Introduction

Music affects us in many ways. It not only makes us move, influences our mood, triggers memories, but with longer exposure and regular practice also shapes our brain. The transfer effect of music has been shown by numerous studies. Besides musical skills, music training has been found to relate to the improvement of language (Degé & Schwarzer, 2011; Forgeard, Winner, Norton, & Schlaug, 2008; Franklin, Moore, Yip, Jonides, Rattray & Moher, 2008; Jakobson, Lewycky, Kilgour, & Stoesz, 2008; Moreno, Marques, Santos, Santos, Castro & Besson, 2009; Moreno, Bialystok, Barac, Schellenberg, Cepeda & Chau, 2011; Piro & Ortiz, 2009), IQ (Schellenberg, 2004, 2006, 2011), executive functions (Moreno et al., 2011), spatial (Patston & Tippett, 2011; Stoesz, Jakobson, Kilgour, & Lewycky, 2007) and mathematical skills (Bahr & Christensen, 2000; Haimson, Swain, & Winner, 2011; Vaughn, 2000), academic achievement (Fitzpatrick, 2006; Schellenberg, 2006), and empathy (Kirschner & Tomasello, 2010; Laurence, 2008; Rabinowitch, Cross, & Burnard, 2013). It has been suggested that the underlying mechanism of the transfer effect of music could be rhythmic entrainment (Miendlarzewska & Trost, 2014). As music is mostly embedded in an underlying temporal structure, called meter, when perceiving music, our attention needs to entrain to the rhythmic patterns of the music (Miendlarzewska

& Trost, 2014). Rhythmic entrainment involves on the neural level the adaptation of brain oscillations to a common phase and period (Rosenblum & Pikovsky, 2003), on the behavioral level the adjustment of behavior, typically movement synchronization (Fitch, 2013), commonly referred to as sensorimotor entrainment.

Several studies found that sensorimotor entrainment to music is linked to various cognitive, linguistic, social (for a review: Miendlarzewska & Trost, 2014), and musical skills (Cheek, 1979; Crumpler, 1982; Joseph, 1982; Rohwer, 1998; Shiobara, 1994). However, these studies investigated the effect of sensorimotor entrainment in only one or two domains (cognitive, linguistic, musical, or social), and they did not examine long-term effects. Only two studies investigated the transfer effect of sensorimotor entrainment in multiple domains in a longitudinal study. Rabinowitch and colleagues (2013) tested 8-11-years old children participating in a music training involving joint music making and rhythmic coordination and compared them with two groups of age-matched children. One group participated in a gaming program, the other group did not participate in either programs. All children were tested before and after the music training (spanning one year) on 3 different measures of empathy (Bryant Empathy Index, Matched Faces, Memory Task - only after the training) and verbal skills (Similarities and Vocabulary subtests on the Wechsler Intelligence Scale for Children (WISC)). At the end of the training, children in

the music program scored higher on empathy compared to the control groups; however, there was no difference in verbal skills.

Another one year-long study (Ilari, Keller, Damasio, & Habibi, 2016) tested 6-7-years old children learning music with the El Sistema method that involves ensemble playing that requires synchronization between instrument players in order to keep a common tempo. During synchronizing in ensemble playing, the exact movements are not determined; therefore, there is more degrees of freedom in entrainment compared to the study of Rabinowitch and colleagues (Rabinowitch et al., 2013). Children in the training program were compared with children who did not participate in any intense after-school program. Testing was administered at the beginning and at the end of the year and included musical skills (Gordon's Primary Measures of Music Audiation, AIRS Test Battery of Singing Skills), rhythmic entrainment (drumming with a computer and with a person), verbal skills (Wechsler Abbreviated Scale of Intelligence (WASI-II) Vocabulary subtest), cognitive skills (WASI-II Matrix Reasoning subtest), and motor skills (Bruininks-Oseretsky Test of Motor Proficiency). After a year, significant improvement was reported only in musical skills in the music group (the results on other skills were not presented).

The different outcomes of these studies suggest that different types of music trainings might have different transfer effects. Furthermore, since the skills related to the

effect in one study were not investigated in the other study, it is not known how different music education programs would influence the same skills. For these reasons, we were seeking to answer the following questions: How sensorimotor entrainment relates to cognitive, linguistic, musical, and social skills, and how do they develop over time? What are the effects of different degrees of freedom in entrainment?

In Hungary, general music education is based on the Kodály method which was also linked to the improvement of numerous musical and non-musical skills. Hurwitz and colleagues (Hurwitz, Wolff, Bortnick, & Kokas, 1975) investigated the transfer effects of the Kodály music training in 6-7-years old children on multiple domains (cognitive, musical, and linguistic skills) compared to a group that did not receive any particular training besides school. Children in the music training showed improvement relative to the control group in intelligence (Raven's Progressive Matrices), executive functions (Stroop Color Interference), spatial skills (Children's Embedded Figures Test), and sensorimotor entrainment (tapping to a metronome), but not in verbal skills (WISC Comprehension and Vocabulary subtests). Since the Kodály method is based on solfeggio and singing, we were additionally interested in whether a music training involving singing and entrainment is more effective in improving musical and non-musical skills than a music training based on singing only?

In order to address the above questions, we launched a study where we compared the transfer effect of three different music education methods: the Kodály method, and two sensorimotor entrainment-based methods. One of them is based on well-defined rules, and the other one emphasizes free improvisation. (Detailed description of each music program is provided in the Methods section.) Comparing the two entrainment-based methods has the benefit to investigate the effect of different degrees of freedom in entrainment (the former uses fixed movement forms, the latter allows free movements). In all 3 programs, we tested 6-7-years old primary school children at the beginning and at the end of their first school year in four domains including cognitive, linguistic, musical, and social skills.

Based on the findings of previous research, we expected that while all methods will increase musical skills, the entrainment-based methods will improve social skills compared to the Kodály method, and the Kodály method will be more effective in improving cognitive skills.

Materials and methods

Kodály method

This method largely relies on the Hungarian folk song repertoire and the use of syllable names and hand signs associated with scale degrees and basic rhythmic elements (Choksy, 1999).

Creative playing with music and movement (Kreatív énekes-mozgásos játékok)

In this new approach developed by Borbála Szirányi and Edina Barabás, sensorimotor entrainment is facilitated by predefined movement forms associated with structural, rhythmic and melodic elements of the given music. Movement forms are based on a *bodyrhythm* set, where rhythmic values are paired with specific movement forms, whereby the experience of sound is coupled with kinetic and visual experience. For melodic elements, the choreography follows the contour of the melody.

Creative music appreciation with movement (Kreatív zenebefogadás mozgással)

In this method created by Klára Kokas (Kokas, 1999), children improvise a free movement performance while listening to music. Movement forms are always arbitrary; no prewritten choreography exists. After the performance, children have to verbally discuss how their movements were related to the music. Finally, they paint or draw images inspired by the music.

The detailed descriptions of the music education programs are presented in the Supplementary Material 1.

Participants

Sixty-three 6-7 years old children participated in the study from three first grade classes of two public elementary schools in Budapest and Győr. Twenty-two children (6 boys, mean age = 6.46 years, SD = 0.51) were recruited from one class in Budapest who received music education based on the Creative playing with music and movement method (in the following: rule-based synchronization). This method was integrated into the regular school curriculum. Twenty-five children (12 boys, mean age = 6.6 years, SD = 0.5) were recruited from Győr. They received music education based on the Creative music appreciation with movement method (in the following: free movement), which was also integrated into the school curriculum. Sixteen children (6 boys, mean age = 6.44 years, SD = 0.52) from the second class in Budapest formed the control group and were taught by the Kodály method. Despite the different locations of the two schools, all children who participated in the study came from middle class families living in similar urban communities. The selection of the groups was semi-randomized. All children received the music lessons as part of their curriculum in the primary school they enrolled. However, it

was not known before enrollment that two of the classes were going to be taught with music education methods different from the National Curriculum's.

One child from the control group withdrew his consent during participation and another child from the free movement group discontinued her participation due to her family's relocation. Four other children did not participate in the post measurement due to an enduring illness, and seventeen children had missing data on some tests due to measurement error or incomplete responses. These children were excluded from the final analyses, which resulted in a total of 40 children (control group n = 13, 4 boys; rule-based synchronization group n = 13, 3 boys; free movement group n = 14, 7 boys).

Parents/guardians gave written consent for their child's participation, and children declared orally that they assent in participating in the tests. Neither the children nor the parents/guardians received any compensation for their child's participation.

Procedures

Children in all groups participated in music lessons 4 times a week, each lasting for 45 minutes. Our test battery consisted of measurements commonly used in previous studies mentioned above. The tests for musical skills and phonological processing are standardized measures that were tested on a large sample in Hungary. Children underwent all tests individually in two 45-minutes sessions. The measurements took place in one of the

classrooms of the primary school during school time. The order of administering the tests was counterbalanced across children and test data were handled confidentially. Each child received a code, and identification information were stored separately from the test measurement results in the office of the principal investigator.

Sensorimotor entrainment test

The test has two parts: a paced tapping test in which children had to tap along a metronome in three tempo conditions (1.5 Hz, 2 Hz, 2.5 Hz) and a continuation tapping test in which children had to continue tapping the pace that the metronome gave them previously but without hearing the metronome. The latter measures the internal representation of the beat. Analyses were performed for each tempo and tapping condition (paced, unpaced) separately.

Online Diagnostic Test of Music Perception

The test developed by Asztalos and Csapó (Asztalos & Csapó, 2015) included three subtests: melodic discrimination, pitch discrimination, and rhythm discrimination. On each trial, children had to decide whether two melodies/pitches/rhythms they just heard were the same or not. Scores were calculated by summing the number of correct responses separately for each subtest.

Attention Network Task for Children (ANT)

For testing executive functions, we used the Attention Network Task for Children (Rueda, Fan, McCandliss, Halparin, Gruber, Lercari & Posner, 2004) obtained from www.sacklerinstitute.org/cornell/assays_and_tools/ant/jin.fan/. The test is a type of flanker task that measures reaction time, accuracy, alerting, orienting, and conflict. The alerting score represents the difference in reaction time between trials that contained a double cue (two marks above and below the fixation cross) versus trials that did not contain any cues. The orienting score represents the difference in reaction time between trials with spatial cue (marks the location of the upcoming target) versus trials with central cue (a mark on top of the fixation cross). Finally, the conflict score represents the difference in performance between congruent and incongruent trials.

3DM-H Test of Phonological Awareness

For linguistic skills, we applied the Phoneme Deletion subtest of the Hungarian version of Dyslexia Differential Diagnosis Maastricht (3DM-H) (Tóth, Csépe, Vaessen, & Blomert, 2014) in which children were asked to skip the first, last, or middle phoneme of auditory presented pseudo-words and to utter the remaining part of the letter strings. The derived variables indicated the accuracy and the speed of responding. Response acceptance criteria was determined by the user's handbook, and raw scores were converted into age matched standardized scores.

Wechsler Intelligence Scale for Children IV

We used four subtests of the Hungarian adaptation of the fourth version of the Wechsler Intelligence Scale for Children (Nagyné Réz, Lányiné Engelmayer, Kuncz, Mészáros, & Mlinkó, 2008): Block Design, Similarity, Vocabulary, and Digit Span.

Empathy Index of Bryant

In this test children had to state whether they agree or disagree with various statements pertaining to typical scenarios from children's lives (Bryant, 1982). Scores were averaged for children.

The detailed descriptions of the tests are presented in the Supplementary Material 2.

Data analysis

First, we ran a one-way ANOVA on age and a Kruskal-Wallis test on gender to explore possible group differences. In order to determine any preexisting differences between groups on the behavioral measures, we ran a series of univariate ANOVAs with group as independent factor. A number of test results (sensorimotor entrainment, ANT orienting and conflict, rhythm discrimination, Block Design, Similarity and Digit Span) were non-normally distributed; therefore, we used a Kruskal-Wallis test on those behavioral measures instead of the ANOVA. For post-hoc multiple comparisons, we applied Bonferroni correction. In regard to the results after training, a series of mixed

ANOVAs were run on each behavioral measure with group as between-subjects factor and time of testing (ToT) as within-subjects factor with two levels: Pre-training and Post-training. For the sensorimotor entrainment test, we included tempo in the mixed ANOVA as within-subjects factor with three levels (2 Hz, 2.5 Hz and 1.5 Hz). When sphericity assumption failed, we applied a Greenhouse-Geisser correction to the p value. Where data were non-normally distributed, such as in sensorimotor entrainment, ANT accuracy, orienting and conflict, pitch and rhythm discrimination, phonological speed, Block Design, Similarity and Digit Span, we used a Mann-Whitney U Test and a Wilcoxon Signed Rank Test for post-hoc analyses and report medians where appropriate. We applied Bonferroni corrections for multiple comparisons. Effect sizes are reported along with the ANOVA test results. Means, standard deviations, and medians for all measures are shown in Table 1.

Results

Pre-training

We did not find significant group differences in age $F(2,37) = 0.88$, $p = 0.42$ and gender χ^2 $(2, N = 40) = 2.24$, $p = 0.33$; therefore, these factors were excluded from further analyses.

Regarding the behavioral tests, we did not find significant group differences except in two measures. There was a significant difference between the groups in the paced signed error of the sensorimotor entrainment test at 2.5 Hz, χ^2 (2, N = 40) = 7.033, p = 0.03. Post hoc tests revealed a significant difference between the solfeggio-based group and the free movement group, p = 0.018. While the solfeggio-based group tended to slow down in this condition, the free movement group seemed to speed up. There was a significant group difference in pitch discrimination as well, F(2,37) = 4.55, p = 0.017, η^2 = 0.19. Pairwise comparisons revealed that the solfeggio-based group performed significantly higher than the free movement group, p = 0.015. Means, standard deviations and medians for all measures are reported in Table 1. Since performance did not differ significantly in IQ and in linguistic skills, Pre-training results provided us with a reliable baseline for measuring development.

Post-training

Sensorimotor entrainment

For the paced absolute error, there were no main effects of ToT, tempo, and group, and there were no significant interactions between any factors. However, at 2 Hz there were differences in performance from Pre-training to Post-training between the groups. The

solfeggio-based group showed greater improvement from Pre-training to Post-training, whereas the rule-based synchronization group improved slightly, and the free movement group declined. A Wilcoxon Signed Rank test revealed a significant improvement in the solfeggio-based group ($Z = -2.132$, $p = 0.033$) but not in the other two groups. The results are displayed in Figure 1.

For the paced signed error, there were no main effects of ToT and group, but there was a main effect of tempo, $F(2,74) = 3.95$, $p = 0.024$, $\eta^2 = 0.096$. Children sped up more relative to the target tempo at 1.5 Hz (Median = -0.045) than at 2 Hz (Median = -0.005), which was supported by a strong trend toward a significant difference, $Z = -2.34$, $p = 0.057$. There were no significant interactions between any factors.

For the paced standard deviation, there was no main effect of ToT and group, but there was a main effect of tempo, $F(2,74) = 3.68$, $p = 0.03$, $\eta^2 = 0.091$. Children tapped with more variability at 2.5 Hz (Median = 0.113) than at 2 Hz (Median = 0.09), which was supported by a strong trend toward a significant difference, $Z = -2.35$, $p = 0.057$. There were no significant interactions between any factors. However, at 2 Hz the rule-based synchronization group showed a greater improvement from Pre-training to Post-training, whereas the solfeggio-based group improved slightly, and the free movement group declined. A Wilcoxon Signed Rank test revealed a significant improvement for the rule-

based synchronization group (Z = -2.062, p = 0.039) but not in the other two groups. The results are displayed in Figure 1.

For the continuation absolute error, there were no main effects of ToT and group, but there was a main effect of tempo, $F_{Greenhouse\text{-}Geisser}(1.529,56.573) = 6.45$, $p = 0.006$, $\eta^2 = 0.149$. Children tapped less accurately to 1.5 Hz (Median = 0.089) than to 2 Hz (Median = 0.05), $Z = -3.9$, $p < 0.001$. There were no significant interactions between any factors.

For the continuation signed error, there were no main effects of ToT and group, but there was a main effect of tempo, $F_{Greenhouse\text{-}Geisser}(1.715,63.463) = 8.29$, $p = 0.001$, $\eta^2 = 0.183$. Children sped up more relative to the target tempo at 1.5 Hz (Median = --0.066) than at 2 Hz (Median = -0.024), $Z = -3.88$, $p < 0.001$. There were no significant interactions between any factors.

For the continuation standard deviation, there were no main effects of ToT and group, but there was a main effect of tempo, $F_{Greenhouse\text{-}Geisser}(1.707,63.149) = 5.46$, $p = 0.009$, $\eta^2 = 0.129$. Children tapped with more variability to 2.5 Hz (Median = 0.093) than to 1.5 Hz (Median = 0.083), $Z = -2.47$, $p = 0.039$. There were no significant interactions between any factors; however, at 2.5 Hz the free movement group showed a strong decline from Pre-training to Post-training, while both the solfeggio-based and the rule-based synchronization groups improved. A Wilcoxon Signed Rank test revealed a significant

decline in the free movement group, $Z = -1.977$, $p = 0.048$. The improvements in the other two groups were not significant. The results are displayed in Figure 1.

Musical skills

Concerning musical skills, all groups demonstrated a significant increase in performance from Pre-training to Post-training in melodic discrimination as shown by a main effect of ToT, $F(1,37) = 25.99$, $p < 0.001$, $\eta^2 = 0.413$. There was no significant effect of group and interaction between ToT and group.

There was also a main effect of ToT in pitch discrimination, $F(1,37) = 30.27$, $p < 0.001$, $\eta^2 = 0.45$ with a significant increase in performance from Pre-training to Post-training in all groups and a significant effect of group $F(2,37) = 4.3$, $p = 0.021$, $\eta^2 = 0.189$. A Mann-Whitney U test revealed that the control group performed significantly better (Median = 12.5) than the free movement group (Median = 9.5), $U = 32$, $p = 0.012$. There was no significant interaction between ToT and group although both entrainment-based groups showed a larger improvement compared to the solfeggio-based group. Wilcoxon Signed Rank tests revealed significant improvement in the rule-based synchronization group, $Z = -2.221$, $p = 0.026$ and in the free movement group, $Z = -3.197$, $p = 0.001$ but not in the solfeggio-based group. The results are displayed in Figure 1. For the rhythm discrimination, the main effects and interactions were not significant.

ANT test

Pertaining to the ANT tests, we found a main effect of ToT in reaction time: there was a significant decrease in reaction time from Pre-training to Post-training for all groups, $F(1,37) = 186.4$, $p < 0.001$, $\eta^2 = 0.834$. There was no significant effect of group and no interaction between ToT and group.

There was also a main effect of ToT in accuracy, $F(1,37) = 4.49$, $p = 0.041$, $\eta^2 = 0.108$; all groups showed a significant increase in accuracy from Pre-training to Post-training. There was no significant effect of group and no interaction between ToT and group. However, the solfeggio-based group showed a larger improvement, whereas the two entrainment-based groups improved slightly. A Wilcoxon Signed Rank test revealed a significant improvement in the solfeggio-based group, $Z = -2.229$, $p = 0.026$ but not in the other two groups. The results are displayed in Figure 1. We did not find any significant main effects or interactions for the alerting, orientation, and conflict subtests.

Linguistic skills

In regards to linguistic skills, there was a trend towards a significant main effect of ToT in speed, $F(1,37) = 3.7$, $p = 0.062$. There was no significant effect of group or interaction between ToT and group. However, the two entrainment-based groups showed a larger improvement from Pre-training to Post-training, whereas the solfeggio-based group

improved slightly. A Wilcoxon Signed Rank test revealed a significant improvement in the rule-based synchronization group, $Z = -2.003$, $p = 0.045$ but not in the other two groups. The results are displayed in Figure 1.

There was a main effect of ToT for phonological accuracy, $F(1,37) = 75.1$, $p < 0.001$, $\eta^2 = 0.67$ with a significant improvement from the Pre-training to the Post-training for all groups. There was no significant effect of group and interaction between ToT and group.

WISC

Regarding the WISC test, we found a main effect of ToT for the backwards counting of the Digit Span task $F(1,37) = 33.03$, $p < 0.001$, $\eta^2 = 0.472$ with a significant improvement from Pre-training to Post-training in all groups. There was no significant effect of group or interaction between ToT and group. However, both entrainment-based groups showed a larger improvement whereas the solfeggio-based group did not seem to change. Wilcoxon Signed Rank tests revealed significant improvement in the rule-based synchronization group, $Z = -2.979$, $p = 0.003$ and in the free movement group, $Z = -2.724$, $p = 0.006$ but not in the solfeggio-based group. The results are displayed in Figure 1.

For the Vocabulary test, we did not find any main effects for ToT or group, but we found a significant interaction between group and ToT $F(2,37) = 4.2$, $p = 0.023$, $\eta^2 =$

0.185. Post-hoc tests revealed that the free movement group improved significantly more compared to the solfeggio-based group from Pre-training to Post-training, $p = 0.021$. The results are displayed in Figure 1. We did not find significant main effects or interactions in any other measures of the WISC test.

Empathy

Considering empathy, all groups showed significant improvement from Pre-training to Post-training as revealed by a main effect of ToT, $F(1,37) = 6.12$, $p = 0.018$, $\eta^2 = 0.142$. There was no significant main effect of group and there was no significant interaction between ToT and group.

Table 1. Descriptive statistics for all measures

[insert Table 1.]

Means and standard deviations for Pre-training and Post-training in all behavioral measures per group. For non-normally distributed data medians are reported.

Figure 1. Differences in performance from Pre-training to Post-training per group with standard errors or 95% confidence intervals for non-normally distributed data.

[insert Figure 1.]

**Significant at $p < 0.05$. **Significant at $p < 0.01$.*

In order to examine whether entrainment in music education mediated development in musical and non-musical skills, we ran non-parametric correlations between all variables (except the signed measures of the sensorimotor entrainment test) and the other tests on the Post-training scores. We did not include the signed measure because results are bidirectional: positive when slowing down and negative when speeding up, and both directions could reflect the same amount of error. We applied Benjamini-Hochberg correction for multiple comparisons. We found a significant positive correlation between the paced absolute error at 1.5 Hz and the Conflict subtest of the ANT ($r_s = 0.331$). The difference in performance between congruent and incongruent trials decreased with decreased sensorimotor synchronization error in the paced condition at 1.5 Hz. Paced tapping variability at 1.5 Hz also positively correlated with the Conflict subtest of the ANT ($r_s = 0.331$). Tapping variability at 1.5 Hz decreased with decreased difference in performance between congruent and incongruent trials. Finally, we found significant negative correlations between continuation tapping variability at 2.5 Hz and both phonological accuracy ($r_s = -0.418$) and the backward version of the Digit Span subtest of WISC ($r_s = -0.379$). Phonological accuracy and working memory increased with decreased tapping variability at 2.5 Hz in the continuation condition.

Discussion

In the present study, we compared cognitive, linguistic, musical, and social skills for three classes of 6-7 years old children receiving one of two different sensorimotor entrainment-based or a solfeggio and singing-based music education method. On the initial assessment, there were no significant differences in performance between the three groups except in the paced signed error of the sensorimotor entrainment test at 2 Hz and in pitch discrimination. We found that while tapping at 2 Hz the solfeggio-based group tended to slow down, the free movement group rather sped up. Neither direction of deviation is better than the other; therefore, the difference between the values does not reflect differences in skills. Pertaining to pitch discrimination, the solfeggio-based group scored significantly higher than the free movement group, but this initial difference was taken into account in further analyses when comparing the development of the three groups. As there were no significant differences in performance between the groups in IQ and linguistic skills, we used our Pre-training measurement results as a reliable baseline that is not affected by preexisting cognitive and linguistic differences.

Sensorimotor entrainment

In general, the development in sensorimotor entrainment skills was very subtle. This could be due to the fact that sensorimotor entrainment skills were already very high at the beginning of the training in all groups. Differences in sensorimotor entrainment could

be better detected with a more difficult task or by measuring entrainment on the neural level.

Musical skills

In line with our hypothesis, we found an increase in performance from Pre-training to Post-training in all groups in melodic and pitch discrimination. Although the solfeggio-based group scored higher on the Post-training in pitch discrimination, only the entrainment-based groups improved significantly from Pre-training to Post-training. The higher score of the solfeggio-based group was the result of the initial difference in performance on the Pre-training, where the solfeggio-based group performed significantly better compared to the other two groups. The improvement of the entrainment-based groups compared to the solfeggio-based group could be a result of the fact that sensorimotor entrainment requires detection of fine details in sound (Moore, 1995).

Attention Network

We found significant increases in performance relative to Pre-training in all groups in both reaction time and accuracy. The solfeggio-based group showed a significant improvement in accuracy while the entrainment-based groups did not. Based on the research of (Hurwitz et al., 1975), we expected that the Kodály method will be effective in improving cognitive skills. However, the worse performance of the entrainment-based

groups is surprising given that previous research found that entrainment of neural oscillations is responsible for attentional selection (Calderone, Lakatos, Butler, & Castellanos, 2014; Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008; Lakatos, Musacchia, O'Connel, Falchier, Javitt & Schroeder, 2013; Miller, Carlson, & McAuley, 2012). One possible explanation is that the attention task did not contain an entraining stimulus; therefore, entrainment skills were not necessary to complete the task. Second, the attention task was completely visual, and both entrainment-based methods work with auditory stimuli. Third, it is possible that the transfer effect of entrainment on attention will manifest later, after longer exposure.

Linguistic skills

We found a trend towards a significant improvement in speed of phonological awareness in all groups, and the rule-based synchronization group showed a significant improvement relative to Pre-training whereas the other two groups did not. Our results are consistent with previous studies (Carr, White-Schwoch, Tierney, Strait, & Kraus, 2014; Tierney & Kraus, 2013) that found relations between entrainment and linguistic skills. Other studies found that people with reading deficits have problems entraining to a metronome (Goswami, 2011; Thomson, Fryer, Maltby, & Goswami, 2006; Thomson & Goswami, 2008). We additionally found an increase in performance relative to Pre-training

in phonological accuracy in all groups, but we did not find differences in development between groups. The reason why we could not see an advantage for the entrainment groups in accuracy could be that linguistic skills were found to relate to other elements of the music training, such as tonal discrimination (Atterbury, 1985), tonal memory (Barwick, Valentine, West, & Wilding, 1989), and pitch perception (Lamb & Gregory, 1993). These elements are part of the solfeggio-based method, too. It is possible that during a longer training, the effect of sensorimotor entrainment would prevail stronger. Phonological skills were measured only with one test; therefore, it is possible that a more thorough test battery could provide a more detailed picture of the transfer effect of sensorimotor entrainment on linguistic skills.

WISC

We additionally found an increase in performance in all groups in working memory on the backwards version of the Digit Span subtest of the WISC for Children. The entrainment-based groups improved significantly while the solfeggio-based group did not. Recent studies found that music training enhanced auditory working memory for musical stimuli (Bailey & Penhune, 2010; Pallesen, Brattico, Bailey, Korvenoja, Koivisto, Gjedde & Carlson, 2010; Schulze, Müller, & Koelsch, 2011), and one study found better performance for musicians in a digit backwards test similar to ours (George & Coch, 2011).

Based on our results, it could be that entrainment can further increase or it is directly responsible for the effect of music training on auditory working memory that became apparent in the more memory demanding backwards version of the Digit Span task. We also found that in the Vocabulary subtest of the WISC the free movement group improved significantly more compared to the solfeggio-based group. The large increase in vocabulary in the free movement group could be due to that the method focuses on verbal description of the musical experience.

Empathy

All groups improved in empathy relative to Pre-training, but we did not find differences in development between the groups. In our study, we used the Empathy Index of Bryant, which asks children's judgements about different hypothetical scenarios. It is possible that some complex statements were difficult to understand for the children; therefore, their answer did not reflect their real thoughts. Rabinowitch and colleagues (2013) used the same test and found significant improvement in the music group compared to the two control groups. However, it is possible that comprehension of the sentences was not a problem because their participants were between 8 and 11 years. In the future, comprehension check will be necessary before letting children to answer.

We found that better entrainment correlated with better phonological accuracy. This is in line with the result that the rule-based synchronization group improved significantly in phonological speed. Additionally, there was a larger improvement from Pre-training in the entrainment-based groups in phonological accuracy (rule-based synchronization: 42.85-55, free movement: 37.36-50.28) compared to the solfeggio-based group (37.08-45.61). Our results are consistent with previous research that found significant correlations between sensorimotor synchronization ability and linguistic skills, specifically reading (Tierney & Kraus, 2013). We also found significant correlations between entrainment and performance on the Conflict subtest of the ANT. Entrainment increased with decreased difference in performance between congruent and incongruent trials. Previous research found relationship between tapping skills and auditory attention (Tierney & Kraus, 2013). In our study, the attention task was visual, and on the Conflict subtest only the solfeggio-based and the rule-based synchronization group showed improvement from Pre-training. However, the rule-based synchronization group showed a larger improvement (108-54) compared to the solfeggio-based group (82-56). Finally, there was a significant correlation between entrainment and working memory. Performance on the backward version of the Digit Span task of WISC increased with increased sensorimotor synchronization skills. The correlation between entrainment and working memory supports our finding that both

entrainment-based methods showed a significant improvement relative to Pre-training, whereas the solfeggio-based group did not. Based on our results, we propose that entrainment could directly mediate the effect of music training on linguistic skills, attention, and working memory.

Differences between the rule-based synchronization and the free movement methods

The effects we found for entrainment were similar in the two groups; however, there were some differences in the tapping test, pitch discrimination, phonological skills, and working memory that could be attributed to particular elements of the different methods. There were minor differences between the two entrainment-based groups in sensorimotor synchronization. The rule-based synchronization group tended to perform slightly better than the free movement group. The rule-based synchronization group uses so called *bodyrhythms* when learning a new rhythmic or melodic element, where rhythmic values or melodic elements are paired with the same movement forms. This consistency and the parallel processing of musical elements cognitively and physically could result in a better tapping performance. For pitch processing, both groups showed improvement. The high performance could be due to the pairing of movement to the different scale degrees in melody learning in the rule-based synchronization group and due to movement

dramatization of the musical narrative in the free movement group. For phonological speed, the rule-based synchronization group seemed to be more effective, which might relate to the use of *bodyrhythms*, that requires quick associations between rhythmic percepts and rhythmic concepts that helps finding the appropriate movement form to the corresponding rhythmic value. Lastly, both groups improved in working memory. This is not surprising given that both methods train cognitive maintenance of the musical beat when moving to the music.

Limitations

Our study's major limitation is that children in the free movement experimental group were going to school in a different city than the other two groups. This raises the question whether the differences we found could be due to non-experimental factors. We addressed this problem in several ways. First, both schools were public schools that work upon the same national curriculum. In addition, we regularly (every 1-2 months) kept meetings with each music teacher and made sure that each method is taught consistently without any changes in the teaching methods or in the system of the classes. Second, children came from similar socioeconomic background. Finally, children did not differ in their baseline performance. Because of the above factors we attribute our findings predominantly to the result of the music education methods.

Another limitation of the study is the small sample size, which was primarily due to incomplete test answers. In the future, we would like to further elaborate our measurements in order to provide a more suitable test battery for children's age.

Conclusion

In the present study, sensorimotor entrainment related to musical and phonological skills, attention, and working memory; these skills showed larger improvement after 8 months in children receiving the two entrainment-based methods compared to children receiving the solfeggio-based method. Contrary to previous findings, sensorimotor entrainment did not show relation to empathy. Since all groups received music training, it is difficult to isolate the effect of entrainment during this short period of time. A future study that spans multiple years could shed light on possible effects of entrainment that may take years to unfold. Our results extend the findings of previous research, and we showed that different teaching forms of sensorimotor entrainment could result in different transfer effects.

Ethical approval

Ethical approval for this project was given by the Ethical Review Committee for Research in Psychology [reference number: 46/2015].

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