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SHORT COMMUNICATION

Distinct rhythmic abilities align with phonological awareness and rapid naming in school-age children

Silvia Bonacina[1,2] · Jennifer Krizman[1,2] · Travis White-Schwoch[1,2] · Trent Nicol[1,2] · Nina Kraus[1,2,3]

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Abstract

Difficulty in 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 55 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 suggests 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

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 et al. 2008; Tierney and Kraus 2015; Di Pietro et al. 2004; Fries and Swihart 1990; Liégeois-Chauvel et al. 1998; Phillips-Silver et al. 2011). A recent study extended previous findings to school-age children and documented that the ability to drum along with an isochronous beat dissociates from the ability to remember and repeat rhythmic patterns in early childhood (Bonacina et al. 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 and Wolf 2012). PA refers to the knowledge of the different sounds of a language and the ability to manipulate them (Kirby et al. 2003; Scarborough and Brady 2002), whereas RAN refers to the ability to quickly retrieve and produce the sounds associated with a visually presented stimulus (Norton and Wolf 2012; Scarborough and 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 and Goswami 2009; Thomson and 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

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✉ Nina Kraus
nkraus@northwestern.edu

[1] Auditory Neuroscience Laboratory, Northwestern University, 2240 Campus Drive, Evanston, IL 60208, USA

[2] Department of Communication Sciences and Disorders, Northwestern University, Evanston, IL, USA

[3] Department of Neurobiology, Northwestern University, 2240 Campus Drive, Evanston, IL 60208, USA

rhythmic activities to specifically address PA and RAN deficits in reading disabled children.

We pitted two hypotheses against each other: (1) The two rhythmic skills (drumming to an isochronous beat and tapping rhythmic patterns) would relate to both PA and RAN; (2) 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 5–7.9 years (mean = 6.37 SD = .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 nonverbal 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 = .7) and occupied the kids for about 2 h 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*, second edition (CTOPP-2; Wagner et al. 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 with 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

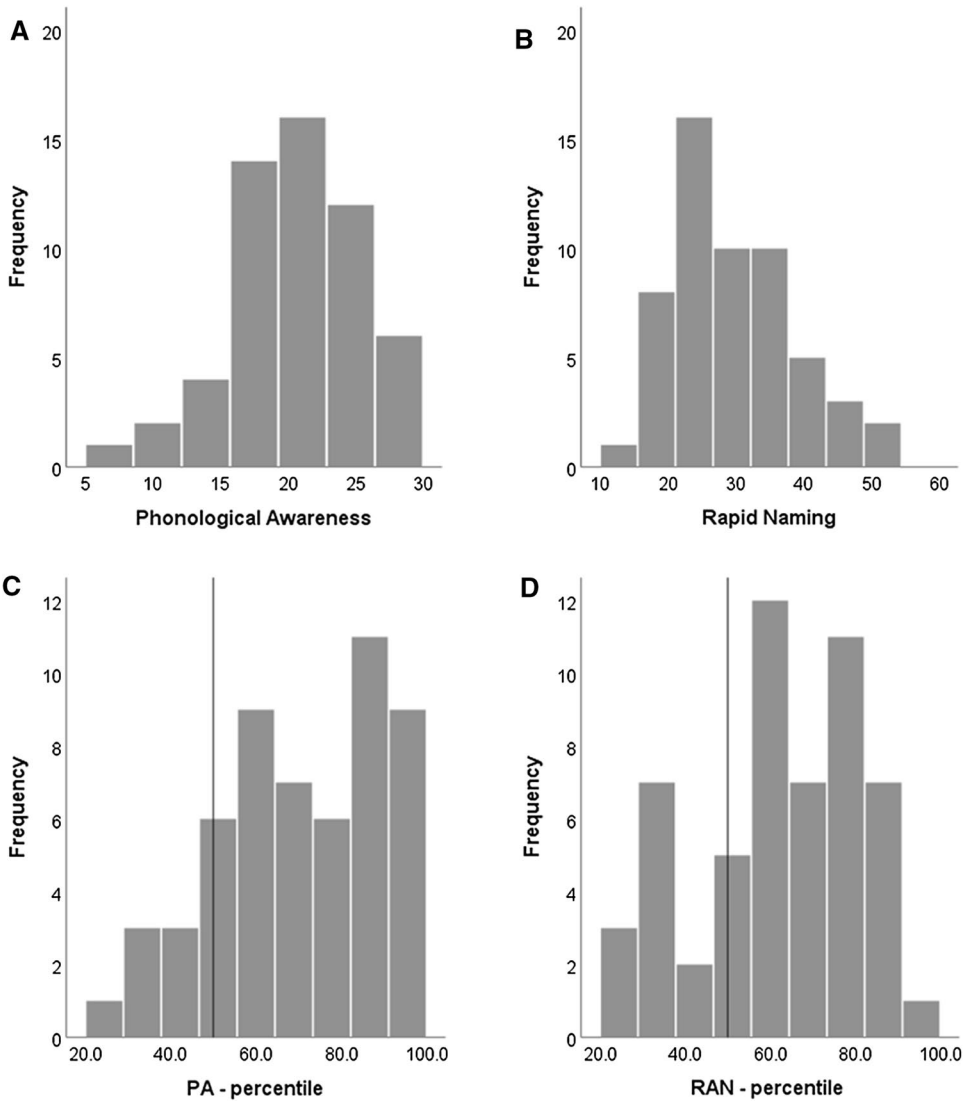

Fig. 1 Distribution of PA and RAN performances. Top row displays histogram for raw scores; bottom row displays percentile

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-ms 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 plot in Fig. 1 the histograms of their scores distribution, for both raw scores and percentiles.

To investigate the relationships between 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 $1/((X_{\text{Highest}} - X_{\text{i}}) + 1)$, where X_{Highest} is the highest score of all subjects, in order to obtain a normal distribution for that measure.

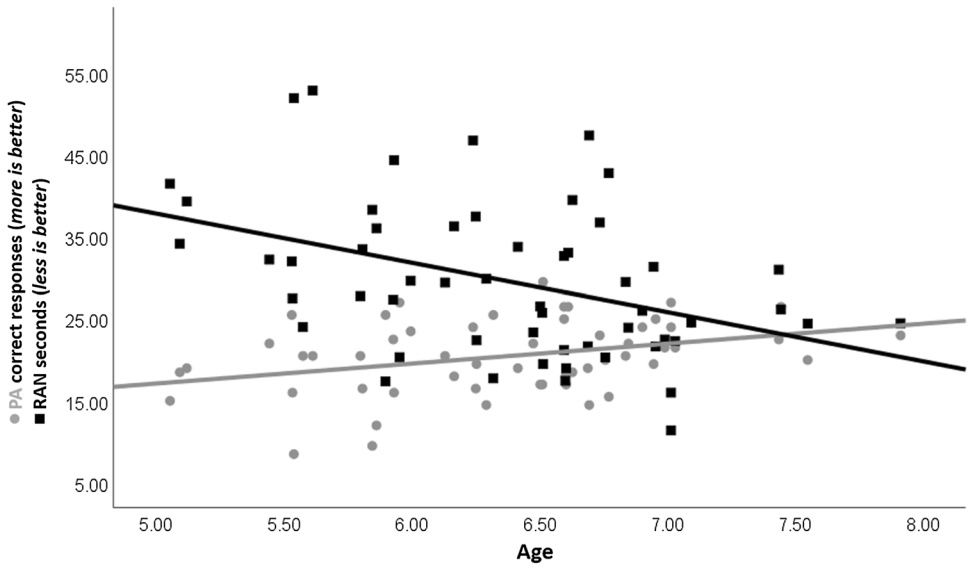

Fig. 2 PA (in gray) and RAN (in black) performances on *y*-axis plotted against participants' age *x*-axis. Lines of best fit are plotted. PA performance with higher score means better performance; RAN performance with lower score means better performance

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

and standard deviation (raw and percentile) for each composite score are 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 ($r = .465$, $p \leq .001$), 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

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

*$p < .05$

**$p < .01$

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 (Fig. 2). Mean

[1] The 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 Fig. 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.

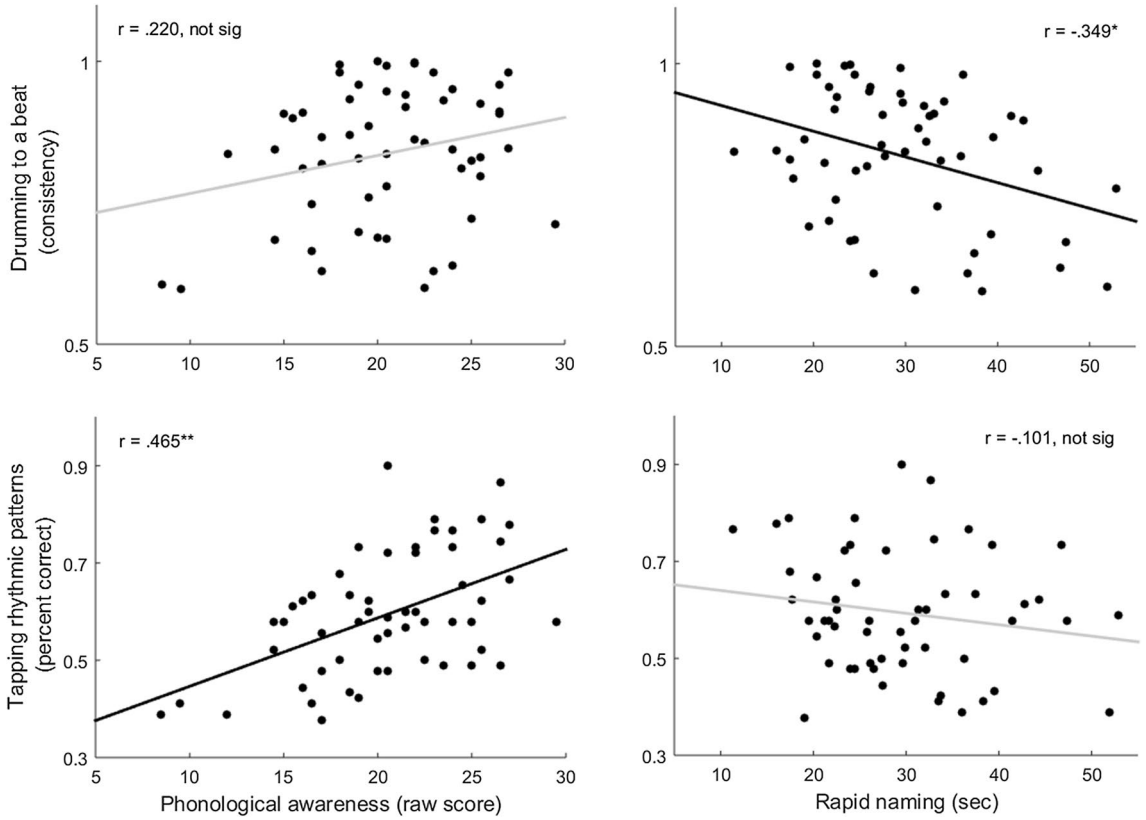

Fig. 3 Drumming to a beat performance (first row) and tapping to rhythmic patterns (second row) plotted against phonological awareness (first column) and rapid naming (second column). Lines of best fit are plotted. A black line indicates statistical significance ($p < .05$), while a gray line indicates no statistical significance ($p > .05$)

the correlations explored, and Fig. 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)

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

*$p < .05$

**$p < .01$

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 (1) children with no deficit in either PA or RAN, (2) children with a deficit in PA only, (3) children with a deficit in RAN only, and (4) children with deficits in both PA and RAN (Wolf and 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 rhythmic activities as part of a broader music intervention when dealing with children with a PA deficit only, or RAN deficit only (Politimou et al. 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 et al. 1998) and to identify phonemes (Eimas et al. 1971). Accentuating stress and rhythmic patterns are 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 et al. 2002; Schneider et al. 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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Authors' contributions SB, JK, TW-S, TN, and NK designed research; SB performed research; JK, TW-S, and TN contributed analytic techniques; SB analyzed data; the first draft of the manuscript was written by SB; and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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

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

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