Eötvös Loránd University Faculty of Education and Psychology

Measurement of sensorimotor synchronization and spontaneous motor tempo and its relation to reading development

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Theses of the dissertation

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Introduction

In my dissertation I deal with the behavioural measurement of sensorimotor synchronisation in primary school children. The processing of temporal regularities of auditory stimuli is an innate human ability that develops into young adulthood and is associated with a range of language and reading skills. Since the ability to synchronize can be easily tested from the beginning of school age, it has the potential to be used for early identification of later reading difficulties. The number of studies exploring the development of synchrony a longitudinal design, as well as those with native Hungarian speakers, is scarce in the literature. We followed the development of children between first and third grade using our own adaptation of the sensorimotor synchronization (SMS) and spontaneous motor tempo (SMT) tasks, assessing their word reading, spelling and phonological awareness, as well as their general cognitive abilities. In the synchronization task, we used a more natural, motivating, complex musical stimulus with greater ecological validity for this age group, in addition to the metronome sound commonly used, and investigated differences between the two stimulus types in synchronization and in relation to language and reading skills. Based on the results of three studies, I summarise our findings along seven theses within three main research questions.

Literature review

Several studies seem to support the link between early rhythmic skills, language and reading. Individual differences in rhythmic abilities have been shown to correlate with speech perception, receptive and expressive grammatical performance, and reading proficiency (Nayak et al, 2021). In addition to reading, several literacy-related cognitive skills have been found to be associated with rhythm perception and production, such as verbal working memory, intelligence, rapid automatized naming (RAN) and phonological awareness, which are considered reliable predictors of reading level (Landerl et al, 2022; Miendlarzewska & Trost, 2014). Rhythmic tests appear to not only show a cross-sectional relationship with language and reading domains but also have the potential to predict their later performance. Several studies have shown that rhythm perception and production measures of preschool and first-grade children are good predictors of their reading performance years later (David et al, 2007;

Dellatolas et al., 2009; Moritz et al., 2013), which is a promising line of research because of its potential in the early identification reading difficulties.

Since synchronizing one's movements to music appears spontaneously in children very early in their development (around 2-3 years of age), synchronization-based tasks seem more suitable for assessing rhythmic skills earlier than rhythm discrimination or reproduction tasks, which are more challenging to understand and rely more on short-term memory (Tierney et al, 2017). Behavioural measures of spontaneous sensorimotor synchronization in are possible from early childhood (Provasi & Bobin-Bègue, 2003), and from preschool and early school age (Woodruff Carr et al, 2014), the so-called Sensorimotor Synchronization (SMS) task can be applied, in which the subject is required to perform simple finger tapping, in response to a periodic tone stimulus (usually a metronome). The two measures of task performance are the accuracy (asynchrony) and the consistency of the tapping. Synchrony may be followed by unpaced tapping called the continuation phase. A special type of SMS is the spontaneous motor tempo (SMT) task, in which no external reference is present and therefore no stimulus is involved. The subject's task is to produce a movement at a steady pace that is comfortable for him or her (Repp, 2005).

The interplay of SMS and SMT is reflected in the dynamics of the development of synchronization skills. Initially, children are only able to adapt to an external reference around their spontaneous tempo, but as the average SMT gradually decreases, they become able to synchronise over a wider range of tempi (McAuley et al., 2006). The process described shows a major developmental leap between the ages of 6-8 years, after which their spontaneous tempo approaches the adult level of around 100 bpm (beats per minute) and their performance in SMS tasks becomes significantly more accurate and consistent. It is important to note, however, that our knowledge of the development of synchronization is based on cross-sectional data, and a more accurate picture could be obtained from longitudinal studies. Although the SMS task stimulus is most often a simple metronome sound, for preschool and early school age groups, complex music is more appropriate, providing a natural and motivating task situation. The number of studies comparing the two types of stimuli is scarce (Carrer et al., 2022; Einarson, 2017). It is a general observation that the widely observed, anticipated response tendency (Negative Mean Asynchrony - NMA) decreases with increasing rhythmic complexity (Wohlschläger & Koch, 2000), as subjects have more rhythmic cues available for effective error correction. The opposite effect has also been observed in children with ADHD in whom music seems to impair performance (Puyjarinet et al., 2017). Presumably, children who are able to efficiently process the regularities of the complex, hierarchical auditory stimulus can use these to accurately predict the timing of beats, and correct their own asynchrony.

In the last decades, there is a growing body of research using the SMS paradigm, which suggests that, as with rhythm perception and production tasks, synchronization performance is related to reading and literacy-related cognitive skills, such as phonological awareness, spelling, RAN and verbal memory (Bonacina et al, 2018; Lê et al., 2020; Lundetræ & Thomson, 2018; Tierney et al., 2017; Woodruff Carr et al., 2014). However, the number of studies exploring the relationship between synchronization and literacy among Hungarian native-speaking children is low, with only one study available to our knowledge. Maróti et al. (2019) found a correlation between unpaced tapping consistency in 90 bpm metronome trials and children's phonological, attentional and working memory performance in 6-7-year-old children, and observed a slight improvement in synchronization performance over 8 weeks of music training. In their study, they did not investigate reading performance, so there is no data available on its relationship with synchronisation in Hungarian native speakers. Based on the literature presented, I formulated the following research questions:

The effect of tempo and stimulus type in the SMS task

1. How does stimulus tempo affect SMS task performance?
2. How does stimulus complexity affect SMS task performance?

Longitudinal changes in SMS and SMT task indicators

3. Do the measures representing the different aspects of the SMS task (consistency, asynchrony, continuation consistency) change between 1st and 3rd grades?
4. Do the SMT task measures (spontaneous tempo, consistency) change between the 1st and 3rd grades?

The relationship between the SMS and SMT task and reading, spelling and phonological awareness

5. Is SMS and SMT performance related to reading, spelling and phonological awareness in first grade?
6. Does the relationship between SMS and SMT performance remain with reading, spelling and phonological awareness two years later in third grade?
7. Are the measures of the SMS and SMT tests taken in the first grade appropriate for predicting reading, spelling and phonological awareness in the third grade?

Results

Study 1

In the first study, we sought to investigate whether the relationship between synchronization and phonological awareness (PA) and word reading level described in the literature also exists among Hungarian native-speaking school-age children and whether the widely observed anticipatory tendency (NMA) is also present using complex musical stimuli.

We assessed 39 first-grade children's word reading (Meixner Reading Test, Sipos, 2018), phonological awareness (Phonological Awareness Test, Jordanidisz, 2009), spontaneous motor tempo and sensorimotor synchronization using instrumental music excerpts in 3 tempi (80, 120, 150 bpm) for the latter.

Based on our results, NMA appeared in children's task performance, and its magnitude was related to stimulus tempo and presumably to SMT, as expected from the literature. We observed the highest degree of anticipation at the lower tempo, while a slight NMA was observed at 120 trials that were close to the SMT and a slight positive asynchrony in 150 bpm trials, presumably due to limitations in motor execution. Word reading accuracy and fluency, as well as phonological awareness, were associated with SMT and SMS measures of unpaced tapping. Children who produced a lower spontaneous tempo and more consistent tapping in the continuation phase performed better in PA and reading tasks. A particularly good predictor was the acceleration measure, which characterised children's ability to overcome their tendency to speed up (see Figure 1) in the absence of an external reference. Our results confirmed the validity of the use of the SMT and SMS tasks and the musical stimulus and raised further questions, in particular regarding the role of general cognitive abilities that are known predictors of reading.

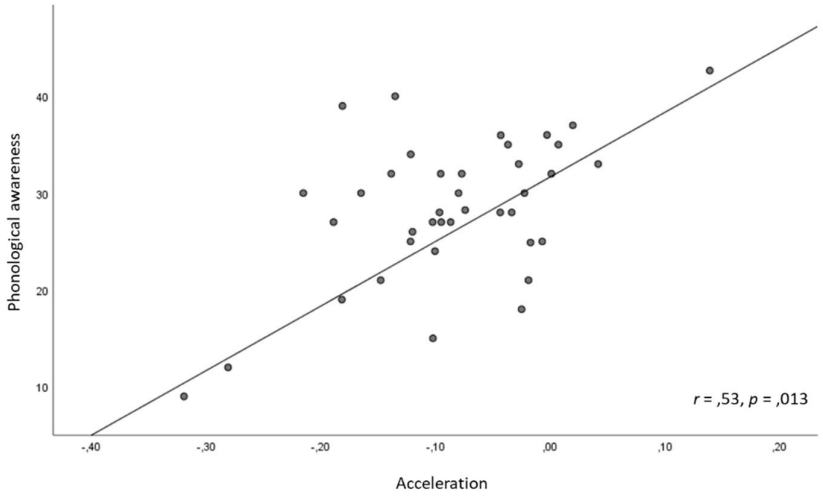

Figure 1. The relationship between the acceleration measure and phonological awareness

Study 2

In the second study, we aimed to explore in more detail the previously found relationship between synchronization and phonological awareness and reading, and control for the possible role of general cognitive abilities such as working memory, nonverbal intelligence, and vocabulary and therefore included them in the test battery. These three domains were measured using the WISC-IV (Nagyné Réz et al., 2008), intelligence test's digit span, block design and vocabulary subtests. For the assessment of reading and phonological awareness, we chose a digital test (3DM-H, Tóth et al., 2014), which also allowed the assessment of spelling and RAN, the latter also used as a predictor in the models. We included metronome stimulus trials in the SMS task and used more sophisticated circular statistics in the analysis of the data. These modifications allowed not only to include general cognitive domains in the analysis but also to investigate how the complexity of the stimuli used affects different aspects of synchronization performance.

A total of 39 typically developing Hungarian first-grade students were assessed with the battery. Using Welch's test to examine the effect of stimulus type on the SMS task measures, we found significant differences between the music and metronome tests. Consistent with the literature (Dalla Bella et al., 2017; Einarson, 2017), while higher tapping consistency was observed in the latter, we found lower asynchrony scores with the musical stimulus, meaning 6-7-year-olds were already able to reduce their asynchrony by more accurate error correction using the regularities of the musical stimulus, thus leading to lower consistency. To predict reading, spelling, and phonological awareness, we built linear models of the SMS, SMT, and general

cognitive variables, in which measures of musical trials proved more successful (see Figure 2). The musical consistency measure explained 28% of the variance in phonological awareness and 16% of the variance in reading accuracy. Musical asynchrony was related to spelling, explaining 20%, while reading fluency to metronome consistency accounting for 16% of variance.

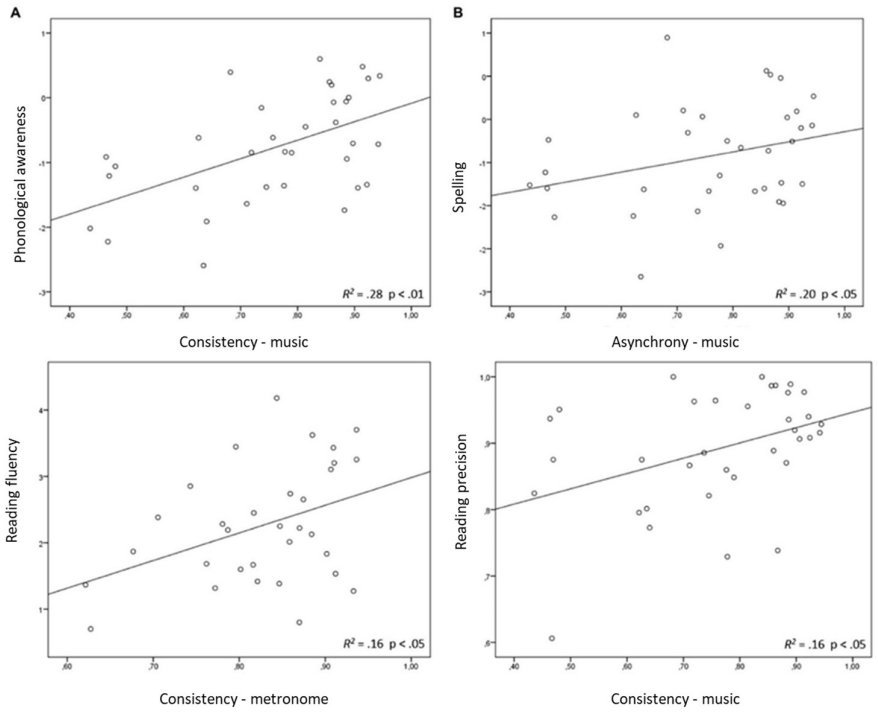

Figure 2. Linear models built from first-grade SMS, SMT and general cognitive ability variables.

Study 3

In our third study, we focused on three sets of questions. Our knowledge of the development of synchronization ability is mainly based on cross-sectional data, so we considered it appropriate to investigate changes over our period of interest. Our main focus, however, was on the development of the relationship of sensorimotor synchronisation with general cognitive abilities and with the language and reading domains, and we, therefore, re-administered the earlier test battery in the third grade on the sample described in Study 2. The data were analysed from two perspectives. First, we examined whether SMS and SMT performance in grade 1, which was related to reading, spelling, and phonological awareness in the same year, predicted their level in grade 3. Second, we examined the same relationship between tests taken in third grade.

Examining changes in SMS performance using a 2x2 repeated measures ANOVA, an overall developmental effect in children's task performance was observed for all three measures, as indicated by an increase in the consistency, albeit at trend level, a decrease in asynchrony, and an increase in continuation consistency (see Figure 3). After two years, children were able to error correction more accurately and to tap more consistently overall than in first grade, regardless of stimulus type. The analysis confirmed the difference between musical and metronome stimulus material described in Study 2: while musical stimulus favoured accuracy, consistency was higher in metronome trials.

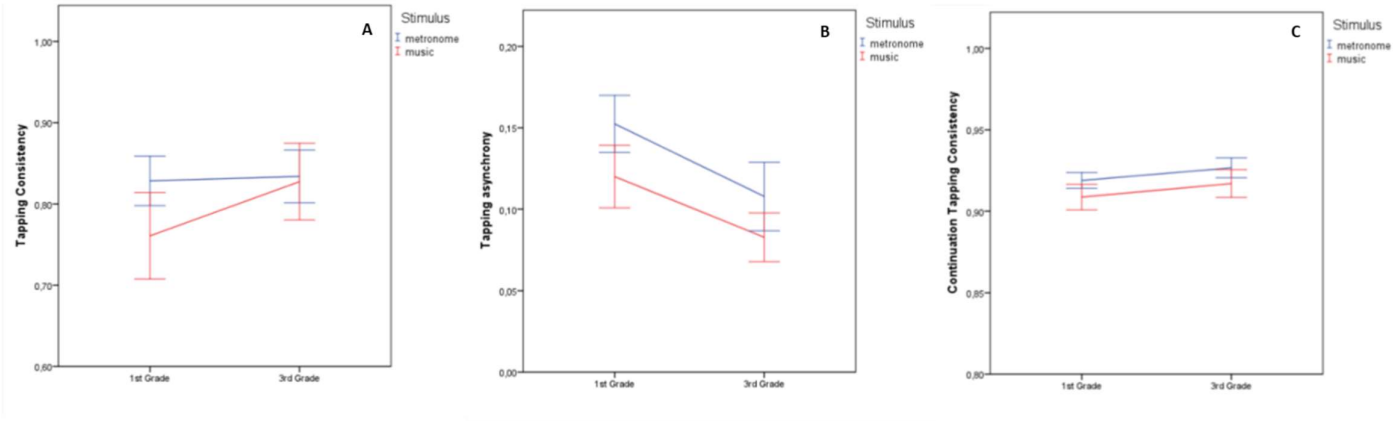

Figure 3. Changes in SMS consistency (A), asynchrony (B) and continuation consistency (C) between first and third grades.

There were no significant changes in children's spontaneous motor tempo and SMT consistency scores between the two measurements. We found a 116 bpm mean SMT, not differring significantly from the 115 bpm tempo of first graders, which is consistent with values found in the literature (Drake et al., 2000; McAuley et al., 2006). Again, we used linear modelling to examine which first-grade SMS and SMT measures and cognitive variables best predict third-grade literacy scores. Children's word reading was best explained by metronome consistency and RAN accounting for 37% of the variance, while spelling and phonological awareness were related to musical consistency explaining 30%-30% of children’s performance (see Figure 4).

However, the above relationship was no longer evident in models constructed from third-grade SMS, SMT and cognitive variables. Variance in reading was explained by RAN alone (20%), spelling by working memory and SMT consistency (27%), while for phonological awareness we obtained a model with weak explanatory power (12%), whose validity is questioned by post-

hoc power analysis, and in which mean SMT was the only significant predictor, but with an opposite directional relationship to that expected.

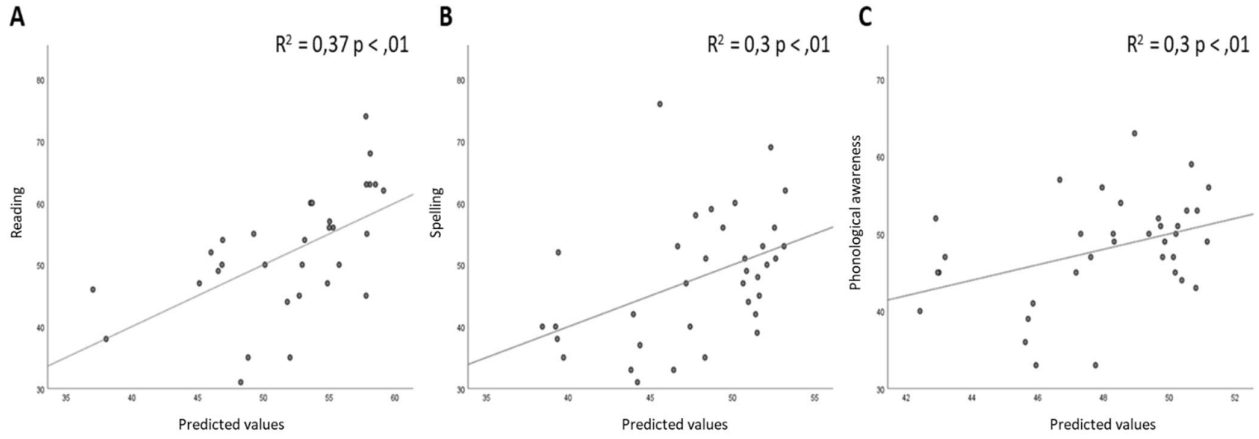

Figure 4. Linear models constructed from first-grade SMS, SMT and general cognitive ability measures predicting third-grade reading (A), spelling (B) and phonological awareness (C) scores. The horizontal axis shows non-standardized predicted values, while the vertical axis the variable.

Theses

In the following, I summarise the results of the three studies, grouped according to the research questions formulated earlier, in 7 theses:

The effect of tempo and stimulus type in the SMS task

How does stimulus tempo affect SMS measures?

(1. study)

THESIS 1.

Negative mean asynchrony (NMA) is highest for the low tempo reference and its absolute value is lowest for the near SMT. The degree of acceleration in unpaced tapping is also well explained by the distance from the SMT. In the continuation phase, tapping consistency is independent of the starting tempo, presumably because it does not require error correction.

How does the complexity of the stimulus affect the SMS task indicators?

(2-3. studies)

THESIS 2.

Paced tapping is more accurate but less consistent with the more complex musical stimulus, and less accurate but more consistent with the metronome, indicating that typically developing first and third-graders are able to process the denser, hierarchic rhythmic structure of the complex stimulus and use it to for more effective error correction.

Longitudinal changes in SMS and SMT task indicators

Do the measures representing the different aspects of the SMS task (consistency, asynchrony, continuation consistency) change between 1st and 3rd grades?

(3. study)

THESIS 3.

The accuracy of synchronisation (asynchrony) and the consistency of task performance, as well as the consistency measured in the continuation phase, also showed an overall improvement over the period under review.

1. *Do the SMT task indicators (spontaneous tempo, consistency) change* between the 1st and 3rd grades?

   (3. study)

THESIS 4.

In the SMT task, neither the average spontaneous tempo of the children nor the consistency of their tapping changed in this period. The developmental leap in SMT known from the literature is likely to have already occurred earlier, around the age of 6, in the children and remained stable during the period we studied.

The relationship between the SMS and SMT task and reading, spelling and phonological awareness

Are SMS and SMT performance related to reading, spelling and phonological awareness in first grade?

(1-2. study)

THESIS 5.

The SMS and SMT tasks had significant explanatory power in the first grade in terms of levels of word reading, spelling and phonological awareness. The relationship between these domains was maintained when children's general cognitive skills (verbal working memory, RAN, nonverbal intelligence, vocabulary) were included in the models.

Does the relationship between SMS and SMT performance remain with reading, spelling and phonological awareness two years later in third grade?

(3. study)

THESIS 6.

Third-grade SMS and SMT measures were not related to reading level, to a lesser extent to spelling, and were found to be weakly and inconsistently related to phonological awareness. However, RAN and verbal working memory emerged as significant predictors reading and spelling.

Are first-grade SMS and SMT measures predictive of third-grade reading, spelling and phonological awareness?

(3. study)

THESIS 7.

First-grade SMS and SMT measures successfully predicted third-grade levels of word reading, spelling and phonological awareness. The success of the musical trials' measures compared to the metronome confirms the validity of this more natural and engaging testing approach for this age group

Discussion

The central finding of the present thesis is that in Hungarian native-speaking children, too, sensorimotor synchronization ability is related to literacy skills. The SMS task has proven suitable for measuring individual differences that are not only related to word reading, spelling and phonological awareness in the first grade but are also able to predict their performance two years later in the third grade.

Synchronisation skills account for unique variance of literacy skills in addition to well-established predictors such as working memory, non-verbal intelligence and vocabulary. The link between the rhythmic and language and reading domains, although weakening, presumably does not disappear completely by the third grade, but the use of different stimuli and tasks than those presented in the studies may be necessary to measure individual differences in synchronisation ability.

SMS tasks using musical stimuli are suitable for testing this age group. Typical developing first-graders are already able to process their complex, hierarchical rhythmic structure and extract temporal regularities for more accurate tapping. Synchronisation skills show an overall improvement over the study period, with an increase in both accuracy and consistency in children's tapping. Spontaneous motor tempo is close to that of adults in the first year and remains stable in the following two years.

The studies summarized in this thesis contribute to the understanding of the relationship between synchronization and literacy skills by providing longitudinal data from Hungarian native-speaking children and confirming the applicability of the sensorimotor synchronization task as a potential diagnostic tool for the early identification of reading difficulties.

Publications related to the dissertation

Kertész, C., F. Földi, R., & Honbolygó, F. (2020). A ritmikai szinkronizáció kapcsolata a fonológiai tudatossággal és az olvasással iskolakezdő gyerekeknél. *Magyar Pszichológiai Szemle*, *75*(3), 455-476.

Kertész, C., & Honbolygó, F. (2021). Tapping to music predicts literacy skills of first-grade children. *Frontiers in psychology*, *12*, 741540.

Kertész, C., & Honbolygó, F. (2023). First school year tapping predicts children's third-grade literacy skills. *Scientific Reports*, *13*(1), 2298.

Bibliography

Bonacina, S., Krizman, J., White-Schwoch, T., & Kraus, N. (2018). Clapping in time parallels literacy and calls upon overlapping neural mechanisms in early readers. *Annals of the New York Academy of Sciences*, *1423*(1), 338–348. https://doi.org/10.1111/nyas.13704

Carrer, L. R. J., Pompéia, S., & Miranda, M. C. (2022). Sensorimotor synchronization with music and metronome in school-aged children. *Psychology of Music*. https://doi.org/10.1177/03057356221100286

Dalla Bella, S., Farrugia, N., Benoit, C. E., Begel, V., Verga, L., Harding, E., & Kotz, S. A. (2017). BAASTA: Battery for the Assessment of Auditory Sensorimotor and Timing Abilities. *Behavior Research Methods*, *49*(3), 1128–1145. https://doi.org/10.3758/s13428-016-0773-6

David, D., Wade-Woolley, L., Kirby, J. R., & Smithrim, K. (2007). Rhythm and reading development in school-age children: A longitudinal study. *Journal of Research in Reading*, *30*(2), 169–183. https://doi.org/10.1111/j.1467-9817.2006.00323.x

Dellatolas, G., Watier, L., Le Normand, M. T., Lubart, T., & Chevrie-Muller, C. (2009). Rhythm reproduction in kindergarten, reading performance at second grade, and developmental dyslexia theories. *Archives of Clinical Neuropsychology*, *24*(6), 555–563. https://doi.org/10.1093/arclin/acp044

Drake, C., Jones, M. R., & Baruch, C. (2000). The development of rhythmic attending in auditory sequences: Attunement, referent period, focal attending. In *Cognition* (Köt. 77, Szám 3). https://doi.org/10.1016/S0010-0277(00)00106-2

Einarson, K. M. (2017). *Beat perception and synchronization abilities in young children (Doctoral dissertation)*.

Jordanidisz, Á. (2009). A fonológiai tudatosság fejlődése az olvasástanulás időszakában. *Anyanyelv Pedagógia*, *4*.

Landerl, K., Castles, A., & Parrila, R. (2022). Cognitive Precursors of Reading: A Cross-Linguistic Perspective. *Scientific Studies of Reading*, *26*(2), 111–124. https://doi.org/10.1080/10888438.2021.1983820

Lê, M., Quémart, P., Potocki, A., Gimenes, M., Chesnet, D., & Lambert, E. (2020). Rhythm in the blood: The influence of rhythm skills on literacy development in third graders. *Journal of Experimental Child Psychology*, *198*, 104880.

Lundetræ, K., & Thomson, J. M. (2018). Rhythm production at school entry as a predictor of poor reading and spelling at the end of first grade. *Reading and Writing*, *31*(1), 215–237. https://doi.org/10.1007/s11145-017-9782-9

Maróti, E., Barabás, E., Deszpot, G., Farnadi, T., Norbert Nemes, L., Szirányi, B., & Honbolygó, F. (2019). Does moving to the music make you smarter? The relation of sensorimotor entrainment to cognitive, linguistic, musical, and social skills. *Psychology of Music*, *47*(5), 663–679. https://doi.org/10.1177/0305735618778765

McAuley, J. D., Jones, M. R., Holub, S., Johnston, H. M., & Miller, N. S. (2006). The time of our lives: Life span development of timing and event tracking. *Journal of Experimental Psychology: General*, *135*(3), 348–367. https://doi.org/10.1037/0096-3445.135.3.348

Miendlarzewska, E. A., & Trost, W. J. (2014). How musical training affects cognitive development: Rhythm, reward and other modulating variables. *Frontiers in Neuroscience*, *7*(8 JAN), 1–18. https://doi.org/10.3389/fnins.2013.00279

Moritz, C., Yampolsky, S., Papadelis, G., Thomson, J., & Wolf, M. (2013). Links between early rhythm skills, musical training, and phonological awareness. *Reading and Writing*, *26*(5), 739–769. https://doi.org/10.1007/s11145-012-9389-0

Nagyné Réz, I., Lányiné Engelmayer, Á., Kuncz, E., Mészáros, A., Mlinkó, R., Bass, L., & Kõ, N. (2008). WISC-IV: A Wechsler Gyermek Intelligenciateszt Legújabb Változata (Hungarian Version of the Wechsler Intelligence Scale for Children—Fourth Edition, WISC-IV). *Budapest: OS Hungary Tesztfejlesztõ*.

Nayak, S., Coleman, P. L., Ladányi, E., Nitin, R., Gustavson, D. E., Fisher, S. E., Magne, C. L., & Gordon, R. L. (2021). The Musical Abilities, Pleiotropy, Language, and Environment (MAPLE) Framework for Understanding Musicality-Language Links Across the Lifespan. In *Under Review*.

Provasi, J., & Bobin-Bègue, A. (2003). Spontaneous motor tempo and rhythmical synchronisation in 2½- and 4-year-old children. *International Journal of Behavioral Development*, *27*(3), 220–231. https://doi.org/10.1080/01650250244000290

Puyjarinet, F., Bégel, V., Lopez, R., Dellacherie, D., & Dalla Bella, S. (2017). Children and adults with Attention-Deficit/Hyperactivity Disorder cannot move to the beat. *Scientific Reports*, *7*(1), 1–11. https://doi.org/10.1038/s41598-017-11295-w

Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychonomic Bulletin & Review*, *12*(6), 969–992. https://doi.org/10.3758/BF03206433

Sipos, Z. (2018, június 18). *Az első évfolyam végén alkalmazott a Meixner olvasólapok sztenderdizálásának tapasztalatai.* .

Tierney, A., White-Schwoch, T., MacLean, J., & Kraus, N. (2017). Individual differences in rhythm skills: Links with neural consistency and linguistic ability. *Journal of Cognitive Neuroscience*, *29*(5), 855–868. https://doi.org/10.1162/jocn_a_01092

Tóth, D., Csépe, V., Vaessen, A., & Blomert, L. (2014). 3DM-H: A diszlexia differenciáldiagnózisa: Az olvasás és helyesírás kognitív elemzése. *Technikai kézikönyv*.

Wohlschläger, A., & Koch, R. (2000). *Synchronization error: An error in time perception. InP. Desain & L. Windsor, Rhythm perception and performance (pp. 115-127)*. Lisse, The Netherlands: Swets and Zeitlinger.

Woodruff Carr, K., White-Schwoch, T., Tierney, A. T., Strait, D. L., & Kraus, N. (2014). Beat synchronization predicts neural speech encoding and reading readiness in preschoolers. *Proceedings of the National Academy of Sciences*, *111*(40), 14559–14564.