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Distinct Rhythmic Abilities Align With Phonological Awareness And Rapid Naming In School-Age Children

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Abstract

Difficulty performing rhythmic tasks often co-occurs with literacy difficulties. Motivated by evidence showing that people can vary in their performance across different rhythmic tasks, we asked whether two rhythmic skills identified as distinct in school-age children and young adults would reveal similar or different relationships with two literacy skills known to be important for successful reading development. We addressed our question by focusing on fifty-five typically developing children (ages 5–8). Results show that drumming to a beat predicted the variability of rapid naming but not of phonological awareness, whereas tapping rhythmic patterns predicted phonological awareness, but not rapid naming. Our finding suggest that rhythmic interventions can be tailored to address PA and RAN deficits specifically in reading disabled children.

Keywords

rhythm; literacy; beat; patterns; phonological awareness; rapid naming

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Authors contributions

Silvia Bonacina, Jen Krizman, Travis White-Schwoch, Trent Nicol and Nina Kraus designed research; Silvia Bonacina performed research; Jen Krizman, Travis White-Schwoch, Trent Nicol contributed analytic techniques; Silvia Bonacina analyzed data; the first draft of the manuscript was written by Silvia Bonacina and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declaration of interest

The authors declare no competing interests.

Ethics approval

All procedures performed in this study were approved by Northwestern University Institutional Review Board.

Consent

Parents or legal guardians provided informed consent and assent was given by the child prior to participation.

Introduction

Rather than being a global, unitary skill, rhythm is a combination of multiple skills, as people can vary in their performance on different rhythmic tests (Iversen, Patel, & Ohgushi, 2008; Tierney & Kraus, 2015; Di Pietro, Laganaro, Leemann, & Schider, 2004; Fries & Swihart, 1990; Liegeois-Chauvel, Peretz, Babai, Laguitton, & Chauvel, 1998; Phillips-Silver, Toivianen, Gosselin et al., 2011). A recent study extended previous findings to school-age children and documented that the ability to drum along to an isochronous beat dissociates from the ability to remember and repeat rhythmic patterns in early childhood (Bonacina, Krizman, White-Schwoch, Nicol, & Kraus, 2019). Motivated by this discovery and the knowledge that difficulties in performing rhythmic tasks can co-occur with language/reading difficulties, we wanted to investigate the relations between these two rhythmic skills vis-à-vis phonological awareness (PA) and rapid automatized naming (RAN). PA and RAN represent the two constructs most reliably implicated in reading ability (Norton & Wolf, 2012). PA refers to the knowledge of the different sounds of a language and the ability to manipulate them (Kirby, Parilla, & Pfeiffer, 2003; Scarborough & Brady, 2002) whereas RAN refers to the ability to quickly retrieve and produce the sounds associated with a visually presented stimulus (Norton & Wolf, 2012; Scarborough & Brady, 2002). The discussion about their relationships and their existence as truly independent subskills is ongoing, with some studies reporting them as moderately correlated in typically developing school-age children (Swanson et al., 2003; Wagner et al., 1999).

The link between rhythm skills and language skills has been extensively documented in poor readers (Flaugnacco et al., 2014; Corriveau & Goswami, 2009; Thomson & Goswami, 2008). However these studies did not directly compare two dissociated rhythmic tasks with respect to the two most essential scaffolds for reading development, namely PA and RAN. Moreover, these studies focus on impaired populations. Knowing whether PA and RAN similarly or distinctively contribute to distinct rhythmic skills (beat- or patterns- based task) in typically developing children could reveal common mechanisms on which both rhythm and language rely. Such results could inform targeted rhythmic activities to specifically address PA and RAN deficits in reading disabled children.

We pitted two hypotheses against each other: (i) the two rhythmic skills (drumming to an isochronous beat and tapping rhythmic patterns) would relate to both PA and RAN; (ii) each rhythmic skill would only correlate with one literacy skill. In particular we predict that the beat-based task would relate to RAN, whereas the pattern-based task would relate to PA.

Methods:

Participants:

Fifty-five children aged 5 to 7.9 years (mean = 6.37 SD = 0.638, 29 girls) participated in this study. None of the participants had a history of a neurologic condition or diagnosis of autism spectrum disorder, learning disabilities, or attention disorder. Depending on their age, intelligence was assessed by WPPSI III (N=51) or WISC 5 (N= 4) on the Information and Matrix Reasoning subtests. On average, the children's scaled score for the verbal subtest was

12.9 (SD = 3.05; percentile = 76.21) and for the non-verbal subtest was 13.3 (SD = 2.92; percentile = 79.49).

Some of the children (N = 16) were involved in music or dance programs, according to the history form completed by the parents. No differences in rhythmic skills were found between the children who participated in music or dance training and the ones who did not (Drumming to an isochronous beat: $t = -.356$, $p = .723$; Tapping rhythmic patterns: $t = -1.329$, $p = .189$). The absence of any rhythmic skills difference may be due to the fact that the music experiences reported started fairly recently (Mean years of experience = 1.65 SD = 0.7) and occupied the kids for about 2 hours in a week with some variability (Mean hours/week = 1.81, SD = 1.35), presumably not enough systematicity and duration to gain any strong benefit. All procedures were approved by the Northwestern University Institutional Review Board and the children and a parent/guardian gave their informed assent and consent.

Literacy and rhythmic tests:

Phonological Awareness:

Phonological awareness (PA) was assessed using the Elision and Blending Words subtests of the *Comprehensive Test of Phonological Processing*, 2nd edition (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 1999; 2013). The Elision subtest requires children to create a new, real word by removing a phoneme or syllable from an existing word (i.e. *Say "toothbrush" without saying "tooth"*), while the Blending Words subtest requires children to combine syllables or phonemes to make a real word (i.e. *"What do these sounds make? Cow-boy"*). The arithmetic average of the raw scores (number of correct answers) on these subtests was used to calculate PA performance, with a higher number indicating better performance. Raw scores were used for all tests, as age was taken into account in the regression model, and standard scores account for developmental trends.

Rapid Automatized Naming:

Rapid automatized naming (RAN) was assessed using the Rapid Digit Naming and Rapid Letter Naming subtests of the *CTOPP-2*. The composite of these two scores is termed rapid symbolic naming in the *CTOPP-2* manual. The child named four rows of nine numbers (Rapid Digit Naming) or letters (Rapid Letter Naming) out loud as fast as he/she could. The arithmetic average of the time (in seconds) on each subtest was used to calculate RAN performance, with a lower number indicating better performance.

Drumming to an isochronous beat:

Drumming to an isochronous beat (Beat) is a rhythmic task in which the participant is asked to drum with their dominant hand along to an isochronous pacing beat presented through headphones. Four trials were presented consisting of a snare drum pacing sound repeated with a constant inter-onset-interval (IOI). Two trials were presented at 2.5 Hz (50 beats each) followed by two at 1.67 Hz (33 beats each). The consistency of each participant's drumming was averaged across all trials (both IOIs) and was calculated using circular statistics. From each hit on the conga drum by the child, a phase angle θ was calculated based on the difference between the time of the actual hit and the child's hit, which was then divided by

the ISI rate and multiplied by 360 degrees. An average was taken of all the vectors of a given rate to compute a value R which represents how consistently a child was able to maintain the rate of drumming, with a higher number indicating better performance (refer to Woodruff Carr et al. 2014 for details on data processing and analyses). The use of two rates allowed us to assess general synchronization ability rather than the ability to synchronize to a specific rate and eliminated the potential bias of an individual's preferred tempo for isochronous drumming.

Tapping rhythmic patterns:

Tapping rhythmic patterns (Patterns) requires the participant to listen to three 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) via loudspeaker. The performance of each participant was calculated as percentage correct, which counts the proportion of drum hits and pauses that are correctly executed. For each sequence, the analysis determined whether the participant correctly produced either a rest or a drum hit in a 250 msec window centered on the timing of either the expected rest or hit, respectively. The score for each trial, therefore, consisted of the number of correctly performed hits or rests divided by the total number of analyzed segments (refer to Tierney et al. 2017 for details on data processing and analyses). The final score was the average percent correct across the ten trials, with a higher number indicating better performance.

Data analysis

To check whether the distribution for both PA and RAN scores was approximately normal, we performed the Shapiro Wilk test. The test for both PA and RAN is non-significant (PA, $p = .443$; RAN, $p = .160$) therefore their distribution is likely to be normal. We plotted in Figure 1 the histograms of their scores distribution, for both raw scores and percentiles.

To investigate the relationships among the literacy tests and rhythmic tasks, Pearson's correlations controlling for sex and participant's age were run among the four measures. Furthermore, two independent linear regressions were performed to investigate the unique contribution of the two distinct rhythmic measures (Beat and Patterns) to literacy skills, considering phonological awareness (raw scores) and rapid naming (seconds) as the dependent variables. Prior to running these analyses, we employed a reciprocal transformation for the Beat data, using the equation $1/((X_{\text{Highest}} - X_i) + 1)$, where X_{Highest} is the highest score of all subjects, in order to obtain a normal distribution for that measure.

Results

We explored the relationship between each behavioral task and the participant age when the task was performed. PA and RAN, which are highly correlated ($r = -.445^{**}$), relate with Age (PA, $r = .347^{**}$; RAN, $r = -.412^{**}$), revealing that older children perform better at each task, as expected for raw scores in typically developing children (Figure 2). Mean and Standard Deviation (raw and percentile) for each composite score is reported in Table 1.

Consistent with previous reports, there was no correlation between performance on the Beat and Patterns tests ($r = .181$, $p = .195$). Participants who were better at phonological awareness had better performance on Patterns ($r = .465$, $p = .001$), without showing a systematic relationship to Beat performance ($r = .220$, $p = .114$)¹. Participants who were better at rapid naming performed better on Beat ($r = -.349$, $p = .011$) with no association to Patterns performance ($r = -.101$, $p = .470$). Table 2 shows all the correlations explored and Figure 3 shows the scatterplots related to literacy and rhythmic skills relationships.

To explore the contributions of drumming to a beat and tapping out rhythmic patterns in predicting the two literacy skills considered, we ran two separate linear regressions using the raw score of each literacy skill as the dependent variable. Sex, age, matrix reasoning, Beat, and Patterns were considered as independent variables. Only Patterns predicted subjects' phonological awareness performance. In contrast, only Beat predicted subjects' rapid naming performance. Table 3 shows full regression results.

Discussion

This study reinforces the idea of rhythm as a multidimensional skill set. Here we supported this finding in a cohort of school-age children, and we also showed that two rhythmic skills relate distinctively to PA and RAN. Specifically, we showed that drumming to a beat predicted the variability of RAN, but not of PA, whereas tapping rhythmic patterns predicted PA, but not RAN. The rhythmic-pattern task considered in our study requires the ability to retain and integrate temporal information about the relationship among sounds which engages the ability to attend to, think about, and manipulate sounds within words, all foundational processes of PA. Drumming to an isochronous beat, instead, requires the ability to temporally coordinate an action with a predictable external event; it is evocative of the pace and the processes involved in linking and producing a spoken word related to a visually presented stimulus, which underlies RAN. Our finding supplements previous results showing the absence of relationship between literacy skills (PA/RAN) and rhythmic skills (drumming to a beat/tapping rhythmic patterns) in young adults (Tierney et al., 2017). In particular, our results are consistent with the idea that these associations may change with age and may manifest themselves only in young children who are still in the process of learning and refining their reading ability.

While further investigation is necessary to understand how these links may differ in reading impaired populations and across languages, our findings can be promising in informing music-based interventions for the different reader profiles identified in the literature (i) children with no deficit in either PA or RAN, (ii) children with a deficit in PA only, (iii) children with a deficit in RAN only, and (iv) children with deficits in both PA and RAN (Wolf & Bowers 1999). Specifically, the distinctive predictive roles of drumming to the beat and tapping rhythmic patterns for RAN and PA raise the possibility of tailoring specific

¹The trending behavior between PA and beat performance is entirely driven by the two observations in the lower left corner of the top left scatterplot in figure 3. If we were to exclude those two points, then we will get $r = .077$, $p = .592$. Conversely, removing those two subjects with poor PA scores leaves the PA / Rhythm Pattern finding nearly unaffected: $r = .410$, $p = .003$. We take this as evidence supporting our claim that the relationship between PA and Beat performance is not robust, while the PA and Rhythm Pattern performance is.

rhythmic activities as part of a broader music intervention when dealing with children with a PA deficit only, or RAN deficit only (Politimou, Dalla Bella, Farrugia, & Franco, 2019). Increasing evidence shows how rhythm scaffolds the development of language and communication skills. As early as infancy, rhythmic information in speech provides primary cues to discriminate between languages (Nazzi, Bertoncini, and Mehler, 1998) and to identify phonemes (Eimas, Siqueland, Jusczyk, & Vigorito, 1971). Accentuating stress and rhythmic patterns is the most common and natural strategy used by parents and teachers to teach language to children, and it is what inspires many interventions for speech and language delays (Goswami, 2002; Schneider, Roth, & Ennemoser, 2000). While music training in general is thought to foster language development, it is the rhythmic components of music that have been highlighted as particularly effective (Tallal, 2004; Goswami, 2011).

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Figure 1. Distribution of PA and RAN performances. Top row displays histogram for raw scores, bottom row displays percentile.

Figure 2.

PA (in grey) and RAN (in black) performances on y-axis plotted against participants' age x-axis. Lines of best fit are plotted. As for PA higher score means better, as for RAN lower score means better.

Figure 3.

Drumming to a beat performance (first row) and Tapping to rhythmic patterns (second row) plotted against Phonological Awareness (first column) and Rapid Naming (second column). Lines of best fit are plotted. A black line indicates statistical significance ($p < .05$) while a gray line indicates no statistical significance ($p > .05$).

Table 1.

Mean and standard deviation for Phonological Awareness and Rapid Naming (raw scores and percentile)

	Phonological Awareness (Elision, Blending)	Rapid Naming (Digit, Letter)
Mean, Standard Deviation (raw scores)	20.482; 4.48	29.57; 9.31
Mean, Standard Deviation (percentile)	69.86; 19.35	62.12; 18.81

Table 2.

Results of Pearson's partial correlations controlling for Sex and Age

	Phonological Awareness	Rapid Naming	Drumming to a beat	Tapping rhythmic patterns
Phonological Awareness	1.000			
Rapid Naming	-.445 **	1.000		
Drumming to a beat	.220	-.349 *	1.000	
Tapping rhythmic patterns	.465 **	-.101	.181	1.000

*
p < 0.05**
p < 0.01

Table 3.

Results of linear regression

Predictors	Phonological Awareness β	Rapid Naming β
Drumming to a beat	.148	-.337 *
Tapping rhythmic patterns	.416 **	-.027
Sex, Age, Matrix reasoning	✓	✓
R^2	.339	.284

*
p < 0.05**
p < 0.01