

How Rhythmic Skills Relate and Develop in School-Age Children

Global Pediatric Health
Volume 6: 1–7
© The Author(s) 2019
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/2333794X19852045
journals.sagepub.com/home/gph



Silvia Bonacina, MS^{1,2}, Jennifer Krizman, PhD^{1,2}, Travis White-Schwoch, BA^{1,2}, Trent Nicol, BS^{1,2}, and Nina Kraus, PhD^{1,2,3} 

Abstract

Rhythmic expertise can be considered a multidimensional skill set, with clusters of distinct rhythmic abilities evident in young adults. In this article, we explore relationships in school-age children (ages 5–8 years) among 4 rhythmic tasks hypothesized to reflect different clusters of skills, namely, drumming to an isochronous beat, remembering rhythmic patterns, drumming to the beat in music, and clapping in time with feedback. We find that drumming to an isochronous beat and remembering rhythmic patterns are not related. In addition, clapping in time with feedback correlates with performance on the other 3 rhythm tasks. This study contributes to the taxonomy of rhythmic skills in school-age children. It also supports the use of clapping in time training as a way to possibly affect a broad spectrum of rhythmic abilities that are linked to language and literacy processes.

Keywords

rhythm, rhythmic skills development, beat, rhythmic patterns, beat alignment task, synchronization

Received January 18, 2019. Received revised April 11, 2019. Accepted for publication April 15, 2019.

Introduction

Rhythm helps organize events into predictable and coherent patterns. In music, rhythm is the primary element that creates the perception of time.¹ In speech, rhythm helps us select and extrapolate phonemes, syllables, words, and phrases from an ongoing speech stream.² Having good rhythmic skills, therefore, appears to be essential not only for music or dance but also for language and communication skills.

Rhythm abilities are not simply heritable skills; recent studies have shown that rhythm skills can be improved through training^{3,4} and that the performance of an individual may vary across different rhythm tests.⁵ This and related observations have supported a hypothesis that rhythm should be conceptualized as a multidimensional skill set, in contrast to the concept of a single “rhythmic IQ.” To date, the dissociation between sets of rhythmic abilities (drumming to the beat and discriminating/reproducing rhythm) has been reported in several case studies, including musicians and nonmusicians following a stroke,^{6,7} respectively, patients undergoing unilateral temporal cortex resection,⁸ and a patient with congenital amusia.⁹ Additionally, this dissociation has been shown in a population of healthy young adults.⁵ However, this dissociation has not been investigated in a school-age population.

Understanding the taxonomy of rhythm skills in school-age children is important not only from a theoretical standpoint but also for its clinical implications. In fact, struggling with certain rhythmic skills can reflect underlying language and/or perceptual impairments; this has led to increasingly popular rhythm-based trainings to treat literacy and auditory processing problems, especially at early stages of life.^{10–14} Therefore, a more thorough understanding of the development and interconnection of different rhythmic abilities in early childhood can crucially help in sculpting such interventions to the specific needs of each individual.

In this article, we focus on 4 rhythmic tasks that have been selected to represent multiple hypothesized rhythmic skills:

¹Auditory Neuroscience Laboratory, Northwestern University, Evanston, Illinois, USA

²Department of Communication Sciences, Northwestern University, Evanston, Illinois, USA

³Department of Neurobiology, Northwestern University, Evanston, Illinois, USA

Corresponding Author:

Nina Kraus, Northwestern University, 2240 Campus Drive, Evanston, IL 60208, USA.

Email: nkraus@northwestern.edu



1. *Drumming to an isochronous beat.* This widely studied task assesses the ability to drum synchronously to an isochronous (steady) pacing beat. It has been described as the simplest rhythmic action that humans can perform.¹⁵ However, studies have shown how it represents a challenge for people with reading and language impairments.^{11,16,17} It requires the ability to temporally coordinate an action with a predictable external event, and neuroimaging studies have identified cerebellum, basal ganglia, and primary motor cortex as areas activated during it.^{17,18}
2. *Remembering and reproducing a rhythmic pattern.* This task assesses the ability to remember and repeat back a rhythmic sequence after listening to it 3 times. It requires the ability to retain and integrate temporal information. In addition to the coordination of the auditory-motor systems involved in tapping to a beat, this task also calls on the premotor cortex and the supplementary motor area.¹⁹⁻²¹
3. *Drumming to a beat of music.* This task assesses the ability to tap along to a beat of a musical excerpt. It involves the ability to identify the beat within musical stimulus, a skill that has been shown to have a strong link to the overall perception of temporal patterns. The use of excerpts of actual music from different genres makes this task uniquely realistic.
4. *Clapping in time with visual feedback.* This task assesses the ability to clap in time with an isochronous pacing beat. The goal is to align one's clap with a pacing tone and use visual feedback to facilitate clapping at the correct rate and phase. It has been largely investigated for its therapeutic potential in (a) supporting cognitive and motor dexterity in healthy older adults, (b) augmenting overall motor function, activity of daily living, and quality of life in stroke patients, and (c) helping attention, impulsivity, motor coordination, and learning skills in children with attention deficit hyperactivity disorder.²²⁻²⁴ It has also been shown that performance on the task is linked to literacy and auditory processing—both at cortical and subcortical levels—in adolescents and young children.^{25,26}

All these tasks highlight different elements of rhythmic ability. Together, they provide a wide-ranging picture of people's rhythmic processing. This study aims to (a) uncover the reciprocal relationships among the 4 rhythmic tasks performances in school-age children and (b) investigate changes in performances across 2 consecutive years. Given aforementioned evidence of multiple

dissociable rhythmic skills in adolescents and young adults, we hypothesized distinct clusters of rhythmic interconnections also in school-age children. Thus, we predicted that we would observe steady growth in rhythmic skills from Year 1 to Year 2; but we also predicted that the rate of development would differ among the multiple rhythm skills we considered.

Materials and Methods

Participants

Sixty-eight children between 5.0 and 8.1 years of age (mean age = 6.34; SD = 0.69; 32 female) were recruited from the Chicago area. On average, maternal education level was high (mean = 17.54 years of school; SD = 2.29, range = 12-20 with 16 = all years college completed, proxy for socioeconomic status according to D'Angiulli et al²⁷) and the children had relatively high IQs (assessed by the Wechsler Preschool and Primary Scale of Intelligence Information subtest, mean percentile = 72.67, SD = 27.79, and Matrix Reasoning subtest, mean percentile = 75.42, SD = 26.00). Some of the kids (N = 18) are involved in music or dance program according to the history form completed by the parents.

They were assessed with a battery of 4 different rhythmic tasks. Forty-six of these participants were retested 1 year later to monitor the development of these rhythm skills.

All of the participants passed screening tests of peripheral auditory function (normal otoscopy, tympanometry, and distortion product otoacoustic emissions at least 6 dB sound pressure level above the noise floor from 0.5 to 4 kHz).

None of the participants had a history of a neurologic condition or a diagnosis of autism spectrum disorder, learning disabilities, or attention disorder. For all participants parents or legal guardians provided informed consent and children provided verbal assent to participate. This study was approved by Northwestern University's Institutional Review Board (#STU00016500). Participants were monetarily compensated for their participation.

Rhythm Testing

The rhythmic battery includes 4 tasks. The first 3 tasks use the same system for stimulus presentation, collection, and analysis of drumming data (for data collection details refer to Tierney and Kraus⁵). For each, a conga drum, with a trigger to register drum hits, was used and practice trials were given. The clapping in time task was performed using the Interactive Metronome technology (for data collection details refer to Bonacina et al²⁶).

Drumming to an Isochronous Beat

Participants are asked to listen and drum to an isochronous pacing beat presented through in-ear headphones. Four trials are presented, 2 at 2.5 Hz (50 beats each) followed by 2 at 1.67 Hz (33 beats each). Each trial consists of a snare drum pacing sound repeated with a constant inter-onset-interval. The consistency of each participant's drumming is averaged across all trials (both inter-onset-intervals) and is calculated using circular statistics (refer to Carr et al²⁵ for complete details about data processing and analyses). Drumming consistency is defined as measure of the synchronicity of the participant's taps averaged across both drumming rates. Throughout the article we will refer to this task as "Drumming to a beat."

Remembering and Repeating Rhythmic Patterns

Participants are asked to listen to 3 repetitions of a rhythmic sequence without drumming and then drum out the sequence during a pause, producing the sequence exactly when it would have occurred had it repeated a fourth time. Ten trials were presented (a mix of strongly and weakly metrical sequences). No earphones are used. The performance of each participant is calculated as percentage correct, which counts the proportion of drum hits and pauses that are correctly remembered within a certain timeframe across an entire condition. Throughout the article we will refer to this task as "Remembering rhythmic patterns."

Drumming to the Beat of Music

This task is an adaptation of the beat-alignment task from Iversen and Patel.²⁸

Participants are asked to listen to a musical excerpt through speakers and are instructed to tap to the perceived beat. Twelve instrumental musical excerpts from a range of genres are used and tap times are collected. Synchronization accuracy is measured as the absolute value in milliseconds of the difference between the average inter-drum interval produced by the participants and the actual beat tempo of each musical excerpt.

Participants may choose different tactus levels with which to synchronize. For example, if an excerpt is in 4/4 time, the participant might tap 4 times in every measure, or twice, on beats 1 and 3. Tapping performance is compared with the tactus level in the excerpt closest to the tapping tempo. Throughout the article we will refer to this task as "Drumming to the beat of music."

Clapping in Time With Visual Feedback

Participants are asked to clap their hands together in a fluid circular motion against a hand trigger in time with a pacing tone delivered over headphones. A visual indicator is shown on a computer screen, reflecting the asynchrony between their last clap and the target beat (milliseconds before or behind the beat). Synchronization is performed at a rate of 0.9 Hz for 1 minute without any practice period. Synchronization variability is calculated as the standard deviation of the asynchronies in milliseconds. Throughout the article we will refer to this task as "Clapping in time."

Table 1 contains an overview of the main measure for each rhythmic task.

Statistical Analysis

The data related to each rhythmic tasks are not normally distributed, even after performing transformations (i.e. log, arcsin, square root, and inverse). This might be the result of young participants having a dispersed distribution of rhythmic skills due to different rates of development at early ages. The main descriptive statistics are reported in Table 1.

To investigate the relationships between rhythmic tasks, performances on the 4 measures of rhythmic skills were correlated using Spearman's ρ correlations controlling for sex and participant's age when the task was performed.

To monitor the change in performance over time, we employed repeated-measures analyses of variance for the 46 children who were assessed for 2 consecutive years. Given the not normal distribution of our data, we also ran Friedman tests to complement the results.

Results

No significant relationship was found between drumming to a beat and remembering rhythmic patterns ($\rho = .116$). Participants who showed less variability in clapping in time were better at drumming to a beat ($\rho = -.417^{**}$), remembering rhythmic patterns ($\rho = -.271^*$), and drumming to a beat of music ($\rho = .398^{**}$).

Children who performed better at drumming to the beat of music were better at both drumming to a beat ($\rho = -.305^*$) and remembering rhythmic patterns ($\rho = -.317^*$).

Figure 1 shows scatterplots comparing performance across all 4 rhythmic tasks with Spearman ρ and P values for each correlation.

Table 1. Overview of Main Measure of Performance for Each Rhythmic Task^a.

Rhythmic Task	Main Measure Description	Direction ^b	First Year of Testing, Mean \pm SD
Drumming to a beat	Consistency: consistency of intertap intervals produced	→	0.609 \pm 0.229
Remembering rhythmic pattern	Percent correct: proportion of notes that are correctly remembered and produced across an entire condition	→	0.587 \pm 0.128
Drumming to the beat of music	Accuracy: the absolute value in milliseconds of the difference between the average inter-drum interval produced by the participants and the actual beat tempo of each musical excerpt	←	34.782 \pm 19.704
Clapping in time	Variability: standard deviation of the asynchronies, in milliseconds	←	180.525 \pm 84.613

^aDescriptive statistics (mean \pm SD) for each rhythmic task performance during the first year of testing are reported.

^bThe arrows indicate the direction of the score. An arrow pointing left indicates that a lower value corresponds to better performance, whereas an arrow pointing right indicates that a higher value reflects better performance.

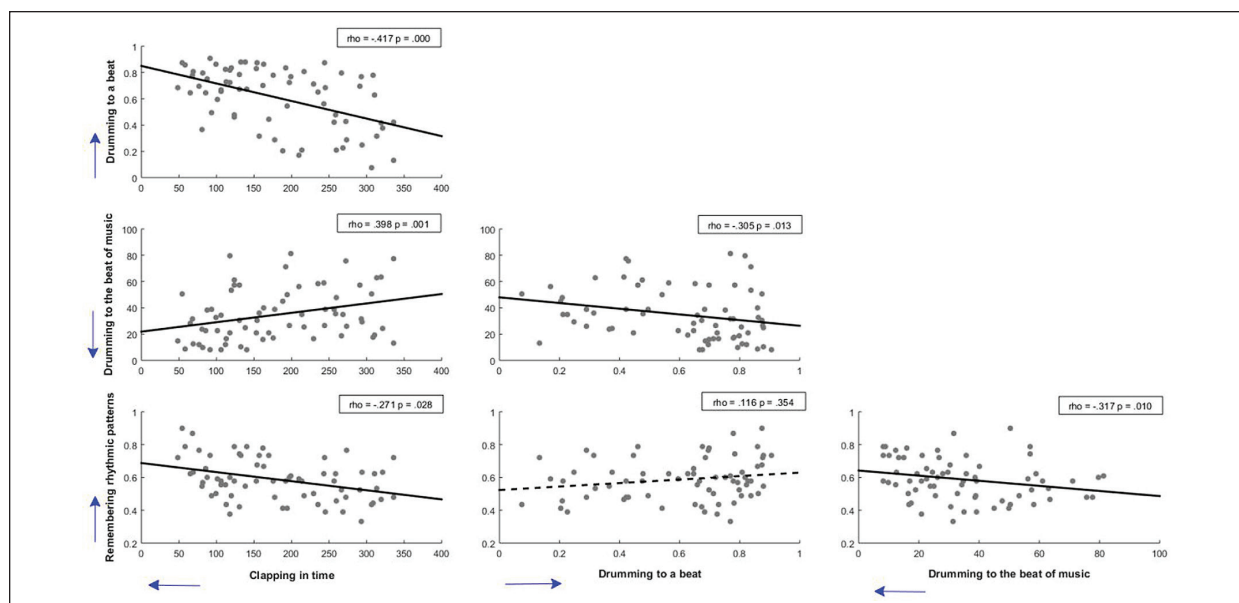


Figure 1. Relationships between rhythmic tasks with Spearman ρ correlation coefficients and P values for each relationship ($df = 62$). The arrow indicates the direction of the score.

The performance on each rhythmic task was compared across 2 consecutive years (Year 1; Year 2) using a repeated measures analysis of variance and percent change calculations. While drumming to a beat of music did not change, the other 3 rhythm skills improved from Year 1 to Year 2 (Table 2 and Figure 2).

Discussion and Conclusion

This study is the first to provide evidence of the interconnections among rhythmic skills in school-age

children. It provides 3 main results. First, performance on a drumming to a beat task is separate from performance on a remembering rhythmic patterns test in this age group. This finding is in line with previous evidence in adolescents⁵ and indicates that these 2 skills follow divergent maturational paths as early as childhood (ie, ages 5-8 years).

Second, despite the above-reported independence between drumming to a beat and remembering rhythmic patterns, both tasks relate to performance on a drumming to the beat of music task. It is also noteworthy that,

Table 2. Repeated-Measures Analysis of Year 1 and Year 2 ($n = 46$)^a.

	Year 1 (Mean; SD)	Year 2 (Mean; SD)	<i>F</i>	Sig	η_p^2	% Y2 - Y1/Y1	χ^2	df	Asymp. Sig.
Drumming to a beat	0.601; 0.236	0.697; 0.191	15.076	.000	0.251	16%	8.696	1	.003
Remembering rhythmic patterns	0.561; 0.124	0.669; 0.138	35.728	.000	0.443	19%	13.091	1	.000
Drumming to the beat of music	33.943; 15.997	34.119; 20.351	0.002	.962	0.000	-0.5%	1.391	1	.238
Clapping in time	184.406; 82.902	147.284; 88.180	11.668	.001	0.206	20%	8.696	1	.003

^aColumn 7 reports % improvement from Year 1 to Year 2 of testing. The last 3 columns report Friedman test results (χ^2 and asymptotic significance level)

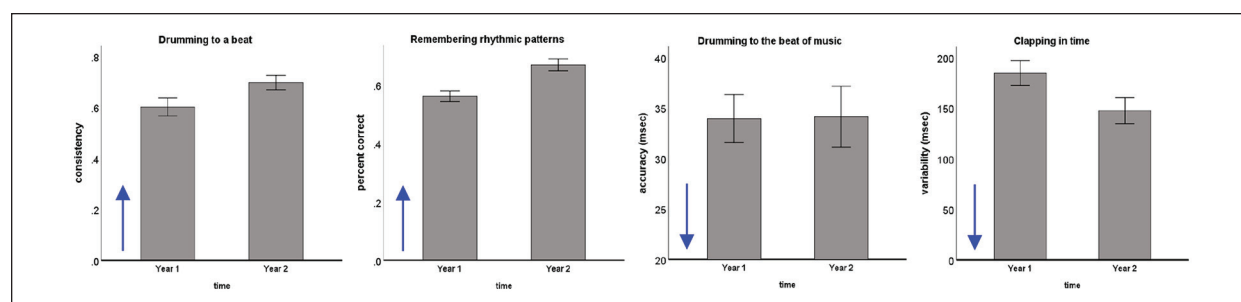


Figure 2. Bar graphs comparing mean performance at each rhythmic task across Year 1 and Year 2. The arrow indicates the direction of better performance for a given measure.

despite these relationships, children did not improve in their performance on the drumming to music task between Years 1 and 2. This could be for several reasons, including the excessive demands of following the structure of real music, along with the development of other sensory and cognitive skills during this age range. Future studies can test drumming to music performance in older children to better understand its developmental trajectory.

Third, performance on the clapping in time task correlates with the other 3 tests considered. These relationships may reveal the complexity of the process that clapping in time with feedback requires. It is also noteworthy that this is the only task requiring the incorporation of feedback. The extensive relationships between this task and other tasks may also underlie the rehabilitative benefit of Interactive Metronome, which uses clapping in time with feedback as an intervention. Several clinical populations exhibit timing deficits that co-occur with to language deficits; for example, individuals with reading impairment often struggle to tap along to an isochronous beat. It is conceivable that clapping in time to feedback could be a viable intervention for populations with distinct rhythmic deficits (such as one group who struggles

to synchronize to a beat and another who struggles to remember rhythmic patterns).

Taken together, our findings suggest a model whereby rhythm starts off early in life as a global skill across different facets of rhythm, subsequently becoming more specialized later in life. Therefore, it would be interesting to explore these relationships with a longitudinal design, using age-appropriate tests in older populations.

While this study contributes to our knowledge of the taxonomy and developmental trajectory of rhythmic skills, it has limitations that call for further investigation. Following the same population for beyond 2 years, from childhood to adulthood, would have been ideal to further understand the taxonomy of rhythmic skills from a broader developmental perspective. Previous work has shown that rhythmic tasks are more specialized in adolescents and adults⁵ than earlier in life.

Figure 3 represents current findings and schematic diagrams of hypothesized relationships for further investigations. Together with the available literature, the present study suggests that rhythmic skill is less differentiated in young children with specialization developing throughout childhood.

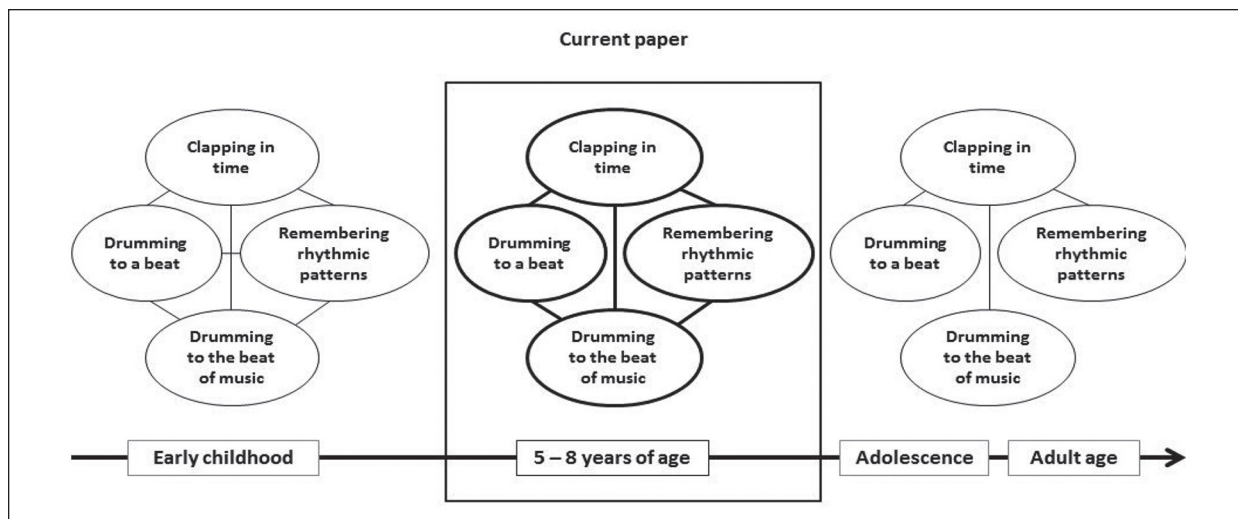


Figure 3. Schematic representation of current findings (in the square box) and hypothesized relationships motivated by the current work for future investigation.

Acknowledgments

We would like to thank the members of the Auditory Neuroscience Laboratory, past and present, for their contributions to this work, and the children and families who participated in this study.

Author Contributions

S.B., J.K., T.W.-S., T.N., and N.K. designed research; S.B. performed research; J.K., T.W.-S., and T.N. contributed analytic techniques; S.B. analyzed data; and S.B., J.K., T.W.-S., T.N., and N.K. wrote the paper.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Supported by the National Institutes of Health (R01 HD069414 and F31 DC016205), the National Science Foundation (BCS 1430400), National Association of Music Merchants, Hunter Family Foundation, Dana Foundation, and the Mathers Foundation. The authors thank Interactive Metronome who graciously donated equipment used in this study. Interactive Metronome had no role in the study design, execution, or interpretation.

ORCID iD

Nina Kraus  <https://orcid.org/0000-0002-0182-8673>

References

1. Thaut MH. *Rhythm, Music, and the Brain: Scientific Foundations and Clinical Applications*. Abingdon, England: Routledge; 2013.
2. Fujii S, Wan CY. The role of rhythm in speech and language rehabilitation: the SEP hypothesis. *Front Hum Neurosci*. 2014;8:777.
3. Miendlarzewska EA, Trost WJ. How musical training affects cognitive development: rhythm, reward and other modulating variables. *Front Neurosci*. 2014;7:279.
4. Moritz C, Yampolsky S, Papadelis G, Thomson J, Wolf M. Links between early rhythm skills, musical training, and phonological awareness. *Read Writ*. 2013;26:739-769.
5. Tierney A, Kraus N. Evidence for multiple rhythmic skills. *PLoS One*. 2015;10:e0136645.
6. Di Pietro M, Laganaro M, Leemann B, Schnider A. Receptive amusia: temporal auditory processing deficit in a professional musician following a left temporo-parietal lesion. *Neuropsychologia*. 2004;42:868-877.
7. Fries W, Swihart AA. Disturbance of rhythm sense following right hemisphere damage. *Neuropsychologia*. 1990;28:1317-1323.
8. Liégeois-Chauvel C, Peretz I, Babai M, Laguitton V, Chauvel P. Contribution of different cortical areas in the temporal lobes to music processing. *Brain*. 1998;121(pt 10):1853-1867.
9. Phillips-Silver J, Toiviainen P, Gosselin N, et al. Born to dance but beat deaf: a new form of congenital amusia. *Neuropsychologia*. 2011;49:961-969.
10. Tallal P, Gaab N. Dynamic auditory processing, musical experience and language development. *Trends Neurosci*. 2006;29:382-390.
11. Tierney AT, Kraus N. The ability to tap to a beat relates to cognitive, linguistic, and perceptual skills. *Brain Lang*. 2013;124:225-231.

12. Bhide A, Power A, Goswami U. A rhythmic musical intervention for poor readers: a comparison of efficacy with a letter-based intervention. *Mind Brain Educ.* 2013;7: 113-123.
13. Bonacina S, Cancer A, Lanzi PL, Lorusso ML, Antonietti A. Improving reading skills in students with dyslexia: the efficacy of a sublexical training with rhythmic background. *Front Psychol.* 2015;6:1510.
14. Bégel V, Di Loreto I, Seilles A, Bella SD. Music games: potential application and considerations for rhythmic training. *Front Hum Neurosci.* 2017;11:273.
15. Repp BH. Sensorimotor synchronization: a review of the tapping literature. *Psychon Bull Rev.* 2005;12:969-992.
16. Corriveau KH, Goswami U. Rhythmic motor entrainment in children with speech and language impairments: tapping to the beat. *Cortex.* 2009;45:119-130.
17. Thomson JM, Goswami U. Rhythmic processing in children with developmental dyslexia: auditory and motor rhythms link to reading and spelling. *J Physiol Paris.* 2008;102:120-129.
18. Grahn JA, Brett M. Rhythm and beat perception in motor areas of the brain. *J Cogn Neurosci.* 2007;19:893-906.
19. Bengtsson SL, Ullen F, Ehrsson HH, et al. Listening to rhythms activates motor and premotor cortices. *Cortex.* 2009;45:62-71.
20. O'Boyle MW, Sanford M. Hemispheric asymmetry in the matching of melodies to rhythm sequences tapped in the right and left palms. *Cortex.* 1988;24:211-221.
21. O'Boyle MW, Bormann L, Harts K. How knowledge of the song influences the matching of "melodies" to rhythm sequences tapped in the right and left palms. *Cortex.* 1990;26:639-642.
22. Trujillo LG. The Effectiveness of Interactive Metronome® as a restorative modality to improve cognition and motor performance in healthy older adults in Eastern North Carolina. *J Neurol Neurosci.* 8(2).
23. Yu GH, Lee JS, Kim SK, Cha TH. Effects of interactive metronome training on upper extremity function, ADL and QOL in stroke patients. *NeuroRehabilitation.* 2017;41:161-168.
24. Shaffer RJ, Jacokes LE, Cassily JF, Greenspan SI, Tuchman RF, Stemmer PJ Jr. Effect of Interactive Metronome® training on children with ADHD. *Am J Occup Ther.* 2001;55:155-162.
25. Carr KW, Fitzroy AB, Tierney A, White-Schwoch T, Kraus N. Incorporation of feedback during beat synchronization is an index of neural maturation and reading skills. *Brain Lang.* 2017;164:43-52.
26. Bonacina S, Krizman J, White-Schwoch T, Kraus N. Clapping in time parallels literacy and calls upon overlapping neural mechanisms in early readers [published online May 12, 2018]. *Ann N Y Acad Sci.* doi:10.1111/nyas.13704
27. D'angiulli A, Herdman A, Stapells D, Hertzman C. Children's event-related potentials of auditory selective attention vary with their socioeconomic status. *Neuropsychology.* 2008;22:293-300.
28. Iversen JR, Patel AD. The Beat Alignment Test (BAT): surveying beat processing abilities in the general population. Miyazaki KI, Hiraga Y, Adachi M, Nakajima Y, Tsuzaki M, eds. Paper presented at: Proceedings of the 10th International Conference on Music Perception and Cognition (ICMPC10); August 25-29, 2008; Sapporo, Japan.