$, aged from 20 to 48 years old). We assessed the reading abilities, rhythm perception performance and memory performance, and sensorimotor music reward experiences of our participants. Our results indicate that in adulthood rhythm perception appears to correlate with aspects of memory function, rather than with measures of reading fluency. Our results also suggest an indirect relationship between rhythm perception and word text reading fluency through short-term memory within the family risk for dyslexia group. A weak positive correlation between sensorimotor musical reward experience and pseudoword reading fluency was detected as well. We suggest family risk for dyslexia as an additional variable in future research.

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The ability to perceive music rhythm patterns has been suggested to be related to reading skills. In a recent article by Ladányi et al. (2020), the authors introduce the Atypical Rhythm Risk Hypothesis, positing a causality between atypical rhythm skills and higher risk for developmental speech- and language-related disorders. Ladanyi et al. (2020) reframes their work on a few dominant theories, concentrating on a relationship between rhythm skills and speech processing; among them is, for example, the dynamic attending theory (DAT; Jones, 1976), which has also inspired the temporal sampling framework (TSF) by Goswami (2011). In TSF, the impaired language and rhythmic processing (and atypical rhythm perception) of dyslexic children and adults is suggested to be inhibited by dysfunctional entrainment of brain oscillations to sensory input. In particular, the perceptual abilities of amplitude and frequency modulation are important for reading outcomes. This has been linked to deficits in phonological awareness and their connection to lower-level auditory processing deficits (Ozernov-Palchik & Gaab, 2016). Despite the evidence in favor of the phonological deficit hypothesis, phonological skills are a dimensional phenomenon and can be observed alongside other deficits in dyslexia (Snowling et al., 2003). This leads back to the multiple deficit model (MDM) of dyslexia (Pennington, 2006) and its intergenerational aspect (intergenerational MDM; van Bergen et al., 2014). Further evidence for a multifactorial approach to dyslexia was provided by O'Brien and Yeatman (2021). They showed that deficits in visual motion processing, perceptual decision-making, and phonological processing were mostly discriminable factors in school-aged children. The proposed risk factor of atypical rhythm perception in dyslexia (Ladányi et al., 2020) follows the cumulative risk and resilience model reviewed by Catts and Petscher (2022) but needs to be tested for evidence to stand alongside other additive risk factors.

The connection between rhythm abilities and reading skills has been approached in the literature with participants from the early stages of literacy development (Bégel et al., 2022; Bonacina et al., 2021; Lundetræ & Thomson, 2018) to the mature adult brain in the context of impairments in reading and rhythm perception (Fiveash et al., 2020; Leong & Goswami, 2014a, 2014b; Thomson et al., 2006). The literature focusing on the connection between rhythm and reading among child populations has approached the phenomenon by studying participants with reading disabilities (Bonacina et al., 2015; Corriveau & Goswami, 2009) as well as typically developing readers (Chern et al., 2018; Gordon

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et al., 2015; Lee et al., 2020; Steinbrink et al., 2019). In recent years, there has been interest in the pre-attentive, pre-literacy, and diagnostic dimensions of children's rhythmic skills (Bégel et al., 2022; Bonacina et al., 2021; Harrison et al., 2018; Lê et al., 2020; Lundetræ & Thomson, 2018; Ozernov-Palchik et al., 2018). It has been argued that musical and rhythmic skills develop and mature with age even in the absence of music training (Ireland et al., 2018; Tichko et al., 2022), but as with participants diagnosed with reading difficulties or dyslexia, there still appears to be a challenge with rhythm perception and the performance of rhythmic skills in adulthood compared to age-matched participants (Bekius et al., 2016; Fiveash et al., 2020; Leong & Goswami, 2014a, 2014b; Thomson et al., 2006). Although there may be culturally specific differences in music and in rhythm perception, the previous literature suggests an evident relationship between music perception and literacy, particularly among children with reading difficulties, regardless of language group (e.g., alphabetic or morphosyllabic language groups) (Flaugnacco et al., 2014; Lee et al., 2015; Nan et al., 2018; Surányi et al., 2009; Zhang et al., 2017; Zuk et al., 2013).

The multimodality of rhythm perception has recently been addressed in the literature by, for example, Fiveash et al. (2022). The perception of musical rhythm is not only cognitive but also physical and therefore the experience of music and musical rhythm can be seen as a highly multisensory experience (Matthews et al., 2020). Musical rhythm has the ability to induce movement in humans; even in the absence of actual body movement, musical rhythm activates motor areas of the brain (Grahn & Brett, 2007). The tendency of music to activate sensorimotor experiences has been identified as a key feature of why music is perceived as rewarding (Mas-Herrero et al., 2012) and there is an argued comorbidity between sensorimotor impairments and reading impairments (Marchetti et al., 2022).

Music training, both in longitudinal (e.g., Degé et al., 2011) and shorter (e.g., Guo et al., 2018) intervention research designs, has been connected with improved memory performance. In a recent study (Ireland et al., 2018) focusing on the development of age-equivalent musicality tests, the authors also observed that working memory (recorded with digit span and letter–number sequencing tests) correlated with the developed rhythm discrimination and syllable sequence discrimination tasks. Memory functions have been acknowledged to be crucial for reading skills (Lonergan et al., 2019; Peng et al., 2018; Swanson et al., 2009; Smith et al., 2021). Working memory, on the other hand, has been discussed as a predictor of later reading difficulties in early childhood (Atkinson & Martin, 2022) and has been noted to moderately correlate with reading ability (for meta-analysis, see Peng et al., 2018; Swanson et al., 2009). Furthermore, working memory function, literacy, and rhythm perception appear to be interconnected (Cancer & Antonietti, 2018). Impaired memory performance in participants with reading difficulties has been proposed to be related to the phonological loop component of working memory (Wang & Gathercole, 2013). However, deficits are present not only in verbal but also visuospatial working memory (Smith-Spark & Gordon, 2022). In the verbal working memory domain, the digit span task has consistently provided evidence of impairment from childhood to adulthood, identifying inhibition as a relevant factor for struggling readers (Brosnan et al., 2002).

Dyslexia has been identified as a heritable condition and a family history of disorders in areas of speech or language is considered as an indicator of a genetic predisposition for reading impairments (Ladányi et al., 2020; Snowling et al., 2003). Moreover, the shared genetics of musical rhythm skills and linguistic skills has been hypothesized but as Ladányi et al. (2020) suggest, the shared-versus-separate genetic influence of musical rhythm and language skill still needs to be disentangled. One of the novelties of the present study was to investigate the possible effect of family risk for reading impairment on rhythm perception. The sample of the current study includes participants with a family risk for dyslexia (FR) and typically developing readers without a family risk (no family risk, NFR) at a young adult age. We investigated whether rhythm perception performance had an explanatory effect on reading fluency in adults of family risk for dyslexia and no risk control participants. Our main hypothesis was that, in support of previous research (see, e.g., Ladányi et al., 2020), there is a connection between the rhythm perception and reading fluency and/or comprehension of family risk for dyslexia groups. As we acknowledged the possibility of a comorbidity between reading and sensorimotor impairments (Marchetti et al., 2022), we also explored the connection between sensorimotor music reward experiences and reading abilities within our sample. Memory functions, in particular in the area of executing working memory, have been considered significant in both reading abilities and rhythm perception (Cancer & Antonietti, 2018), and therefore we included the assessment of short-term and working memory performance of the participants in our analysis. Overall, we explored the possible interconnections of assessed memory functions with rhythm perception, reading abilities and sensorimotor music reward experiences.

Method

PARTICIPANTS

The participants were 119 young adults (age range 20 to 48, $M = 27.32$, $SD = 5.03$) and the data were collected at the University of Jyväskylä, Finland. All participants spoke Finnish as their native language. The sample included readers from different skill levels and family backgrounds with and without family risk for dyslexia. Family risk (FR) is defined here as having one parent and a first-degree relative identified to have reading difficulties. For the participants from the longitudinal data collection ($N = 85$, Jyväskylä Longitudinal Study of Dyslexia, JLD; Lohvansuu et al., 2021; Lyytinen et al., 2015), FR was evaluated at the early recruitment stage of the families, with a test battery evaluating the skill level of participants' parents as well as reports of family history of reading difficulties (for further description on the recruitment process and skill evaluation of the longitudinal sample and their parents see Eklund et al., 2015, Leinonen et al., 2001). For the remaining participants ($N = 34$, CoPSOI adult data collection), family risk was evaluated as self-reported in adulthood. Participants have given informed written consent for their participation in the study, and procedures have been positively reviewed by the ethical board of the University of Jyväskylä, applying the ethical standards of the Declaration of Helsinki.

COGNITIVE MEASURES

Due to some of the data being collected during the COVID-19 pandemic, the cognitive skill assessment of the data collection was partly performed online under the video call supervision of an experienced experimenter (i.e., the participant was given the choice to perform the tests in the laboratory or through a video call). The cognitive skill assessment as a whole took a maximum of two hours and was complemented by an online questionnaire that the participants were able to complete in their own time. During a later onsite visit, hearing abilities were assessed to exclude possible effects on the auditory tasks.

SHORT TERM AND WORKING MEMORY

Digit span forward and backward subtests of the fourth edition of the Wechsler Adult Intelligence Scale (WAIS-IV) were administered as cognitive skill assessment tools to evaluate verbal short-term memory (vSTM) (digit span forward) and verbal working memory (vWM) (digit span backward) (Cullum & Larrabee, 2010; Wechsler, 2008). In digit span forward, participants repeat digits in the same order as they have been spoken by the experimenter. For digit span backward, the recall phase is reversed. The task begins with two digits and increases in difficulty reaching a maximum number of nine digits to recall. The raw points per subtests were used in the presented analysis.

PSEUDO AND TEXT READING FLUENCY

We evaluated oral text reading and pseudoword text reading with texts previously used in the longitudinal data collection of Jyväskylä Longitudinal Study of Dyslexia (Eklund et al., 2015). For text reading, participants read a text consisting of 16 sentences in three paragraphs, and a total of 207 words/1,591 letters. For pseudoword text reading, participants read a text including 38 pseudowords/ 277 letters, which resembled real words and sentences in Finnish but had no meaning. Pseudoword reading fluency is a widely used measure in dyslexia research, reflecting so-called decoding fluency, that is, grapheme–phoneme conversion speed and accuracy (Coltheart et al., 2001). For both texts, the participants were asked to read the texts as fluently and accurately as they normally do, and their performance was recorded to be re-evaluated by a second rater, ensuring the quality of scores taken. The number of errors and the reading time were assessed. Reading time was transformed into words read per minute (wpm) and corrected by the number of mistakes made per minute, resulting in a measure of correctly read words per minute that reflected reading fluency for text and pseudoword text separately.

READING COMPREHENSION

Reading comprehension was assessed through a supervised online screening tool developed by the Niilo Mäki Institute (DigiLukiseula, https://digilukiseula.nmi.fi). The version of the screening tool had been developed for ninth graders and above. Participants filled in missing words in paragraphs presented on the screen. They viewed ten paragraphs and filled in a total of 38 missing words that had to fit the context of the sentences. We evaluated the amount of correctly selected words that fit the context of the paragraphs and compared the result percentile of achievement to Finnish norms in Grade 9. Due to the nature of the test being a screening tool, and a clear ceiling effect observed for the adult readers (82 out of the 118 participants achieved performances in the 90th percentile and above), the obtained percentiles were transformed into a dichotomous variable. Indications of reading comprehension difficulties were seen from the 75th percentile and below ($N = 27$). Any performance above that level was considered to show no indication of reading comprehension difficulties ($N = 89$).

RHYTHM PERCEPTION TASK

A computerized rhythm perception task (originally designed for Huss et al., 2011) was utilized to obtain the participants' rhythm perception performance score. This rhythm task was chosen based on previous studies with reading impaired populations; for example, those by Kalashnikova et al. (2021) at its original size of 36 trials and by Flaugnacco et al. (2014) as a shortened version similar to this study. Due to time constraints of the test battery, together with an apparent link of rhythm perception to a family risk factor in children (Kalashnikova et al. 2021), we did not include an additional rhythm production task in the battery. The rhythm perception task was incorporated and executed as part of the complete set of obtained cognitive measures. The data collection was administered online, under supervision via jsPysch (de Leeuw, 2015) on the cognition.run platform (http://cognition.run). To our knowledge, the task had not been used with adult participants before. The tempo in all the trials was 120 bpm. The design included 18 different rhythm arrangements, of which nine trials presented altered stimuli. The structure of the perception task was built on a call-and-response structure. Every trial included three bars of accented notes, which were either altered in the repetition of the bars in the following response, or not altered at all. Our task included ten trials with five similar pairs, and five 'incorrect' pairs, presented in a 4/4-time signature. Eight trials with four "correct" and four incorrect pairs were presented in a 3/4-time signature. The used note values were doubled eighth notes, quarter notes and half notes, while the note values varied in the trials. The main rhythm stimuli did not include rests. The metrical structure of the incorrect stimuli was altered by adding 166 ms to one interonset interval of the rhythmic pattern. The correct (nine trials) and altered (nine) incorrect trials were delivered randomly. The participants were asked to make correct or incorrect judgments and the number of correctly identified items was taken as a performance score. See Figure 1 for notated examples of non-altered and altered rhythm perception trials in both the 4/4- and 3/4-time signatures.

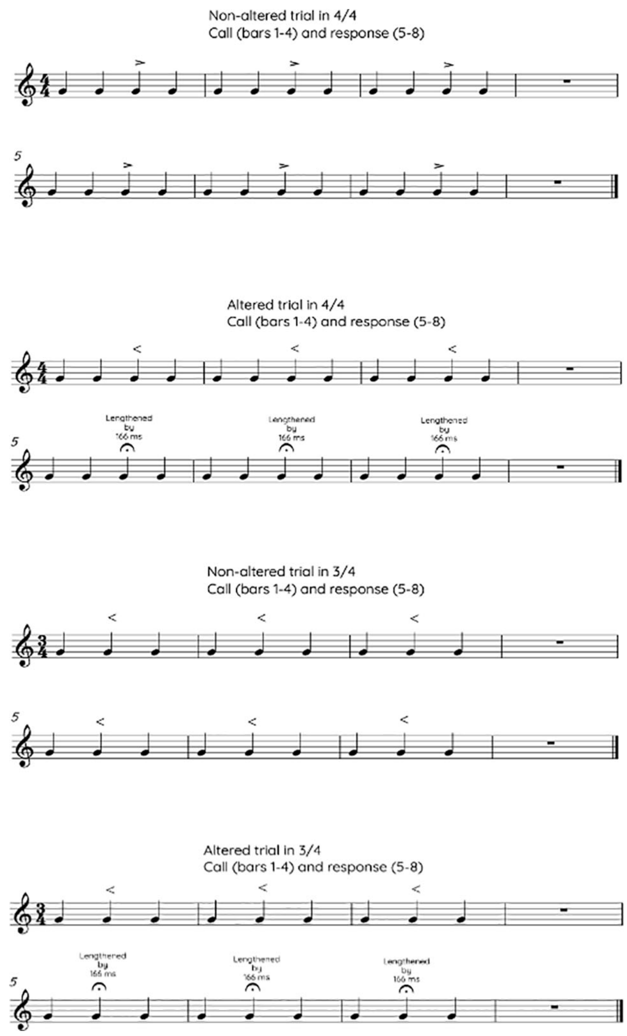

FIGURE 1. Notated examples of non-altered and altered rhythm perception trials with 4/4- and 3/4-time signatures. *Note*: Notated examples of non-altered and altered rhythm perception trials with 4/4- and 3/4-time signatures. The trials were built on a call-and-response structure, the first four (1–4) bars representing the call and the second row (bars 5–8) the response. The altered, incorrect responses were delivered with an 166-ms extension on the accented note. The trials were delivered at a tempo of 120 bpm.

BARCELONA MUSIC REWARD QUESTIONNAIRE

The participants self-evaluated their music reward experiences using a subscale of the Barcelona Music Reward online questionnaire (Mas-Herrero et al., 2012). This sensory-motor experience subscale (BMRQ-SM) consists of five items that concentrate on the personal experiences of beat-induced movement and the ability to detect rhythm in the music. Participants' responses were recorded with a five-point Likert scale. The items were "Music often makes me dance," "I can't help humming or singing along to music that I like," "I don't like to dance, not even with music I like," "I sometimes feel chills when I hear a melody that I like," and "When I hear a tune I like a lot, I can't help tapping or moving to its beat."

STATISTICS AND DATA PROCESSING

The output of the computerized rhythm discrimination task was scored with customized scripts in Matlab (version R2016b) and combined with the cognitive skill databases in IBM SPSS (version 26). The statistical evaluation of the data was performed in JASP (2022, version 0.16.1, Windows). First, correlations were evaluated between the reading fluency, rhythm perception, and vSTM and vWM while participants also reported their evaluation of sensory-motor engagement with musical rhythm. As a second step, a linear regression analysis was performed to evaluate the explanatory value of rhythmic discrimination on reading performance as an outcome. Text reading fluency was entered as the dependent variable, while the following were added as independent variables: correct items in the rhythm discrimination task, BMRQ-SM score, digit span forward, digit span backward, and the family risk factor. For evaluation of rhythm perception skills across different reading fluency levels, a data split of the continuous reading fluency variable was performed, which separated the continuous data to represent fluent, average, and dysfluent participants within the sample; one standard deviation was chosen for evaluating the cut-off points between groups (n fluent = 18, n average reader = 78, n dysfluent = 20). Afterward, a one-way analysis of variance (ANOVA) was performed with the factors of reading fluency and family risk on the dependent variables of rhythm discrimination and digit span forward, as well as BMRQ-SM. To verify the relationship of short-term memory, rhythm perception, and reading fluency within the family risk groups, a mediation analysis was conducted post hoc to examine the flow of an indirect effect via short-term memory between rhythm perception and text reading fluency. Following the four-step approach by Baron and Kennedy (1986), no grounds for mediation effect are given due to rhythm perception performance not presenting a direct effect on reading fluency outcome. Despite this, driven by the empirical and theoretical connection between rhythm perception and memory, as well as between memory performance and reading, the indirect effect was tested (Shrout & Bolger, 2002). Significance testing of the effect was performed with a bootstrapping approach implemented in the lavaan package for R (Biesanz et al., 2010; Rosseel., 2012). Missing value handling was done by full information maximum likelihood, and an ML estimator was utilized. Lastly, we examined the difference in rhythm perception performance in the two groups of reading comprehension skills by applying the Mann Whitney U test.

Results

Our study aimed to explore the relationship of rhythm perception with reading fluency in adulthood within a population of participants with and without family risk for dyslexia. The hypothesized relationship between rhythm perception and reading fluency (word text fluency: r = .056, p = .553; pseudo word text reading: r = .150, p = .111) was not present in the dataset. In a regression model, rhythm perception, BMRQ-SM score, vSTM, vWM, and family risk for dyslexia provided a significant explanatory value of 28.6% of the variance in word text reading fluency in adult participants, $F(5, 97) = 9.19$, p = < .001, with adjusted R^2 = .286. Significant coefficients in the word text fluency model were family risk (b = 7.49, p = .026) and vSTM (b = 3.83, p = < .001). Contrary to our hypothesis, rhythm perception added no explanatory value to text reading fluency (b = −.54, p = .292,). The confidence interval for the slope to predict text reading fluency from the vSTM performance was 95% CI [1.90, 5.76] with beta = 3.83. For other predictors, see Table 1. The RMSE indicated less accuracy in the prediction of word text reading fluency by the given model (RMSE = 15.5, word text reading fluency range = 54.8–140.9), suggesting that there are other predictors necessary for the accurate prediction of reading fluency, which were not taken into account in this investigation of the relationship between rhythm perception and reading. Figure 2 displays the contrasting findings on the relationship of word text reading fluency to rhythm perception, as well as on the relationship between word reading fluency and vSTM. Similar results were obtained with pseudo word text fluency, $F(5, 97) = 6.68$, p = < .001, adjusted R^2 = .218.

Following the interpretation of correlations after Cohen (1988), support was found for a positive medium correlation between word text reading fluency and vSTM (r = .488, p = < .001, N = 114) as well as between word text reading fluency and vWM (r = .332, p = < .001, N = 115). Decoding fluency, as indicated by pseudoword text reading fluency, showed similar correlations to vSTM and vWM. In addition, a small positive correlation between pseudoword text reading and participants' reported sensorimotor reward (BMRQ-SM, r = .224, p = .021) was present. Between participants' own musical sensorimotor reward experience (BMRQ-SM) and working memory, a small correlation was found (vWM, r = .271, p = .005, N = 106). Rhythm perception showed a positive small correlation with short-term memory (vSTM, r = .238, p = .012, N = 112) and with working memory (vWM, r = .187, p = .047, N = 113). Despite the correlations identified in the data set, the

TABLE 1. *Regression Results for Word Text Reading Fluency as Dependent Variable*

Predictor	b	b 95% CI	sr^2	sr^2 95% CI	Fit
(Intercept)	50.62**	[28.29, 72.95]			
Rythm perception	−0.54	[−1.54, 0.47]	.01	[−.02, .04]	
BMRQ SM	0.51	[−0.52, 1.54]	.01	[−.02, .03]	
vWM	0.43	[−1.56, 2.42]	.00	[−.01, .01]	
vSTM	3.83**	[1.90, 5.76]	.11	[.01, .21]	
Family risk factor	7.49*	[0.92, 14.05]	.04	[−.02, .10]	
					R^2 = .321** adjusted R^2 = .286**

Note. b represents unstandardized regression weights. sr^2 represents the semi-partial correlation squared. The values given in brackets are indicating the lower and upper limit of a confidence interval. vWM is standing for verbal working memory, vSTM for verbal short term memory.
*indicates $p < .05$. **indicates $p < .01$.

variance inflation factor (VIF) of the regression performed did not indicate that the regression model should be adjusted (VIF < 2).

The evaluation of rhythm perception within the family risk group revealed a significant indirect effect of rhythm perception via short-term memory on word text reading fluency (Figure 3A). This indirect effect was not significant in the control group (Figure 3B). For both groups, the direct effect of rhythm perception on word text reading fluency was not present. Adding to this, evaluation of rhythm perception between fluency levels and family risk factors showed no significant difference between the fluency groups, $F(2) = 0.468$, $p = .627$, but a small group effect for family risk, $F(1) = 5.38$, $p = .022$, $\eta^2 = .045$ (Figure 4A). Furthermore, the group of participants with reading comprehension difficulties (N = 27) showed a lower rhythmic perception ability compared to those without reading comprehension difficulties (N = 89), $U = 894$, $p = .044$ (see Figure 4B). For the BMRQ-SM, no significant effects of fluency, $F(2)$ = 2.806, p =.065, or family risk factors, $F(1) = 0.738$, p = .392, were found.

Discussion

Following our hypothesis, we investigated whether rhythm perception has an explanatory value for reading fluency in adulthood, and if a rhythm perception deficit is evident within the family risk of dyslexia cohort. Furthermore, we explored the possible link between sensory motor music reward experiences and reading difficulties in our sample. In addition, we investigated the memory performance of our participants to examine interconnections between rhythm perception, reading abilities, memory performance, and sensory motor reward experiences. Contrary to our hypothesis, the rhythm perception task performance showed no significant correlations with the participants' reading performance, nor did it have any explanatory value for the variance in reading fluency. The rhythm perception task had a significant group effect with family risk of dyslexia, supporting and indicating the argued link between rhythm perception and reading deficits, but the mean difference in rhythm task performance between the family risk and control groups was only minor (see Figure 4A).

A significant body of research supports connections between rhythm and reading abilities (e.g., Goswami, 2011; Ladányi et al., 2020) and even a proposed shared genetic influence between these two. It is therefore important to reflect on the possible reasons for not finding a clear effect of challenges in rhythm perception in the group of family risk for dyslexia. The most practical and general challenge possibly affecting our results was the provided time resources for the whole cognitive test battery. It has also been suggested in the literature with both child (e.g., Flaugnacco et al., 2014; Huss et al., 2011) and adult participants (Alcock et al., 2000; Thomson et al., 2006) that the challenges of beat (rhythm, meter) perception seem to be more evident when rhythm production abilities are additionally measured. Due to time constraints within the test battery design here, it was not possible to include a longer rhythm perception task or an additional rhythm production test.

The phenomenon of compensatory mechanisms in adult dyslexic or at-risk reading disability cohorts (Gelbar et al., 2018) may partially explain the nonsignificant impact of the rhythm test, as there may also be compensatory mechanisms in rhythm perception. Another explanation for the lack in sensitivity of the measure could be the target group of the original

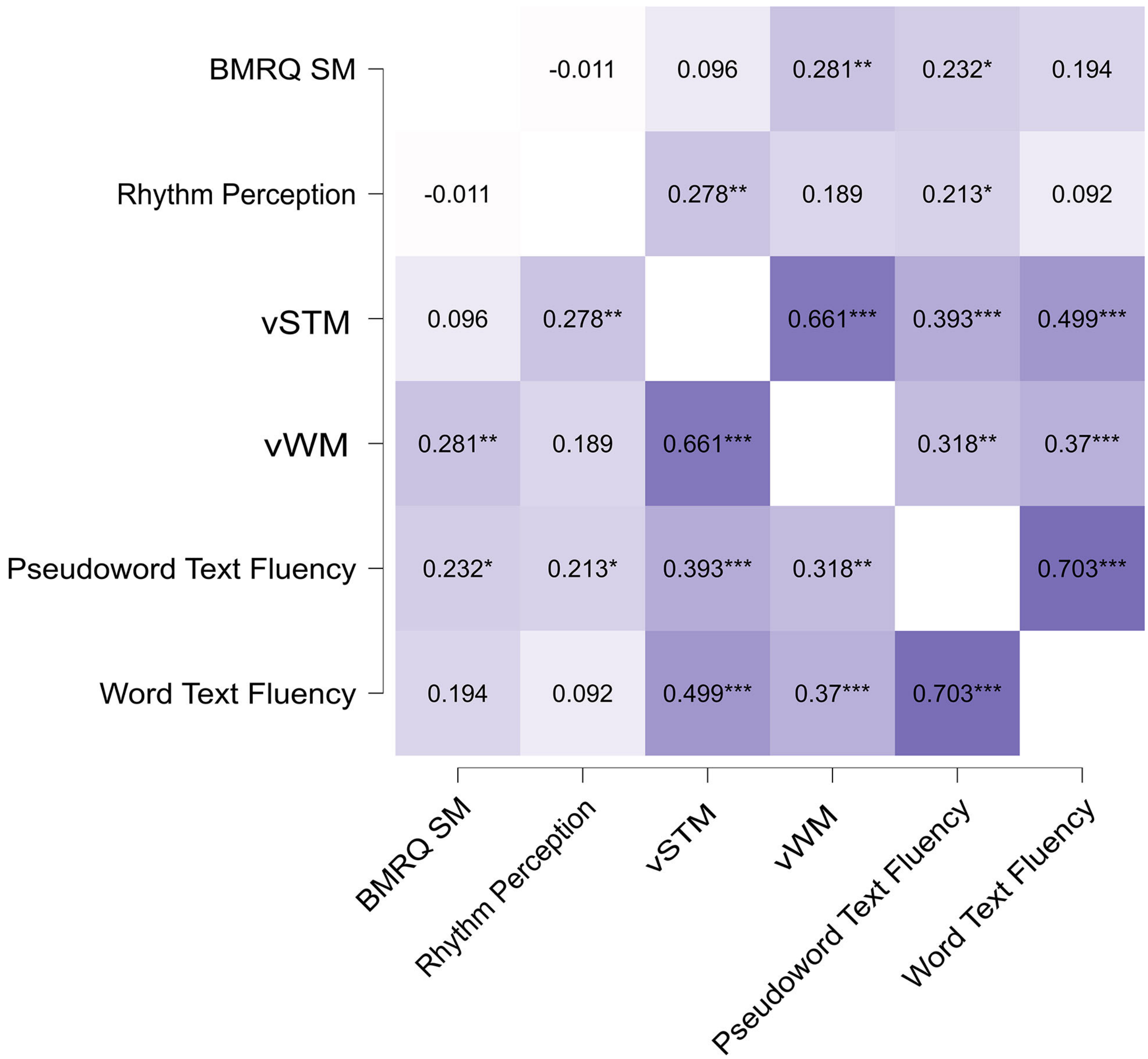

FIGURE 2. Pearson correlation heatmap displaying the associations present in the analyzed sample. Note: Pearson correlation heatmap displaying the associations present in the analysed sample. Shade of blue representing the strength of positive correlation between variables entered. *p < .05, **p < .01, ***p < .001

rhythm perception task itself. The test was originally designed for children and has previously been used with child participants between the ages of 4 and 13. Rhythm perception continues to develop throughout adulthood (Ireland et al., 2018; Tichko et al., 2022) and the lack of a clear effect in the rhythm task could be explained by the lack of comprehensive and age-appropriate assessment tools for rhythm perception.

Additionally, we also examined the possible influence of verbal working memory and short-term memory, as measured by the WAIS-IV Digit Span, on reading performance and rhythm perception. Predictably, verbal working memory and short-term memory yielded moderate correlations with both word and pseudoword text reading fluency. One intriguing idea is to observe the quality of our rhythm task in terms of what it is actually measuring: this type of a call-and-response task could be described as one form of an auditory memory task, or as a short-term memory task. Following from this elaboration, the connection between digit span and rhythm task could be due to the shared cognitive mechanisms these outcome measures are assessing.

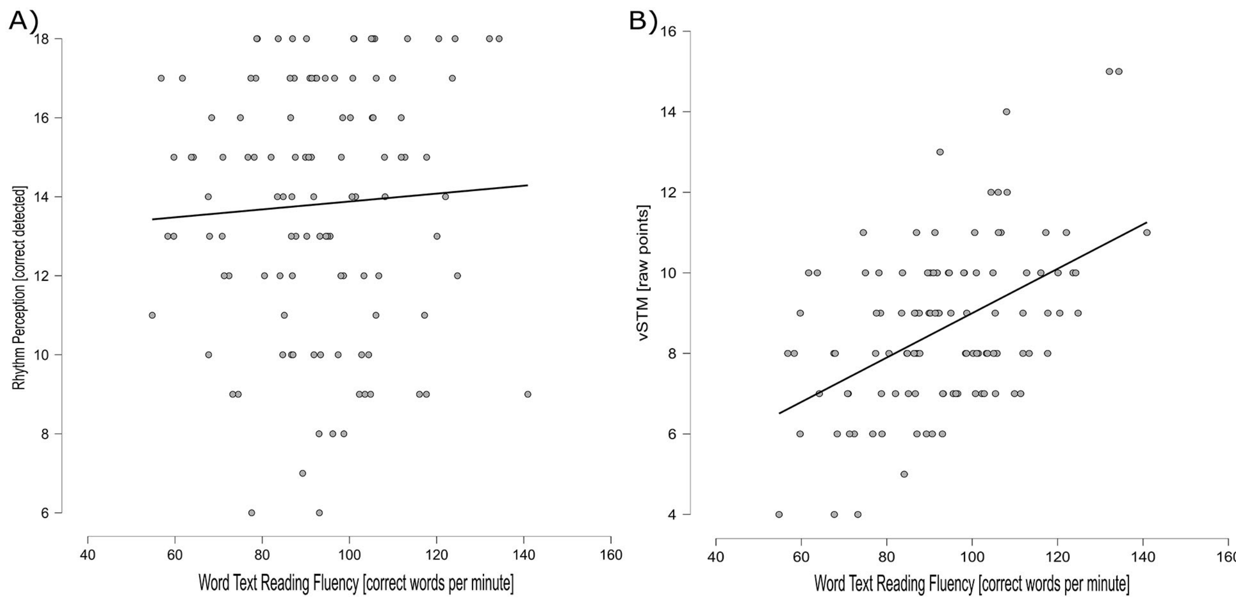

FIGURE 3. Scatter plots illustrating the main outcome of the linear regression. Note: Scatter plots illustrating the main outcome of the linear regression performed with Word Text Reading Fluency ~ Rhythm Perception Performance + Digit Span Forward RP + Digit Span Backward RP + BMRQ-SM + Family Risk Factor. A relationship is visible between word reading fluency and vSTM, but not with rhythm perception.

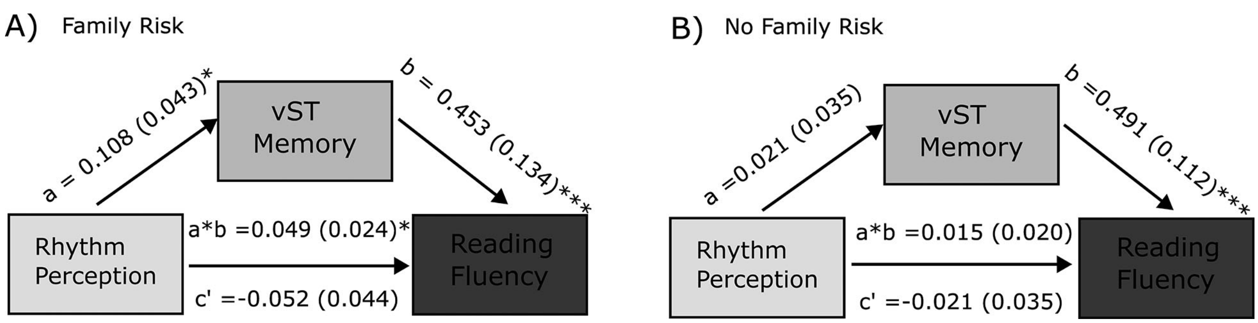

FIGURE 4. Illustration of the detected indirect path between rhythm and reading. Note: Mediation analysis indicating the influence of verbal short-term memory skill on the relationship between rhythm perception and reading fluency within the FR group (A). No significant indirect effect is given in the NFR group (B). AIC indicated a better model fit when groups were separated, compared to the model for the whole participant group. The beta estimates given between rhythm perception and word text reading fluency stand for the indirect (above arrow) and direct (below arrow) effect, with the standard error given in brackets. Significance levels are given by ***$p < .001$, **$p < .01$, and * for $p < .05$.

Regarding the sensorimotor reward experiences, there was a weak positive correlation between sensorimotor reward experience (BMRQ-SM) and pseudoword reading fluency. This dataset suggests that participants' own reflections on their rhythmic motor and physical beat alignment skills are related to challenges in reading fluency when examining text reading without lexicality or meaning. This is consistent with previous research linking motor performance to literacy and, more broadly, to reading disability (Marchand-Krynski et al., 2018; Marchetti et al., 2022).

Within our data, it should be noted, the FR group participants' ability in the pseudoword task—that is, understanding form over content—correlates with the participants' self-reported abilities to feel the musical beat and engage with it. Analysis also revealed moderate correlations between the BMRQ-SM and working memory skills (see Figure 5). Following from that result, in our data the rhythm perception performance correlated with both backward and forward tests of the digit span task. This is in line with previous research highlighting the importance of working memory functions

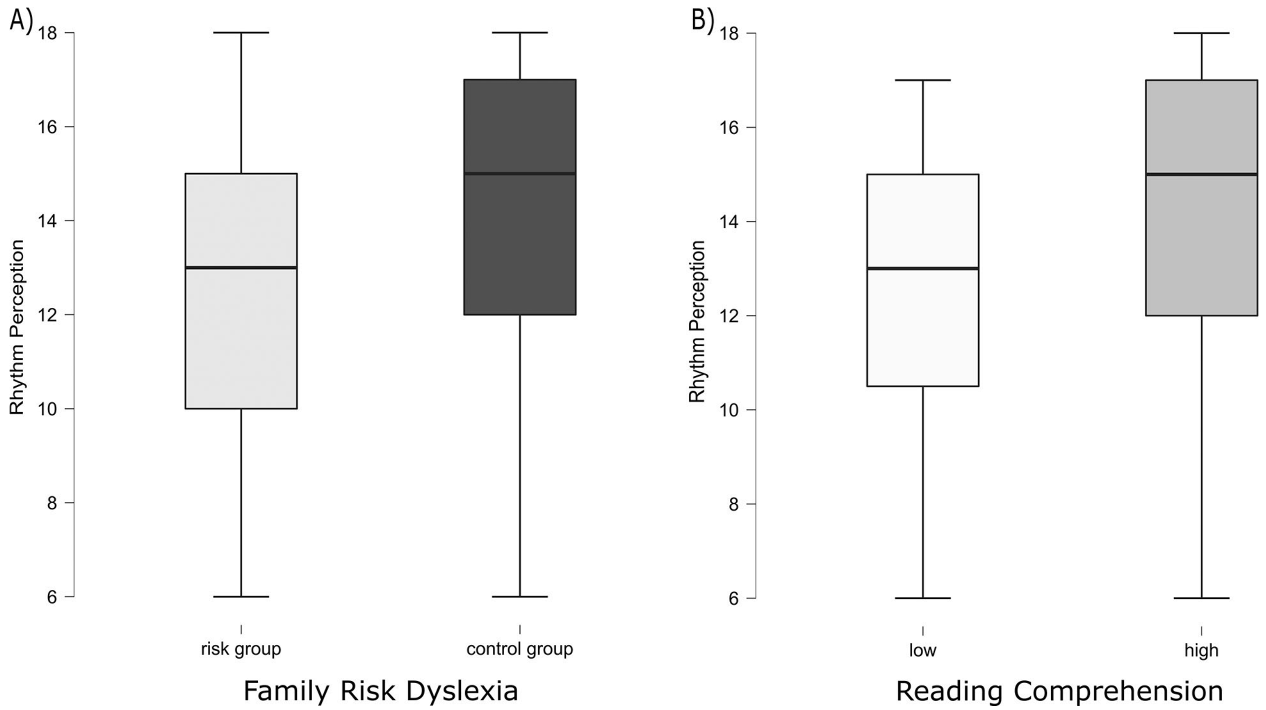

FIGURE 5. Boxplots displaying the difference in rhythm perception between the family risk and control group (5A) and reading comprehension groups (5B). *Note*: Boxplots displaying the weak difference between family risk and control group in the rhythm perception task (A), as well as the weak difference of rhythm perception performance between participants with and without reading comprehension difficulties (B). The range of raw score in the rhythm perception task was 0–18.

for rhythmic skills and perception in early adolescence (Kim et al., 2022). We extend these findings by presenting the possibility of an indirect effect running via vSTM in the FR group, despite the nonsignificant direct effect of rhythm perception on reading fluency in both the FR and NFR groups (Figure 3A and B). This possible indirect effect highlights the association of rhythm perception and short-term memory in the FR group.

Although the main hypothesis was not supported, there was an effect of rhythm perception performance between the FR and NFR groups (see Figure 5), reinforcing the importance of investigating family risk with reading and other cognitive outcomes in adulthood. As dyslexia has been identified as a strongly heritable condition (Ladányi et al., 2020; Snowling et al., 2003), FR is a notable option for an additional variable in future research, even in studies on this topic among adult populations. The effect that our dataset suggests in terms of discriminating between FR and NFR based on performance in the rhythm discrimination task, may be driven more by the short-term memory component of the task. Future research is encouraged to include FR in their investigations to further disentangle this effect.

Conclusions

Based on our findings, possible interconnections between memory performance, rhythm perception, reading ability, and family risk for reading impairment need to be further investigated in adult populations. For any prospective studies on this topic, we would like to emphasize the importance of age-appropriate and standardized assessment tools for rhythm perception and production. Rhythm perception, beat perception, rhythm discrimination ability, musical meter detection ability, and the phenomenon of musical rhythm abilities are, in general, highly complex and multidimensional abilities. It is therefore crucial to measure these abilities as comprehensively as possible.

Author Note

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The dataset is not openly available due to restrictions in regard to the longitudinal data collection. Upon request, the data utilized in the given analyses can be provided.

Correspondence concerning this article should be addressed to J. Riikka Ahokas, University of Jyväskylä, Seminaarikatu 15, (D Educa building, Room 315) PL 35, 40014 Jyväskylä, Finland. E-mail: j.riikka.ahokas@jyu.fi or suvi.saarikallio@jyu.fi (Suvi Saarikallio)

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