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## STRATEGIES OF RHYTHM PERCEPTION IN DEVELOPMENTAL DYSLEXIA

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### SUMMARY

#### Background:

The perception of short time intervals (>1Hz) plays an important role in coping with rhythm exercises prevalent throughout the course of music education. Developmental dyslexia is associated with rhythmic difficulties, including impaired perception of beat patterns. Previous research suggests the existence of two different rhythm perception strategies: interval or entrainment-based. The aim of this research was to determine whether difficulties with rhythm tasks experienced by dyslexic children are connected with a preference for a specific rhythm perception strategy.

#### Material/ Methods:

Non-dyslexic (N=61) and dyslexic (N=48) groups were recruited for the study. To assess rhythm perception strategies, we used an experimental procedure developed by McAuley and colleagues. This method involves listening to the sequences of rhythmically presented tones with the last tone shifted forwards or backwards in time. The participants were asked to judge if the presented sequences felt like 'slowing down' or 'speeding up'.

#### Results:

Our data supports the view that entrainment-based strategies are atypical in dyslexia. These results are discussed in the context of a more general model of potential relationships between types of rhythm perception and improved language and literacy skills.

#### Conclusions:

The results of this research provided evidence that individual differences in rhythm perception strategies are not determined by dyslexia. Future research in this area is recommended, in order to explore other potential explanations for the existence of individual differences in perceiving rhythm.

**Key words:** rhythm, beat, preference, perception strategy, developmental dyslexia

## INTRODUCTION

Dyslexia is a specific learning disability that is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities (Lyon Reid et al., 2003). Numerous theories have been devised, searching for the causes of these difficulties. Stein & Talcott (1999) suggest that dyslectics have problems with transient auditory processing, caused by a magnocellular processing deficit. Current data strongly supports the phonological deficit hypothesis (Beaton, 2004; Høien & Lundberg, 2000; Snowling, 2000), which assumes that phonological awareness and working memory disturbances constitute the core of the disorder. A double-deficit hypothesis adds rapid automatized naming deficits: RAN to the model (Wolf & Bowers, 1999; Wolf et al., 2000). Some explanatory theories, however, argue that a purely linguistic deficit is not enough to explain the phenomenon of dyslexia and dysorthography. Research has shown that timing and temporal processing problems of a neurobiological origin lead to impairment in auditory and motor abilities, which underlie reading and spelling skills (Overy, 2000). Moreover, rhythm-based musical activities help children with dyslexia and dysorthography improve their literacy skills (Overy, 2000; Overy, 2003).

Nicolson & Fawcett (1999; 2008) state that dyslexic problems stem from an impaired functioning of the procedural learning system, and that the biological basis for this are disturbances in the structure and functioning of the cerebellum. The cerebellum is responsible for linguistic functions, as well as balance, visual-motor coordination, and the learning sequences of certain stimuli. Furthermore, this part of the nervous system is crucial for perceiving musical rhythm (Chen et al., 2008). A previous study among dyslexic children (Huss et al., 2001) suggests a difficulty in perceiving rhythmic patterns, or metrical structure, as studied with the usage of short tunes that had simple metrical structures with accents on certain notes. Therefore, the theoretical ground for our research is the approach advocated by Nicolson & Fawcett: the specific procedural learning difficulties hypothesis (SPLD) (Nicolson & Fawcett, 2008; Nicolson & Fawcett, 2011; Nicolson et al., 2001; Nicolson et al., 2010) which states that dyslexia and dysorthography result from general procedural learning difficulties, both linguistic and non-linguistic. These problems are caused by impairments in brain circuits; in procedural learning striatal and cerebellar structures are involved. We believe that the specific procedural learning difficulties hypothesis may potentially explain seemingly contradictory findings in the literature on dyslexia and dysorthography; this provides ground for our assumptions that impaired musical skills are associated with a language-based disorder: specific difficulties in reading and writing. A common element in these theories, is the conviction that timing skills, and particularly rapid timing skills are a fundamental problem area in dyslexia (Overy et al., 2003).

As already noted, a number of studies (Miles & Westcombe, 2001; Oglethorpe, 1996; Overy, 2003) have indicated that dyslexic children manifested deficits in the perceptual experience of rhythmic timing. Research has shown that specific

difficulties in reading and writing affect the rapid temporal processing of auditory stimuli, the rapid naming of visual stimuli, the evaluation of whether a tone is higher or lower than the referenced one, rhythmic finger tapping, and exploring rhythmic structures in speech (Overy et al., 2003). Individuals with dyslexia and dysorthography exhibit problems in the reproduction of model rhythmic structures (Atterbury, 1985), lower sensitivity to amplitude modulations (which correlates with non-word reading ability) (Stein et al., 2001), and impaired processing of musical key (Baldeweg et al., 1999). Equally Overy et al. (2003) has demonstrated that dyslexic children scored higher in pitch skills, but were inferior in timing skills, especially in rapid temporal processing. Does the specificity of timing difficulties among dyslexic children influence their choice of rhythm perception strategies? What is the specific nature of the timing difficulties in applying rhythm perception strategies among dyslectics? Many deficits relevant to dyslexia, such as those concerning the synthesis and analysis of automatical processing, may influence the perception of various musical structures. However, no scientific data is currently available regarding the impact of dyslexia on rhythm perception strategies.

### **Strategies of rhythm perception**

Research on rhythm perception involves many different approaches, from investigating neural mechanisms that control timing in humans (Grahn, 2012), to various studies of vocal-learning animals (Fitch, 2006; Patel et al., 2008). Many different models and theoretical frameworks of rhythm perception (or more broadly, sequence timing) have been proposed throughout history. These theories stem from two main views on the subject: the interval-based and entrainment-based approaches (McAuley et al., 2006a; McAuley, 2010).

The interval-based approach to timing is a model based on an information-processing framework. One example of this approach is the Scalar Expectancy Theory proposed by Gibbon (1977), which postulates three stages of temporal processing: the clock, memory and decision stage. The clock produces regular pulses that flow into an accumulator via an attention-controlled switch. The switch acts as a gate that opens at the onset and closes at the end of the incoming signal. The number of pulses in the accumulator is then evaluated and stored at the memory stage. A temporal judgement (i.e. shorter vs. longer, slower vs. faster) is made at the decision stage, when data stored in the memory is analysed and compared (Gibbon, 1977; McAuley, 2010).

The entrainment-based perspective is an example of a dynamic systems framework. Entrainment theories propose that humans have the ability to synchronize themselves to the rhythms present in the environment (i.e. the sleep-wake cycle). In a musical context (or any periodicity ranging from a few hundred milliseconds to a few seconds), this approach similarly addresses the concept of entrainable oscillation. Decisions about the temporal structure of stimuli are made by synchronizing (*entraining*) the internal oscillator to a given rhythm (Grahn, 2012; Large & Jones, 1999; see McAuley, 2010 for a full review).

### Individual differences in rhythm perception

Some authors propose that both of the models of rhythm perception presented above can be used by individuals when making temporal decisions (Grahn & McAuley, 2009; McAuley et al., 2006a; McAuley et al., 2012). In this view, the tendency to prefer one strategy over another depends on the individual differences between subjects. In one study, individual differences were found using an ambiguous tempo judgment task (detailed below), with participants showing a different response pattern in reaction to the same stimuli (McAuley et al., 2006a). A functional magnetic resonance (fMRI) study reported correlations between results in the ambiguous tempo judgment tasks and different patterns of activity in the auditory and motor areas of the cerebral cortex (Grahn & McAuley, 2009). Another fMRI study using the same task found that decreased beat induction is connected to neural activity in the basal ganglia, premotor and supplementary motor regions, and thalamus (McAuley et al., 2012).

In the ambiguous tempo judgement task developed by McAuley et al. (2006a), participants listened to short tone sequences and decided whether the sequences were ‘speeding up’ or ‘slowing down’ towards the end. These sequences consisted of four or five 50ms piano tones with a 440Hz fundamental pitch. The timing of tones in the sequences is illustrated in Figure 1.

Control (four tone) sequences consisted of two tones with an inter-interval onset (IOI) of 600ms, followed by a 1200ms pause, followed by two tones with variable IOI ( $600\text{ms} \pm \Delta T$ ). Test (five tone) sequences were composed of three tones with 300ms IOIs, followed by a (600ms),  $T/2$  (300ms),  $T \pm 4\%$  (576ms or 624ms),  $T \pm 12\%$  (528ms or 672ms) and  $T \pm 20\%$  (480ms or 720ms). Overall, the task consisted of sixteen possible sequences, eight control and eight test conditions.

All individuals should evaluate control sequences similarly, as they are expected to compare the final interval to the initial, 600 implied beat) should perceive those sequences as ‘slowing down’ regardless of  $\Delta T$ , as the inter-onset intervals between the first three tones are shorter than consecutive IOIs. On the

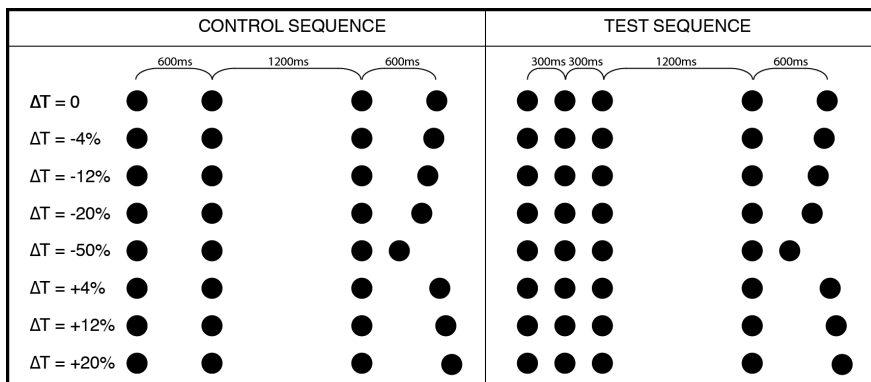


Figure 1. Layout of the tones in the control and test sequences in the rhythm perception task developed by McAuley et al. (2006a)

other hand, strong beat perceivers (more sensitive to an implied beat) should evaluate the test sequences according to  $\Delta T$  ('speeding up' when  $\Delta T < 0$  and 'slowing down' if  $\Delta T > 0$ ) due to the hypothetical induction of the 600ms beat for these individuals.

### **The aim of the study**

In the context of possible individual differences in rhythm perception strategies, an attempt at clarifying their potential relationships with other, psychologically based variables, may seem to be interesting. We attempted to identify a relationship between dyslexia and certain strategies of rhythm perception. The aim of the study has been to test if a temporal deficit, being the basis of dyslexia, leads to the application of a particular rhythm perception strategy by dyslexic children, as opposed to children without this disorder.

The proposed research programme aims to answer the following questions: (1) is the choice of different rhythm perception strategies the result of the characteristics of the children under examination? (2) are there any connections between applied strategies and developmental dyslexia diagnosis?

### **Participants**

Two groups of children (dyslexic/non-dyslexic) from primary schools in the Tricity (Gdansk-Gdynia-Sopot) metropolitan region in northern Poland were recruited for the study. The dyslexic group consisted of forty-eight participants (32 female, 16 male;  $M$  age = 12.02,  $SD$  = 0.84). The non-dyslexic group consisted of sixty-one participants (45 female, 16 male;  $M$  age = 12.42,  $SD$  = 1.09). The children were matched in terms of IQ (as measured by four Wechsler Intelligence Subscales: Similarities, Vocabulary, Blocks, and Object Assembly). Children in the criterion group struggled with non-words and words, as well as phonological processing.

## **MATERIAL AND METHODS**

The stimuli for the listening task were presented using a computer running a custom-developed application written in Java (Oracle Corporation). Participants listened to the task using headphones regulated to a comfortable listening level prior to task commencement. The entire procedure consisted of a familiarization block of sixteen trials (one for each possible sequence, no results were gathered), followed by a test block of forty-eight trials (three for each possible sequence). The trials were randomized independently for each subject. Participants were asked to judge whether the sequences they heard were 'speeding up' or 'slowing down' towards the end. The responses were gathered using a touchpad and two buttons that appeared on the screen.

## **RESULTS**

To analyze the data from the rhythm perception task, we followed a methodology proposed by Grahn & McAuley (2009), based on signal detection theory

(Macmillan & Creelman, 1991). The predicted proportions of the 'speeding up' responses for each sequence were generated using a cumulative normal distribution function,  $P = 1 - \Phi(z)$ . In order to achieve a normality of distributions the predicted probabilities were performed in the profit function:

$$Z = \sqrt{2} \cdot \pi^{-1} \cdot (2p - 1) \quad (\text{see: Howell, 2006}).$$

The results of such a transformation (call them Theta or Z) are normally distributed and can be analyzed using parametric tests. Independent samples t tests were used to test the null hypothesis that dyslectics and non-dyslectics do not differ in mean rhythm perception in each task and sequence. For the sake of a clear presentation of the means and standard deviations for groups of subjects in each sequence after the analysis we transformed the mean score of the theta results of each group and sequence back into the probability mode using the standard cumulative distribution function:

$$Z = \frac{1}{2} \cdot \left( 1 + \pi \cdot \frac{Z}{\sqrt{2}} \right)$$

Values presented in the table and graphs stand for the mean probability of a 'speeding up' response in each sequence and task.

The distributions of the probabilities of 'speeding up' responses in the control sequences for two groups are shown in Figure 2. The values in the vertical axis closer to 1 represent a greater probability of 'speeding up' responses, while the values closer to 0 represent a greater probability of 'slowing down' responses. The dotted line indicates values near 0.5, which show an equal probability of 'speeding up' and 'slowing down'.

The results of the control sequences reveal a generally predictable trend, with the probability of the 'speeding up' responses higher in the shorter final IOIs, and the 'slowing down' responses higher in the longer final IOIs. As expected, the probability curves in the control task show the same pattern of responses for dyslexic and non-dyslexic children. The only condition when the response probabilities seem to differ is the 672 ms condition. Non-dyslexic children tend to judge that condition as 'slowing down', whereas dyslexic children seem to be more ambiguous in their judgements (a probability value closer to the 0.5 line, indicating an ambiguous, no 'speeding up' - no 'slowing down').

The distributions of probabilities of the 'speeding up' responses in test sequences for the two groups are shown in Figure 3. In comparison with the control sequences, the probability curves for the test sequences show a steep drop for final IOIs longer than 300 ms. For the 300 ms IOI, there was a high probability of the 'speeding up' response regardless of dyslexia diagnosis. A 480 ms IOI yielded ambiguous answers, with members of the non-dyslexic group leaning more towards the 'slowing down' response. This pattern is repeated for 576 ms and 600 ms IOIs. The dyslexic children gave more ambiguous responses for

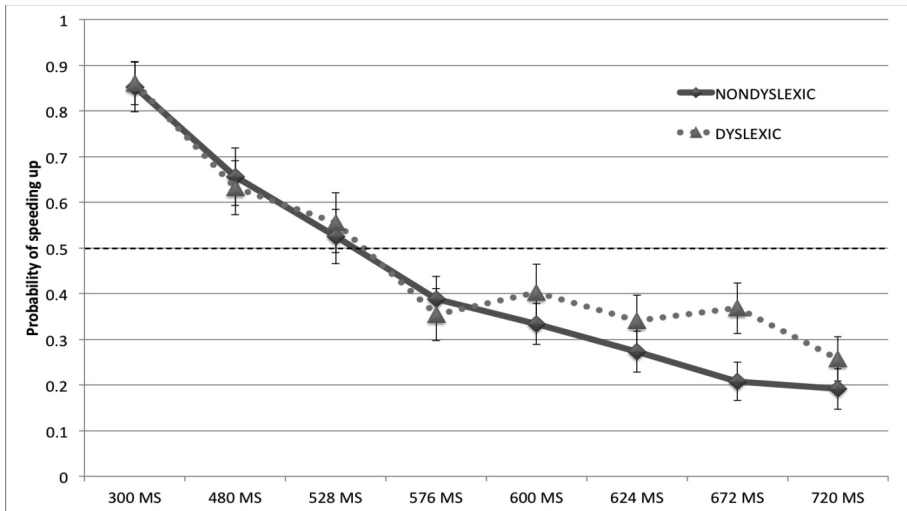


Figure 2. Probabilities of 'speeding up' responses in the control sequences in the dyslexic and non-dyslexic children groups

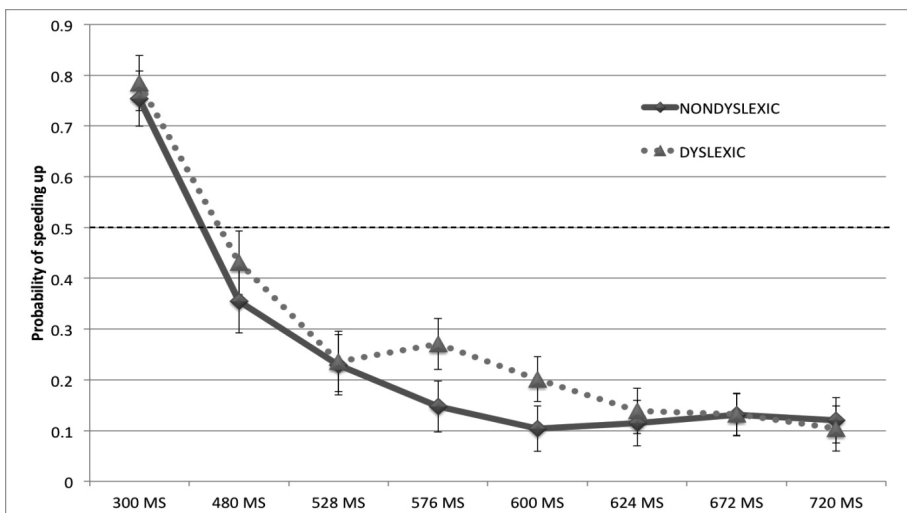


Figure 3. Probabilities of 'speeding up' responses for the test sequences in dyslexic and non-dyslexic children groups

those intervals, while the non-dyslexic children almost universally judged them as 'slowing down'.

Table 1 presents the mean values and standard deviations of responses on the control and test sequences in the two groups. Out of all the control sequences, only the 672 ms IOI yielded significant differences between the two groups. The non-dyslexic children rated this sequence as 'slowing down' significantly more often than the dyslexic children;  $t(107) = -2.605, p < 0.05$ . In the test sequences, the non-dyslexic children rated three IOIs as 'slowing down' sig-

Table 1. Mean differences between the non-dyslexic and dyslexic groups in the control and test sequences

	Non-dyslexic		Dyslexic		t-Test
	M	SD	M	SD	
Control 300ms	.85	.25	.86	.24	-.321
Control 480ms	.66	.31	.63	.29	.572
Control 528ms	.52	.35	.56	.32	-.701
Control 576ms	.39	.31	.35	.26	.726
Control 600ms	.33	.30	.40	.33	-1.171
Control 624ms	.27	.28	.34	.30	-1.071
Control 672ms	.21	.25	.37	.32	-2.605*
Control 720ms	.19	.24	.26	.25	-1.314
Test 300ms	.75	.28	.78	.28	-.546
Test 480ms	.36	.34	.43	.29	-2.188*
Test 528ms	.23	.31	.24	.30	-.182
Test 576ms	.15	.25	.27	.26	-2.446*
Test 600ms	.10	.20	.20	.26	-2.286*
Test 624ms	.11	.23	.14	.24	-.404
Test 672ms	.13	.23	.13	.19	-.075
Test 720ms	.12	.27	.10	.17	-.085

\* -  $p < 0.05$

nificantly more often than the dyslexic children: the 480 ms IOI,  $t(107) = -2.188$ ,  $p < 0.05$ ; the 576 ms IOI,  $t(107) = -2.446$ ,  $p < 0.05$ ; and the 600 ms IOI,  $t(107) = -2.286$ ,  $p < 0.05$ .

## DISCUSSION

The conducted analysis shows that no particular rhythm perception strategy was found amongst dyslexic children tested in the study. As expected, the results in the control task did not yield significant differences between the groups, apart from the 672 ms condition. This deviance can be attributed to an artefact of the method, since adjacent conditions (624 ms, 720 ms) did not produce significant differences between the groups. Apart from the 672 ms condition, the results show a predictable pattern of probabilities, with negative values of  $\Delta T$  judged more often as ‘speeding up’, and positive values of  $\Delta T$  as ‘slowing down’. The only exception to this regularity is the 576 non-dyslexic and 0.35 for the dyslexic children. However, the results in this condition are still relatively close to the 0.5 line, indicating an equal probability of ‘speeding up’ and ‘slowing down’, and can be also interpreted as an artefact.

In contrast with the control sequences, in the test sequences both the dyslexic and non-dyslexic children were more probable to give the ‘slowing down’ response for nearly all  $\Delta T$  values, except for  $\Delta T$  study were relatively insensitive to the implied beat, regardless of dyslexia. The outcome is contradictory to the results presented in previous studies (Grahn & McAuley, 2009; McAuley et al., 2012; McAuley et al., 2006b), which showed individual differences in sensitivity to the implied beat amongst participants.



The results of the test sequences yielded significant differences between the dyslexic and non-dyslexic children groups in the 480 ms, 576 ms and 600 ms conditions. In all these cases the non-dyslexic children tended to assess these conditions as 'slowing down' while the responses of the dyslexic children were closer to the 0.5 ambiguity line. This outcome points to the fact that dyslexic children are ambiguous in their perception of the presented metrical structures. The absence of a specific pattern of perceptive strategies in this group corresponds with the results of studies which indicate that dyslectics exhibit difficulties in keeping a steady beat (Overy, 2003). The effect is most pronounced in tasks based on tapping. Interestingly, no divergence has been observed between dyslectics and non-dyslectics in tapping with a speed that is slower or faster than 80 beats per minute. Statistically significant differences have occurred, however, at the speed of 80 bpm. This result becomes more understandable in the light of the research carried out by Huss et al. (2011) which showed that dyslexic children have difficulty in performing even the simplest metrical tasks based on dividing auditory stimuli into beats. In contrast, the research conducted by Overy et al. (2003) revealed that in comparison to a control group the results of dyslectics have been significantly lower in as many as 7 out of 9 tests of timing skills. They manifested particular problems in the test that required rapid temporal processing, a skill examined in the present study. Dyslexic children tended to over-anticipate the cued stimulus by as much as 100 ms, manifested difficulties in reproducing patterned rhythms of tones (Wolff, 2002) and achieved quite low results in segmentation and grouping tasks, both in speech and music (Petkov et al. 2005).

Although speech sound processing has not been examined in the present study, the results refer to the measurement of temporal processing on a rapid time scale (Tiernay & Kraus, 2013a). Thereby, they are consistent with more general knowledge about the specific difficulties in verbal communication that have been observed in dyslectics (Paçalska et al., 2009). The problems concern perception of the temporal aspect of rapidly changing and alternating sounds, such as in speech. Speech can be understood only if it is structured in time. This pertains to distinctive phonetic differences between syllables (e.g. the difference between /ba/ and /da/) which contain plosives identifiable within the first milliseconds. The mechanism which allows for speech signal identification depends upon the millisecond system, the functioning of which has been reported to be impaired in dyslectics (Tallal et al., 1996). Moreover, researchers have suggested that dyslectics manifest a specific deficit in the accurate processing of sound rise time (the time taken for sounds to reach their maximum amplitude) (Goswami et al., 2010). Rise times are critical for speech signals as they reflect the patterns of amplitude modulation that facilitate syllabic segmentation (Flaugnacco et al., 2014). Among dyslectic children, the sensitivity to rise time is significantly worse not only in comparison to age-matched children without dyslexia but also to younger children matched for reading level (Goswami et al., 2013). Children with dyslexia aged around 11 years need around 100 ms to per-

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a change in amplitude rise time.

Dyslectics' ambiguity in rhythm perception, as suggested by the current results, may be also explained by attention deficits, which are prevalent, though non-specific in developmental dyslexia (Lipowska, 2011; Łockiewicz et al., 2012). Subsequently, we may assume that the accuracy of temporal assessment depends on the degree to which an individual concentrates on the passing of time. Dyslectics, who also manifest deficits in the automation of cognitive and motor processes, may find it challenging. Their attention, while engaged in task completion, may be diverted from time monitoring. Such a hypothesis has been proved by empirical data showing an association between variability in tapping to a beat with performance on reading and attention tests (Tiernay & Kraus, 2013b).

The analysis has shown that dyslexic and non-dyslexic children had a tendency to experience a 'slowing down' of the presented tones both in the test and the control conditions. The underlying factor remains unclear, however it might be associated with the sex of the participants. Women, in comparison to men, tend to overestimate time intervals (Panagiotidi & Samartzi, 2012). Therefore, the sex variable might have acted as a mediator in the observed relation, as the majority of the participants of the study were female. The second possible determining factor is the combination of the age of the tested children and their preferred perceptual tempo (PPT). McAuley et al. (2006b) examined PPT for participants aged between 4 and 95 and found that the preference for slower sequences (PPT) increased systematically with age. For children between the age of 4 and 7, the preferred tempo was typically between 300 and 400 ms; for adults, the preferred tempo was around 600 ms, while for older adults it was close to 700 ms. These findings correspond with the results of the current study and the observed children's tendency to perceive the presented tones as 'slowing down'. For that reason further research should evaluate the designed procedure in terms of its vulnerability to individual differences in preferred perceptual tempo (PPT). A perceived 'slowing down' and 'speeding up' of a beat might be associated with the degree to which the presented beat and individual PPT are congruent, and not necessarily with the application of a different perceptive strategy (Grahn & McAuley, 2009; McAuley et al., 2012). Therefore, it seems justified to include the initial assessment of PPT in future studies on the subject. Participants should be asked to indicate on a continuous scale if the presented tempo is too fast, too slow, or 'just right'. PPT would be then understood as a tempo which is estimated as the closest to the middle of the scale ('just right') (McAuley et al., 2006b). A different measurement of PPT involves presenting subjects with a number of tones and allowing them to adjust the tempo with buttons or a winder until they find it suitable. If the influence of a tempo on the choice of a perceptive strategy was disproved, the hypothesis stating the independence of the strategy preference and PPT could be considered valid.

It is important to point out the limitations of the methodology proposed in the current study. The results of research on rhythm perception strategies based on isolated sequences of tones need to be taken cautiously. The stimuli presented

in the current study are not real music, and therefore the subjects' use of different strategies of rhythm perception may be biased. However, using real music in such studies is difficult due to a number of distorting factors that may influence the results (i.e. individual preferences for certain genres, loudness, prominence of rhythm section in the mix, syncopation).

One question that the current study failed to answer is the problem of the stability of rhythm perception strategies over time. It is unclear if the use of a particular strategy is a constant characteristic of an individual's cognitive apparatus, or it is situationally biased. Different patterns of brain activity found in fMRI studies (Grahn & McAuley, 2009; McAuley et al., 2012) seem to suggest that the preference for a certain strategy is (at least to an extent) stable over time, yet a final empirical confirmation of this fact is necessary.

The results achieved in our study not only correspond with the context of previous research but also complement and broaden it. Difficulties in rapid timing could explain why dyslexic children struggle with phonology across languages. On the other hand, considering the beneficial effects of music on cognitive capacity (Mielnik & Mielnik-Matityahu, 2013; Poćwierz-Marciniak, 2014) music may also help dyslexic children to improve their rhythmic abilities (Overy, 2003).

The conducted statistical analysis also provides a better understanding of the nature of rhythm perception – a musical skill which is often impaired in dyslectics (Miles & Westcombe, 2001; Oglethorpe, 1996; Overy, 2000). Research such as the current study provides a theoretical framework for designing a musical curriculum adjusted to the specific needs, deficits and resources of each student. The application of the presented results allows music teachers to adapt educational tools and procedures to the individual profile of a child; one must bear in mind, however, the distinctive purpose of personalised instruction – this should consort cognitive tendencies, and not contradict them.

## CONCLUSIONS

The results of this research provided evidence that individual differences in rhythm perception strategies are not determined by dyslexia. Future research in this area is recommended in order to explore other potential explanations for the existence of individual differences in perceiving rhythm.

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