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Links between early rhythm skills, musical training, and phonological awareness

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Abstract A small number of studies show that music training is associated with improvements in reading or in its component skills. A central question underlying this present research is whether musical activity can enhance the acquisition of reading skill, potentially before formal reading instruction begins. We explored two dimensions of this question: an investigation of links between kindergartners' music rhythm skills and their phonological awareness in kindergarten and second grade; and an investigation of whether kindergartners who receive intensive musical training demonstrate more phonological skills than kindergartners who receive less. Results indicated that rhythm skill was related to phonological segmentation skill at the beginning of kindergarten, and that children who received more music training during kindergarten showed improvement in a wider range of phonological awareness skills at the end of kindergarten than children with less training. Further, kindergartners' rhythm ability was strongly related to their phonological awareness

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and basic word identification skills in second grade. We argue that rhythm sensitivity is a pre-cursor skill to oral language acquisition, and that the ability to perceive and manipulate time intervals in sound streams may link performance of rhythm and phonological tasks.

Keywords Music · Reading · Rhythm · Phonological awareness · Timing

Introduction

In the development of most academic skills, it is generally assumed that the earlier the better (e.g., Jordan, Grall, Deutsch, & Deutsch, 1985). Reading is among the most important and complex academic skills to be acquired by young learners, and formal reading instruction around the world usually begins in first grade. In recent years, however, many American educators and researchers have looked for ways to use the kindergarten and pre-reading years to better prepare children for the demanding cognitive and linguistic requirements of reading acquisition. Most efforts in pre-school focus on building skills that are directly connected to reading acquisition such as vocabulary, letter, and print knowledge. And, indeed, there exists increasing pressure on many school officials to teach reading precursors early and with more intensity (Elkind, 2010) which could change the dynamics of many early childhood approaches to learning and development. Educators and researchers are exploring whether other developmentally-appropriate, non-academic activities can also bolster a child's reading acquisition skills (e.g., Dana Foundation, 2008).

Claims have been made that musical activity can enhance acquisition of reading skill, even before formal reading instruction begins (e.g., Fisher & McDonald, 2001). However, there have been very few research studies to investigate these claims. In the studies to be reported here, we sought to explore specifically how music and reading acquisition could be connected in pre-readers. Because of overlapping characteristics with regard to timing and segmentation of sound streams, we hypothesized that one way in which music and reading acquisition are connected is through links between rhythm ability and phonological awareness, a central and critical underlying skill for reading acquisition. Working with experimental and control groups of kindergartners, we further investigated whether greater amounts of musical activity with an emphasis on rhythm would be reflected in enhancement of phonological awareness. To lay the groundwork for future investigation of long-term connections between early musical activity and later reading, we also explored whether there are links between kindergarten rhythm ability and second grade phonological skills.

Interest in understanding connections between music and reading has been spurred by a small number of studies showing that music training is associated with improvements in reading or in the underlying component skills of reading (Fisher, 2001; Hurwitz, Wolff, Bortnick, & Kokas, 1975). Associations between music and reading are important because they suggest the possibility that music—an inherently engaging activity for children—might bolster reading acquisition or even be used to help remediate reading disability (Overy, 2003). The *engaging* quality of musical activity makes these possibilities doubly exciting because we know that *engagement* facilitates learning (Wolf, Miller, & Donnelly, 2000).

How could music and reading be associated? Much of the earliest research into this question made broad comparisons: for example, of the SAT verbal achievement scores of high schoolers who had taken at least one music course in high school and those who had not. From a meta-analysis of 24 such studies from 1959 to 1992, Butzlaff (2000) reported that "there is indeed a strong and reliable association between the study of music and performance on standardized reading/verbal tests" (p. 172). He pointed out, however, that the studies' correlational results cannot explain what underlies these associations. The music and reading domains both involve large arrays of component skills. To determine what underlies associations between these complex domains, systematic and developmental investigations of connections between each of the explicit component skills of musical activity and the component skills involved in reading are needed.

The complexity of reading is well-established. To read an alphabetic language, a reader must have a variety of component skills in phonological awareness (defined below), semantics (word meanings, vocabulary), syntax (word order, grammar), morphology (meaning-bearing parts of words, such as *ed* and *ing*), letter and spelling pattern knowledge (orthography), and many other skills (Wolf, 2007).

The first of these—phonological awareness—is an essential oral language skill that is the most studied underlying component skill of reading (Bradley & Bryant, 1978; Brady, 1986; Fletcher et al., 1994; Liberman & Shankweiler, 1979; Torgesen et al., 2001; Wagner & Torgesen, 1987). Phonological awareness (PA) is the ability to segment the flow of speech over time into words, syllables, and phonemes (the individual sounds within words, such as /k/, /a/, and /t/ in the word *cat*), to blend phonemes (e.g., blend /k/, /a/, and /t/ into *cat*), and to manipulate segmented speech sounds (e.g., say *cat* without saying /k/ to produce *at*). PA is necessary for reading words, and new readers must learn to map symbols on the page to the segmented sounds of their language in order to *decode* words. For example, a young child must be able to *sound out* the oral language sounds /k/, /a/, and /t/ sequentially from the written symbols *c*, *a*, and *t*, and then blend the sounds to form the word *cat* by reducing the time intervals between the individual phonemes he or she has articulated.

In the typical trajectory of PA skill development, children begin by being able to segment spoken sentences into words, and then over time develop the ability to segment words into syllables. Later they are able to segment syllables or one-syllable words into their initial phoneme (the *onset*) and the balance of the syllable (the *rime*). Finally, children develop the ability to segment words and syllables into individual phonemes (Goswami, 2002)—the advanced PA skill that they will need to make the correspondences between symbols in print and phonemes of speech. Thirty years of research shows that systematic instruction in PA skills greatly contributes to reading acquisition (see reviews in National Reading Panel, 2000).

In addition to many of the more well-studied PA component skills, such as phoneme perception, PA tasks also involve aspects of *temporal* processing that become exaggerated and more visible in the systematic instruction and testing of PA. In phonological segmentation tasks, the child is asked to insert elongated time intervals between words, syllables, or phonemes that are normally articulated more rapidly and more closely together in the flow of speech. For example, a child may be asked to clap out the syllables in the word *kindergarten*. To perform this task, she brings her hands together and says the first syllable *kin* as her hands meet. Then, as she draws her hands apart, she inserts an elongated time interval between *kin* and the next syllable *der* which she says when she brings her hands together again, and so on. In PA activities that require manipulation of sounds by blending them together, the child is presented with speech sounds separated by elongated time intervals, such as /Sa/…/tur/…/day/. When asked what word these sounds make, the child reduces the time intervals between the sounds and blends them into the word *Saturday*. Many PA tasks involve similar sound segmentation through insertion or reduction of time intervals between sounds that are blended together in oral language.

Could PA, this essential underlying component skill of reading, particularly in the reading acquisition years, be connected to music, and if so, to which components of music? Like reading, musical behavior is complex and made up of numerous underlying components. Many of these components can be divided into the two key domains of frequency (pitch, melody, harmony) and time (rhythm, meter, pulse); which are then organized in systematic ways that tend to vary across cultures, styles, and historical periods. In Western music, some of the temporal aspects of music include the *beat* (the underlying steady pulse of the piece), *tempo* (the speed of the beat), *meter* (regular groupings of a small number of strongly and weakly stressed beats, such as the waltz meter's *Xxx* pattern of three beats), and *rhythm pattern*, a term we use to describe the pattern of time intervals between the attack points of successive notes or sounds (such as drum taps), usually varying throughout the piece. We chose to focus our exploratory research on connections between two component skills: rhythm pattern and PA. As with PA tasks that require perception and manipulation of time intervals between speech sounds, many musical rhythm activities and tests of children's rhythm ability also involve perception and manipulation of time intervals between musical (non-speech) sounds. Therefore, children's ability in both types of tasks may be connected.

How early might connections between rhythm and PA begin? Research shows that sensitivity to the *temporal qualities* of both music and oral language begins in infancy. There is evidence that young infants are sensitive to musical rhythm and can perceive differences in rhythmic patterns (Chang & Trehub, 1977; Demany, McKenzie, & Vurpillot, 1977). Baruch and Drake (1997) reported that 2-month-old infants could detect small changes in tempo in steady rhythms with equal intervals between the sounds. Pouthas (1996) noted that infants can control the temporal intervals of non-nutritive sucking activity, and modify the periodicity of this sucking to obtain desired outcomes. Other researchers found that infants 7–9 months of age can detect changes in rhythmic combinations, such as, 2–1 (*XX*…*X*) versus 1–2 (*X*…*XX*) patterns (Trehub & Thorpe, 1989).

With regard to language, one of the earliest cues infants use to access the phonological information in the speech stream is the perceived rhythm of the language. Newborn infants are able to discriminate languages on the basis of their rhythmic properties (Mehler & Christophe, 1995; Mehler, Jusczyk, Lambertz, &

Halsted, 1988; Nazzi, Bertoncini, & Mehler, 1998). For example, between 1 and 4 months, infants can detect changes in rhythmic patterns of strong and weak syllables (Jusczyk & Thompson, 1978). By 9 months, English infants demonstrate a listening bias for the predominant strong–weak syllable, trochaic rhythm of English (Jusczyk, Cutler, & Redanz, 1993). There is also evidence that these patterns of syllable stress are an integral part of phonological information that is stored by infants learning a language (Curtin, Mintz, & Christiansen, 2005). Stress patterns can also be used to determine where words begin (Cutler & Norris, 1988). For example, learners of English can use the stress rhythm to segment speech into words by assuming that strong syllables are word-initial (Cutler & Otake, 1994). Because rhythm cues are used by infants to discern words and syllable segments in the flow of speech, it is reasonable to assume that rhythm sensitivity is a pre-cursor skill for learning language and developing the PA skills children need for reading acquisition. Further, Wood, Wade-Woolley, and Holliman (2009) review converging findings that connections between rhythm sensitivity and reading are mediated by connections between rhythm and PA.

Reflecting the contribution of PA to reading, problems with PA have been found in 73 % of children with severe reading disability (Morris et al., 2010). If rhythm sensitivity (that is, sensitivity to temporal qualities in sound streams) is a pre-cursor skill to the development of PA, then it is not surprising that temporal processing difficulties are also associated with problems in reading. Studies have found that reading-disabled children have problems with auditory temporal sensitivity (Witton et al., 1998) and detection of complex timing patterns (Kujala et al., 2000). Wolff (2002) reported that 10- to 16-year-old children with reading disability had distinct deficits in copying rhythm patterns compared to typical readers. Reading-disabled children's difficulties with both PA and temporal processing further suggest a possible connection between phonological and rhythm skills.

A small number of prior research studies of children aged 4–8 demonstrated associations between components of music rhythm and PA in oral language contexts. Anvari, Trainor, Woodside, and Levy (2002) tested the ability of 4- and 5-year-old children to copy a rhythm pattern (*rhythm pattern copying*) and tell whether two rhythm patterns were the same or different (*rhythm pattern discrimination*). These rhythm scores correlated significantly to a PA composite score which included rhyme generation and other phonological tasks including sound oddity; blending onsets and rimes to form words; and segmenting, deleting, and recombining syllables and phonemes in words. David, Wade-Woolley, Kirby, and Smithrim (2007) found that first graders' ability to perform beat production tasks (e.g., tap along with the beat of musical pieces at different tempos) was significantly correlated to a composite measure of their PA including four tasks: sound oddity; blending phonemes; blending onset and rimes; and phoneme elision (deleting a phoneme from various parts of a word to make a new word). Holliman, Wood, and Sheehy (2010) found that the rhythm pattern copying and discrimination skills of 6- and 7-year-old children were correlated to their ability to identify rhyming words and perform phoneme deletion tasks. Montague (2002) found significant correlations between both rhythm pattern copying and discrimination and phoneme elision and blending in second and third graders. Most of these studies, with the exception of Holliman et al., used observation by examiners (*human-rater scoring*) to judge the accuracy of the children's rhythm pattern copying performance. Holliman et al. (2010) used a modified automated approach in which simple scores of *correct* or *not correct* were based on a designated level of accuracy. Our current research improved on prior research into links between PA and rhythm skills in oral contexts by using both human-rater scoring and an automated system for rhythm pattern copying performance which produced a score based on precise measurement of deviations in the child's response intervals from the stimuli intervals. Each type of scoring has its strengths and weaknesses: automated scoring is more accurate on measurement of time intervals between sounds, but human raters are better when judgment calls are needed about a child's responses (see "Method: data scoring procedures" for further explanation).

The studies summarized above focused on relationships between rhythm and PA in oral contexts, but when reading begins, children must also be able to apply their PA skills in print contexts. Prior research on 7- to 11-year-olds has found associations between rhythm skills and PA skills in decoding of written words and non-words and in spelling. In second and third graders, Montague (2002) found that both rhythm pattern copying and discrimination were significantly correlated to phonemic decoding efficiency, word reading efficiency, and spelling. She also found that rhythm pattern copying was associated with word attack and word identification, and that tempo copying (continuing at the same tempo after a steady-tempo stimulus ends) was significantly correlated with word reading efficiency. Douglas and Willats (1994) found that rhythm pattern discrimination was significantly correlated to word recognition in fourth graders. Overy, Nicholson, Fawcett, and Clarke (2003) found that rhythm pattern copying was associated with phonological segmentation and spelling ability in 7- to 11-year-olds. These prior studies tested associations of skills during limited time windows in the children's development. Our research expanded upon these earlier studies by increasing the time period of investigation for links between skills: We explored whether children's rhythm skills in kindergarten were associated with their PA skills in both oral and written contexts in second grade.

Why is identification of connections between music and reading skills important? Many have claimed that musical activity can *improve* reading and/or academic performance (e.g., Diamantes, Young, & McBee, 2002; Fisher & McDonald, 2001). Patel (2011) presented a hypothesis (*OPERA*) that musical training benefits speech processing through *overlap* in the brain networks that process music and speech acoustics, *precision* in that music places higher demands on precise performance than speech, *emotion* because musical activity elicits strong positive feelings, musical *repetition* that reinforces engagement of the shared networks, and *attention* because music demands focused attention. Because speech processing is central to reading, Patel suggests that we "put OPERA to work" to support linguistic reading skills through music training (Page 9). However, only a few studies with control groups have tested links between musical activities and improved reading or underlying skills of reading. Moreno et al. (2011) found that 20 days of music training, but not visual art training, using interactive computer software was associated with improvements in vocabulary in 4- to 6-year-olds. Degé and Schwarzer (2011) reported that the kindergartners who had received 100 daily music lessons had the same improvements in awareness of large phonological units as kindergartners receiving lessons in phonological skills. The study suggested that music activity could provide the same benefits as phonological training. Hurwitz et al. (1975) tested two first grade classes (one experimental and one control) in neighboring schools for pre- and post-program achievement in reading performance as measured by standard reading readiness tests. The experimental group received an intensive musical training program and significant positive differences in reading readiness performance were found. Fisher (2001) performed a 2-year study of children from kindergarten to first grade in four classrooms, two of which had daily musical lessons and music woven extensively into their curricula. In year-end testing, music had a positive effect on the phonemic segmentation ability and reading comprehension of the children in the music-intensive classrooms. Moreno et al. (2009) found that twice-weekly musical lessons, but not painting lessons, over a 6-month period was associated with enhanced word reading in 8-year-old children. Costa-Giomi (1997) reported that 2 years of piano instruction significantly improved verbal abilities, broadly defined, of 10- to 11-year-olds compared with controls. However, in 2004, Costa-Giomi reported on a 3-year study of fourth-grade children in which one group was given weekly piano lessons. The latter study found no effects on language achievement as measured by standardized academic achievement tests and school report cards.

Only one prior study looked explicitly at whether musical lessons with an emphasis on rhythm activity can improve PA and literacy skills. Overy (2003) conducted a small study with nine boys with reading disability, aged 7–11, who received rhythm-intensive group music lessons over a 15-week period. The children showed significantly greater improvements in phonological segmentation and spelling skills during the intervention period than during a previous 15-week control period in which the instructor visited the children in the classroom and listened to them read individually. This earlier research on connections between music activity and improvements in reading or its underlying skills focused predominantly on children of reading age. Our research explored whether intensive musical activity throughout the kindergarten (pre-reading) year was associated with improvements in PA.

Research questions

We performed exploratory research into whether PA and music rhythm skills are linked in young children, and whether musical activity is associated with improvements in PA, by performing two studies.

Research questions in Study 1 included:

(1) Are phonological awareness and rhythm ability related in 5-year-olds?
(2) Will kindergartners who receive more music training have better phonological awareness at the end of the year than kindergartners who receive less music training?

We hypothesized that a link between PA and rhythm skills would be found, and that the efficacy of music training in the development of PA would be demonstrated.

The research question for Study 2 was:

(1) Is rhythm ability at the beginning of kindergarten associated with phonological awareness in second grade?

We hypothesized that rhythm ability facilitates the development of PA over time, and therefore, kindergartners' rhythm ability would be associated with their level of PA in second grade.

Method

Study 1

Sample

The sample for Study 1 included two groups of kindergartners from Boston-area schools: 15 from a charter school class (the *experimental group* school) that provided daily 45-min music lessons, and 15 from two kindergarten classes at a public school (the *control group* school) that provided one 35-min music lesson per week.

With parental consent, all kindergartners at the two study sites were included if they (1) were 5 years of age or older at the start of the study; (2) had not repeated kindergarten; (3) had no relevant diagnosed physical or emotional impairments, as reported by their parents; and (4) had scores that were higher than two standard deviations below the national mean on the Peabody Picture Vocabulary Test IIIa (PPVT, Dunn & Dunn, 1997) and the Kaufman Brief Intelligence Test (K-BIT, Kaufman & Kaufman, 1990). No children whose parents had given consent to participate met any of the exclusionary criteria.

The experimental group children ranged in age from 5 years 0 months to 5 years 11 months (mean age 5.6 years) at the beginning of the study. The control group children ranged in age from 5 years 2 months to 5 years 11 months (mean age 5.6). See Table 1 for descriptive data of the sample.

Table 1 Study 1: participant (kindergartners) characteristics by group

Variable	Experimental group ($N = 15$)	Control group ($N = 15$)
Music lessons		
Frequency	Daily	Weekly
Duration	45 min	35 min
Age at fall testing—range (*M*)	5 years 0 months–5 years 11 months (5.6)	5 years 2 months–5 years 11 months (5.6)
Gender		
Boys	9	8
Girls	6	7

Parents were requested to complete a questionnaire providing information about their child's home literacy and music environment; and the parents' educational level as an indicator of socio-economic status (SES). Each school provided information on the percent of the participants who qualified for the Federal government's free or reduced-cost lunch program, as a surrogate income measure of SES.

Information on statistical comparisons of the children's characteristics appears in the "Results" section.

Literacy and music programs at the experimental and control groups' schools

A comparison of the two schools' Language Arts curricula found that the purpose of both schools' curricula was to expose each child to literacy instruction by addressing fundamental emergent reading skills as well as emergent writing skills, including: fundamental concepts about print, emergent reading and writing skills, literacy experiences (e.g., identification of main ideas and details, story mapping, and identification of different genres), and speaking and listening skills. Total time spent on each concept and topic within that concept (e.g., phonological and phonemic awareness, decoding, sight word and high frequency word reading, and spelling, etc.) was similar in both schools. Both schools employed flexible groupings, Big Book literacy activities, Writer's Workshop, Reading Buddies, and Story Time. Three main differences were noted between the schools. First, the experimental group's teacher appeared to focus on each literacy topic in separate lessons, whereas the control group's teachers appeared to integrate various topics into the same lesson. Second, musical activities were integrated more often into experimental group school's literacy practices, in accordance with the school's overall mission to integrate music into other curricula. Thirdly, the control school had an organized home reading program while the experimental school did not. The program included motivational discussions with the parents, weekly home reading record forms, books for low SES children, in-classroom compliance tracking, and discussions with children about books read at home. Parents' program compliance was about 65 % overall although no formal data was kept.

At the experimental group's school, a trained Kodály instructor taught daily music lessons, following a kindergarten curriculum designed by Kodály scholar Jonathan C. Rappaport, M.M. (the school's principal) and Katherine H. Athanasiou (the school's music director) based on the theories of Zoltán Kodály (see Kodály, 1974; Szönyi, 1973). The Kodály method/curriculum is characterized by: student performance of folk songs, rhymes, and singing-game songs from which basic rhythm and melodic units are abstracted; structured listening experiences involving movement; an initial emphasis on beat development; motor rhythm training with significant emphasis on rhythmical patterns; use of rhythmic entities to create new rhythmic combinations; and a sequential approach to teaching singing. The Kodály kindergarten goals include: development of rhythm skills including movement response to divisions of beat and meter and performance of rhythm patterns; concepts such as same/different, fast/slow, loud/soft, high/low; and singing with accurate pitch, vocal placement, intonation, rhythm, and steady tempo.

At the control school, a trained music teacher taught using the Silver-Burdett Making Music Kindergarten Teacher Edition textbook (Beethoven et al., 2005). The Silver-Burdett approach employs a variety of musical instruction techniques and both popular and culturally-diverse music, and involves singing along with recorded music, musical movement, and learning about instruments. Kindergarten goals include developing the abilities to respond to divisions of beat and identify tempo changes; performing simple rhythm patterns, moving to music, dramatizing musical impressions; and understanding concepts of same/different, fast/slow, loud/soft, and high/low. It also emphasizes listening, improvising and composing skills; and singing with accurate pitch, intonation, rhythm, and steady tempo.

A typical music class lesson in the middle of the year was observed at each school. Although the lessons were taught in different pedagogical ways with a greater sense of energy and engagement and with higher expectations and more monitoring of the quality of the children's performance at the experimental group's school, both schools' lessons included singing and listening as key elements. Key differences were that the control group's singing was done along with recordings, whereas experimental group children sang *a cappella*. The experimental group was explicitly taught the words to all the songs, but the control group sometimes did not know the words and just sang along as best they could. The control group lesson contained four major activities and the children sat on chairs for most of the lesson. There were seven main activities in the experimental group lesson and activities often involved standing up and/or moving about.

Procedure

Screening tests of vocabulary and cognition were administered early in the fall of the academic year. In the mid-fall and mid-spring, the participants were then given a battery of PA, musical rhythm pattern copying and discrimination, and tempo copying tests.

All the music testing was done in one 15–20 min session, while the PA measures were spread over several short testing sessions. A researcher administered all tests on a one-to-one basis with the children in quiet areas of the school.

In the PA tests, the researcher read the test stimuli aloud and noted the children's answers on paper score sheets. The music testing was administered using a software application made with the MAX/MSP music programming environment (www.cycling74.com) on a Dell PC laptop computer. The computer produced the audible music stimuli in all tests. In the rhythm pattern discrimination test, the participants' responses (*same* or *different*) were noted on score sheets. In the rhythm pattern copying and tempo copying tests, the participants tapped out their responses with the fingers of their dominant hand on the space bar of a KidsMouse KMK030-04 multi-colored keyboard attached to the computer. The computer calculated and stored the exact number of milliseconds in between each of the child's taps on the spacebar.

Measures

Screening and phonological awareness measures Standardized tests were used for all of the vocabulary screening, cognitive ability screening, and phonological awareness tests:

Kaufman Brief Intelligence Test (K-BIT, Kaufman & Kaufman, 1990) This test measures verbal and non-verbal intelligence. The test provides scores in vocabulary, matrices which measure cognitive ability, and a combined abbreviate score in overall intelligence. We refer to the combined abbreviate score as *overall cognitive ability*.

Peabody Picture Vocabulary Test IIIa (PPVT, Dunn & Dunn, 1997) This test measures English receptive vocabulary.

The Phonological Awareness Test (PAT, Robertson & Salter, 1997) Six subtests of the PAT were used to assess PA in both the fall and spring of the kindergarten year. In each subtest, the researcher read the test stimuli aloud and the children were asked to perform as follows: Rhyming Discrimination (decide if two words rhyme); Rhyming Production (produce a rhyme for a given word); Segmentation of Sentences (clap hands for each word in a sentence as they repeat the sentence aloud); Segmentation of Syllables (clap hands for each syllable in a word as they repeat word aloud); Isolation of Initial Phonemes (identify the phoneme in the initial position in a word); and Deletion of Sounds: Compounds/Syllables (delete a given word part or syllable and repeat the word minus the word part or syllable).

Music ability measures

New test instruments, adapted from the Music Aptitude Test (MAT) described in Overy et al. (2003), were used to assess music rhythm skills. Simplified and automated subtests of the MAT appropriate for kindergarten-age children were developed by Dr. Katie Overy and one of the co-authors (GP). The subtests were then piloted with kindergartners and revised until they were sufficiently simple to be understood by 5-year-olds. The tests included:

Tempo Copying This test contained four stimuli of four identical sounds per stimulus (short bongo drum taps of equal sound level) that differed only in tempo (speed). The time interval between each drum tap in each stimulus was identical in duration. No practice stimuli were presented. After listening to a stimulus, the child was asked to copy it exactly by tapping on the computer keyboard space bar. A tap on the spacebar produced a bongo drum sound from the computer identical to that used in the stimuli. The four sounds in the first stimulus were presented at inter-onset intervals of 1,000 ms, and the second through fourth stimuli were presented at 750, 600, and 441 ms respectively.

Rhythm Pattern Copying This test presented two practice stimuli then 14 test stimuli. The stimuli were simple sequences (rhythm patterns), similar to single-meter patterns shown in Fig. 1, made up of identical short bongo drum taps of equal sound level. The number of taps per stimulus varied from 3 to 7. All inter-onset intervals between successive taps in a stimulus were multiples of a base duration of 300 ms (300, 600, 900, and 1,200 ms). After listening to a stimulus, the child was

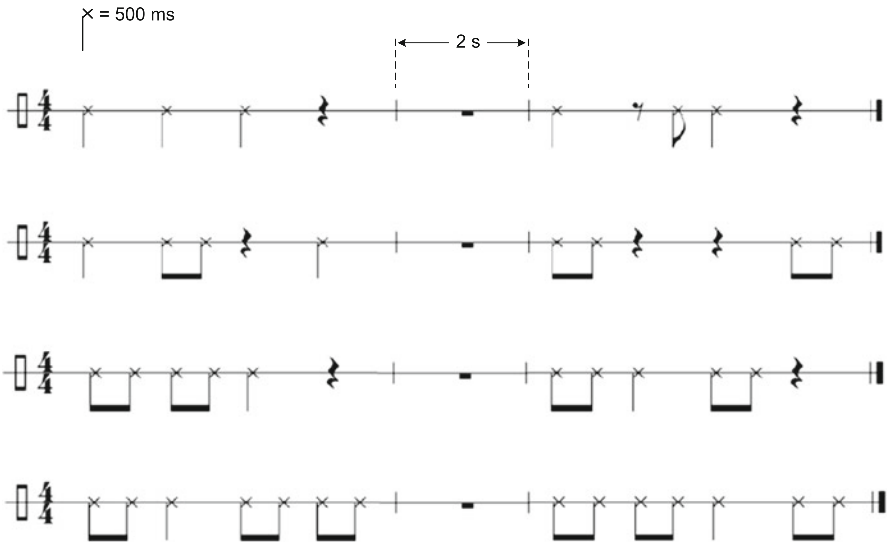

Fig. 1 Illustrative examples of paired stimuli with different rhythm patterns within each pair, used in the rhythm pattern discrimination test. Single-meter patterns of similar structure were used in the rhythm pattern copying test, but in slightly slower tempo

asked to copy it exactly by tapping on the computer keyboard space bar. A tap on the spacebar produced a bongo drum sound from the computer identical to that produced in the stimulus.

Rhythm Pattern Discrimination (Same/Different) This test contained two practice sets and 14 test sets of paired stimuli (pairs of rhythm patterns played on a bongo drum). The child was asked to distinguish whether the paired stimuli in each set were the same or different. The paired stimuli varied from set to set in the number of taps (3–7 taps), but within the set, both halves of the pair contained the same number of taps. Thus, the pair could differ only in rhythm. The stimuli were of similar structure to those used in the Rhythm Pattern Copying test, but were slightly faster. Inter-onset intervals between successive taps in a stimulus were multiples of a base duration of 250 ms (250, 500, 750 and 1,000 ms). Stimuli within each pair were separated by 2 s of silence. Illustrative examples of paired stimuli with different rhythm patterns within each pair are shown in Fig. 1. Seven of the sets presented stimuli that were the same, and seven sets were different. The order of presentation of the stimuli pairs was random as to whether they were the same or different, but the stimuli increased in overall difficulty over the course of the test.

Data scoring procedures

All phonological awareness, overall cognitive ability, and vocabulary tests were standardized tests, and raw scores on these tests were used in all data analyses.

The tempo and rhythm pattern copying tests were scored in two ways, both of which were raw scores. Computerized scores for each test item were derived according to the following procedure: (1) both the stimulus pattern and its corresponding response (child's reproduction of this pattern) were represented as a series of inter-onset time intervals in milliseconds; (2) the absolute difference between each successive time interval within the temporal pattern performed by the child (inter-tap interval), and the corresponding time interval of the stimulus pattern (inter-stimulus interval) was expressed as a percentage of the stimulus interval. This measure illustrated the magnitude of *deviation* of each performed time interval from the stimulus. A lower value indicated less deviation and thus better performance. (3) The geometric mean of all individual deviations within each pattern (test item) was calculated to express the average inaccuracy of child's response. We elected to use a geometric mean as a measure of central tendency, as opposed to an arithmetic mean, because a geometric mean is less biased by extremely high or extremely low values. (4) For the same reason, the grand geometric mean of the geometric means for all test items was calculated to indicate total performance accuracy in tempo copying and rhythm copying tasks. That geometric mean was then used as the *computer-produced score* in all data analysis.

To obtain human-rater scores, all test stimuli together with children's reproductions of these stimuli were converted to audio files. All identifiers were removed and the files for the fall and spring testing from both schools were randomized together. Two independent musicians (*human raters*) then listened to the audio files and scored the copying accuracy of each reproduced rhythm pattern using a Likert scale (1–5, with 1 as the highest/best performance score). The average of the two musicians' scores was the *human-rater score* used in data analysis.

The two types of scoring procedures had different strengths and limitations. The computer was more accurate than a human rater's perception because it could make precise measurements of the time intervals between the child's response taps, but the computer was very unforgiving of mistakes for which a human scorer could adjust. For example, if the child omitted the first tap in a response but performed all subsequent taps with the correct time intervals, the computer did not adjust for the initial missed tap and therefore gave the child a poor score overall. A human rater has an advantage because the rater can perceive that the child's performance was excellent except for the missed tap at the beginning of his or her response, and make a judgment call to assign the child a relatively higher score compared to the score produced by the computer.

Correlational analyses between the two scoring systems showed that despite the differences in their inherent characteristics, they presented moderate to high agreement in their evaluation of children's copying performance: tempo copying computer-produced and human-rater scores were moderately correlated to each other in the fall, $r_s(28) = .39$, $p < .05$, and highly in the spring, $r_s(25) = .78$, $p < .001$; and, rhythm pattern copying computer-produced and human-rater scores were highly correlated to each other in the fall, $r_s(28) = .82$, $p < .001$, and in the spring, $r_s(25) = .78$, $p < .001$.

The rhythm pattern discrimination scores were the simple raw scores of the number of correct answers ("same" or "different") given by the children.

Results

Group characteristics at start of study

No statistically significant differences were found between the two study groups in demographic, surrogate income, or home literacy and music environment factors, nor in any descriptive parameter in Table 1. One difference was found: the experimental group's parents had significantly higher average levels of education than the parents of the control group [$t(23) = 3.85$, $p < 0.01$]. However, this difference did not present a noticeable effect on children's overall cognitive ability, as indicated by the non-significant relationship between parental education level and KBIT Composite standard score [$r(23) = -.17$, *ns*]. Therefore, it was unlikely that parents' educational level had an effect on any experimental variables. Further, we note that the confounding influence of better educated parents in the experimental group possibly performing more home literacy activities with their children may have been partially counterbalanced by the formal home reading program at the control school, whereas the experimental group had no formal home reading program.

Exploratory analysis of children's scores in cognitive ability, vocabulary, PA, and music tests showed that in a considerable number of the assessed variables the distributions of scores within each group were highly skewed, either positively or negatively, and many of them contained outlier values. Testing these distributions with the Shapiro–Wilk's criterion, we also confirmed our observation about the existence of significant deviations from normality. Therefore, most of the analyses presented in Study 1 are based on non-parametric tests. An alpha level of .05 was used for all tests as the threshold of statistical significance, and the exact p value is given for all results. Due to the subtlety of the effects present within a small sample size, we also report results with p values of .051 to .075 as *marginally significant*. For the rhythm findings, computer-produced and human-rater scores are presented for both tempo and rhythm pattern copying tests. Because these two scoring systems have different strengths and weaknesses (see "Data scoring procedures"), the strongest results are those where both scoring systems produce significant results.

Two-tailed, independent t tests of the fall data indicated that there was no significant difference between the study groups in the screening measures of receptive vocabulary and overall cognitive ability in the fall (Table 2).

Table 2 Study 1: mean test scores (M) and standard errors (SE) for the two groups in overall cognitive ability and receptive vocabulary screening tests at the start of the study (fall testing), and test statistics and effect size for the independent t test for the corresponding differences between the two groups

Variable	Experimental group M (SE)	Control group M (SE)	*df*	t	Exact sig. (2-tailed)	r
Overall cognitive ability[a]	96 (2.41)	97.7 (3.92)	28	−0.38	.71	.07
Receptive vocabulary[b]	102.3 (3.15)	102.3 (2.82)	28	0.00	1.00	.00

[a] K-BIT Composite standard score

[b] PPVT-IIIa standard score

Table 3 Study 1: median test scores for the two groups at the start of the study (fall testing), and test statistics and effect size for the Mann–Whitney test for the corresponding differences between the two groups

Variable	Median scores		Mann–Whitney test		
	Experimental group ($N = 15$)	Control group ($N = 15$)	U	Exact sig. (2-tailed)	r
Phonological awareness[a,b]					
Rhyming discrimination	8.0	8.5	72.5	.149	−.27
Rhyming production	7.0	8.5	55.5	.142	−.29
Segmentation of sentences	8.5	8.0	105.5	.776	−.05
Segmentation of syllables	7.0	7.0	110.5	.940	−.02
Isolation of initial phonemes	8.0	6.0	30	.314	−.24
Deletion compounds/syllables	6.5	6.0	64.5	.197	−.25
Rhythm[a]					
Tempo copying					
Computer-produced score[c]	8.7	14.2	72	.098	−.31
Human-rater score[c]	1.75	2.25	17.5	.000***	−.72
Rhythm pattern copying					
Computer-produced score[c]	26.7	31.3	85	.262	−.21
Human-rater score[c]	3.1	3.3	81.5	.205	−.24
Rhythm pattern discrimination					
Raw score[b]	10.0	9.0	64	.070	−.33

* $p < .05$, ** $p < .01$, *** $p < .001$

[a] Raw scores

[b] High score indicates better performance

[c] Low score indicates better performance

Mann–Whitney tests were carried out on all the fall measures of PA and rhythm ability in order to determine if there was a difference between the study groups in any of the assessed variables. Median scores, values of the Mann–Whitney's U statistic together with the corresponding p value and effect size for all these variables are summarized in Table 3.

Interestingly, the only significant difference between groups in fall average scores was obtained in Tempo Copying ability as measured by the human-rater scores ($r = -.72$, well above the .50 threshold for a large effect size). In this test, the experimental group scored significantly better[1] than the control group. Also, the experimental group displayed a marginally significant difference in Rhythm Pattern Discrimination[2] compared to the control group which represents a small to medium effect ($r = -.33$). This slight advantage in rhythm ability of the experimental group may have been because the rhythm tests were administered in mid-to-late October, after the experimental group had participated in 30–40 daily music lessons, whereas, the control group had completed only 5–6 weekly music lessons.

[1] Lower median score indicates better performance in Tempo Copying.

[2] Higher median score indicates better performance in Rhythm Discrimination.

Indicators of relationships between rhythm and phonological awareness

The degree of relationship between all PA and rhythm pattern and tempo variables was measured by calculating correlations among these variables with the fall data in which all children's scores from both the experimental and control group were placed into one sample. Based on preliminary analyses (see "Group characteristics at start of study") this composite sample can be considered as having homogeneous characteristics at the start of study. As a consequence, we merged the scores of the two groups into a single larger sample which allowed us to achieve greater statistical power for correlational analysis without introducing potential effects of extraneous variables to the analyses. Because, as noted, most of our data did not meet parametric assumptions, computation of correlations was based on Kendall's tau-b test (for a detailed account on the advantages of using Kendall's rather than Spearman's statistic, see Field, 2005). Correlations between all assessed PA and rhythm variables are shown in Table 4.

The children's phonological processing ability in Segmentation of Sentences was significantly correlated to their Tempo Copying computer-produced score, $p = .007$. Segmentation of Sentences also displayed correlations of marginal significance with Rhythm Pattern Copying, as measured both by computer-produced

Table 4 Study 1: correlation (Kendall's tau-b) coefficients between phonological awareness and rhythm variables at the start of the study (fall testing)

Variable	Phonological awareness					
	Rhyming discrimination	Rhyming production	Segmentation of sentences	Segmentation of syllables	Isolation of initial phonemes	Deletion compounds/ syllables
Tempo copying						
Computer-produced score[a]	.03	.04	−.37**	−.05	.05	−.16
Human-rater score[a]	.23	.15	−.15	.04	−.11	−.05
Rhythm pattern copying						
Computer-produced score[a]	−.04	.09	−.26[m]	−.27*	−.22	−.28[m]
Human-rater score[a]	−.05	.24	−.25[m]	−.19	−.33[m]	−.13
Rhythm pattern discrimination						
Raw score	.27	.02	.06	−.11	.12	.20

Children from both groups were placed into one sample ($N = 30$)

* $p < .05$, ** $p < .01$, *** $p < .00$, [m] Marginally significant ($.050 < p < .075$)

[a] Negative sign of the correlation coefficient indicates a positive relationship between the rhythm and phonological awareness variables

score, $p = .063$, and human-rater score, $p = .074$. Segmentation of Syllables was significantly correlated to Rhythm Pattern Copying in computer-produced score, $p = .044$, but not in human-rater score. Isolation of Initial Phonemes was marginally correlated to Rhythm Pattern Copying in human-rater score, $p = .067$. Deletion of Compounds and Syllables was marginally correlated to Rhythm Pattern Copying in computer-produced score, $p = .052$.

All these significant and marginally-significant correlational results show a positive small-to-medium-sized relation between measures of music rhythm ability and measures of PA. This association appears to be more pronounced between measures of tempo/rhythm copying ability and measures of children's ability to segment words in sentences and syllables in words. Rhythm Pattern Discrimination ability did not seem to associate with any of the assessed sub skills of PA. Overall, the obtained positive though mild relations across four measures of phonological segmentation ability (sentences, syllables, initial phonemes, and compound words) provide a pattern of exploratory evidence in support of our hypothesis that PA and rhythm ability are related in 5-year-olds. However, power analysis of these results (see Cohen, 1990) indicated that greater sample size is necessary to detect such a small-to-medium effect with high probability.

Indicators of end-of-year differences between groups

To test our hypothesis that the group who received more music training would have better PA skills at the end of the year than the group that had received less training, we used Wilcoxon signed-ranks tests in order to compare children's scores in the fall to those in the spring for each of the assessed variables and within each group separately. Median scores, z values for the Wilcoxon signed-ranks tests together with the corresponding p value and effect size (r) for all these variables are shown in Table 5.

For the experimental group, highly significant differences (all p values $<.01$) between fall and spring scores were obtained in all measures of PA, and all of these results associate with values of r which represent large-sized effect ($r < -.50$)[3] for intensive musical training. In contrast, control group's scores showed statistically significant improvement over time as well, but only in four out of six measures of PA: Segmentation of Sentences, Segmentation of Syllables, Isolation of Initial Phonemes, and Deletion of Compounds/Syllables. These significant differences represent a medium effect size in each case respectively ($-.50 < r < -.30$), and considerably smaller compared to those of the experimental group.

With regard to rhythm abilities, neither group presented significant improvement over time in Tempo Copying ability, as measured by both computer-produced and human-rater scores. The experimental group improved significantly in Rhythm Pattern Copying ability, as measured by the human-rater scores, and in Rhythm Pattern Discrimination, while the control group did not present such an effect in these tests.

[3] Negative value of r does not imply a negative correlation.

Table 5 Study 1: median test scores in fall and spring testing organized by group, and test statistics and effect size for the Wilcoxon signed-ranks test for the corresponding differences between Fall and Spring scores within each group separately

Variable	Median scores				Wilcoxon Signed-ranks test					
	Experimental group		Control group		Experimental group ($N = 15$)			Control group ($N = 15$)		
	Fall testing	Spring testing	Fall testing	Spring testing	z	Exact sig. (2-tailed)	r	z	Exact sig. (2-tailed)	r
Phonological awareness[a,b]										
Rhyming discrimination	8.0	10.0	8.5	10.0	−2.944	.003**	−.54	−0.355	.722	−0.06
Rhyming production	7.0	9.0	8.5	9.0	−2.824	.005**	−.52	−0.777	.437	−0.14
Segmentation of sentences	8.5	10.0	8.0	9.0	−2.840	.005**	−.52	−2.176	.030*	−0.40
Segmentation of syllables	7.0	10.0	7.0	9.5	−3.205	.001**	−.59	−2.106	.035*	−0.38
Isolation of initial phonemes	8.0	10.0	6.0	10.0	−2.955	.003**	−.54	−2.032	.042*	−0.37
Deletion compounds/syllables	6.5	8.0	6.0	7.0	−2.873	.004**	−.52	−2.095	.036*	−0.38
Rhythm[a]										
Tempo copying										
Computer-produced score[c]	8.7	10.1	14.2	10.7	−0.031	.975	−.01	−0.454	.650	−.08
Human-rater score[c]	1.7	1.7	2.2	1.7	−0.246	.806	−.04	−1.687	.092	−.31
Rhythm pattern copying										
Computer-produced score[c]	26.7	21.3	31.3	29.4	−0.282	.778	−.05	−0.874	.382	−.16
Human-rater score[c]	3.1	2.4	3.3	3.0	−2.983	.003**	−.54	−0.455	.649	−.08
Rhythm pattern discrimination										
Raw score[b]	10.0	11.0	9.0	9.5	−2.105	.035*	−.38	−1.039	.299	−.19

* $p < .05$, ** $p < .01$, *** $p < .001$

[a] Raw scores

[b] High score indicates better performance

[c] Low score indicates better performance

These results provide clear evidence in support of our hypothesis that end-of-year PA skills of children in a school with intensive musical training would be better than the skills of children who participated in less musical training.

Study 2

The purpose of Study 2 was to conduct a preliminary exploratory examination of potential correlations between rhythm skills at the beginning of kindergarten and PA and reading skills in second grade, in the same group of children, in order to investigate whether associations between these skills may extend over longer periods of children's development.

Sample

The sample included 12 second-graders who had participated in Study 1 as kindergartners. Eight second-graders were from the Study 1 experimental group and four from the control group, and all were attending the same schools they had attended as kindergartners. Their ages ranged from 7 years 9 months to 8 years 5 months (mean age was 8.1). Table 6 presents descriptive data for the sample.

Procedure

The children's PA and reading skills were tested in the middle of their second grade year. Tests were administered in two or three short sessions by a researcher on a one-to-one basis in quiet areas outside the classroom.

Measures

The participants' kindergarten scores on rhythm ability and KBIT Composite measures administered at the start of Study 1 were used in the Study 2 analyses.

Table 6 Study 2: participant descriptive data—second graders

Variable	Study group ($N = 12$)
# From kindergarten experimental group	8
# From kindergarten control group	4
Age at 2nd grade—range (*M*)	7 years 9 months–8 years 5 months (8.1)
Gender	
Boys	6
Girls	6
Overall Cognitive Ability in Kindergarten[a]—*M* (SD)	97.2 (7.6)
Receptive Vocabulary in Kindergarten[b]—*M* (SD)	99.6 (11.6)

[a] K-BIT Composite standard score

[b] PPVT-IIIa standard score

Second grade PA and reading skills were assessed with the following standardized tests:

Comprehensive Test of Phonological Processing (CTOPP, Wagner, Torgesen, & Rashotte, 1999) Three subtests were used to assess PA: Elision (delete a phoneme from various parts of a word to make a new word), Blending Words (blend two or more syllables or phonemes into a word), Nonword Repetition (repeat nonsense words).

Test of Word Reading Efficiency (TOWRE, Torgesen, Wagner, & Rashotte, 1999) Two subtests were used to assess non-word decoding automaticity and real-word reading: Phonemic Decoding Efficiency (the number of pronounceable non-words decoded within 45 s), Sight Word Efficiency (the number of real words decoded within 45 s).

Woodcock Reading Mastery Tests—Revised (Woodcock, 1998): Subtests administered included: Word Attack (decoding of unfamiliar phonetically-regular non-words), Word Identification (decoding of real words), Passage Comprehension (identify a missing word in a reading passage).

Results

Partial correlations, controlling for overall cognitive ability (KBIT Composite Raw Score) were calculated between the participants' rhythm ability scores at the beginning of kindergarten and their second grade PA and reading raw scores. A summary of these results is presented in Table 7.

The children's second grade phonological processing ability in Blending Words was significantly correlated to their ability in Rhythm Pattern Copying in the fall of their kindergarten year, as measured by both computer-produced scores, $p = .005$, and human-rater scores, $p = .012$, and to their fall kindergarten Rhythm Pattern Discrimination, $p = .035$. Second grade Nonword Repetition was significantly correlated to fall kindergarten Rhythm Pattern Copying, human-rater score, $p = .041$, and Rhythm Pattern Discrimination, $p = .037$, and Phonemic Decoding Efficiency was significantly correlated to fall kindergarten Rhythm Pattern Copying, computer-produced score, $p = .007$. Second grade Word Attack and Word Identification were also significantly correlated to fall Rhythm Pattern Copying, computer-produced score, $p = .033$ and $p = .041$ respectively. Scatterplots of the statistically significant correlations between Rhythm Pattern Copying and Discrimination Skills at the beginning of kindergarten, and measures of PA and reading skills in second grade are shown in Fig. 2a–c.

These results support our hypothesis that kindergarten rhythm ability would be significantly related to PA in second grade. The associations were predominantly to tasks that rely heavily on PA, phonics, and phoneme-based decoding skills (i.e., Blending words, Non-word Repetition, Phonemic Decoding Efficiency, and Word Attack). It should be noted that other than a significant correlation to Word Identification, the association did not extend to second grade tests that measured real-word reading, including Sight Word Efficiency and Passage Comprehension.

Table 7 Study 2: partial correlation (Pearson's r) coefficients between rhythm variables at the start of Study 1 (kindergarten—fall testing) and measures of phonological awareness and reading skills in second grade

Variable	Phonological awareness and reading skills in second grade							
Control variable: overall cognitive ability (KBIT Composite Raw Score)	CTOPP			TOWRE		Woodcock Reading Mastery tests		
	Elision	Blending words	Nonword repetition	Phonemic decoding efficiency	Sight word efficiency	Word attack	Word identification	Passage comprehension
Tempo copying								
Computer-produced score[a]	−.06	−.49	−.16	−.22	−.13	−.55	−.38	.04
Human-rater score[a]	−.09	−.42	.25	−.20	−.22	−.30	−.24	−.46
Rhythm pattern copying								
Computer-produced score[a]	−.36	−.77**	−.33	−.76**	−.51	−.64*	−.62*	−.31
Human-rater score[a]	.26	−.72*	−.62*	−.33	−.19	−.21	−.25	.11
Rhythm pattern discrimination								
Raw score	−.23	.64*	.63*	.44	.38	.16	.33	.06

Control variable: overall cognitive ability (KBIT Composite raw score). Children from both groups of Study 1 were placed into one sample ($N = 12$)

* $p < .05$, ** $p < .01$, *** $p < .001$

[a] Negative sign of the correlation coefficient indicates a positive relationship between the rhythm and phonological awareness variables

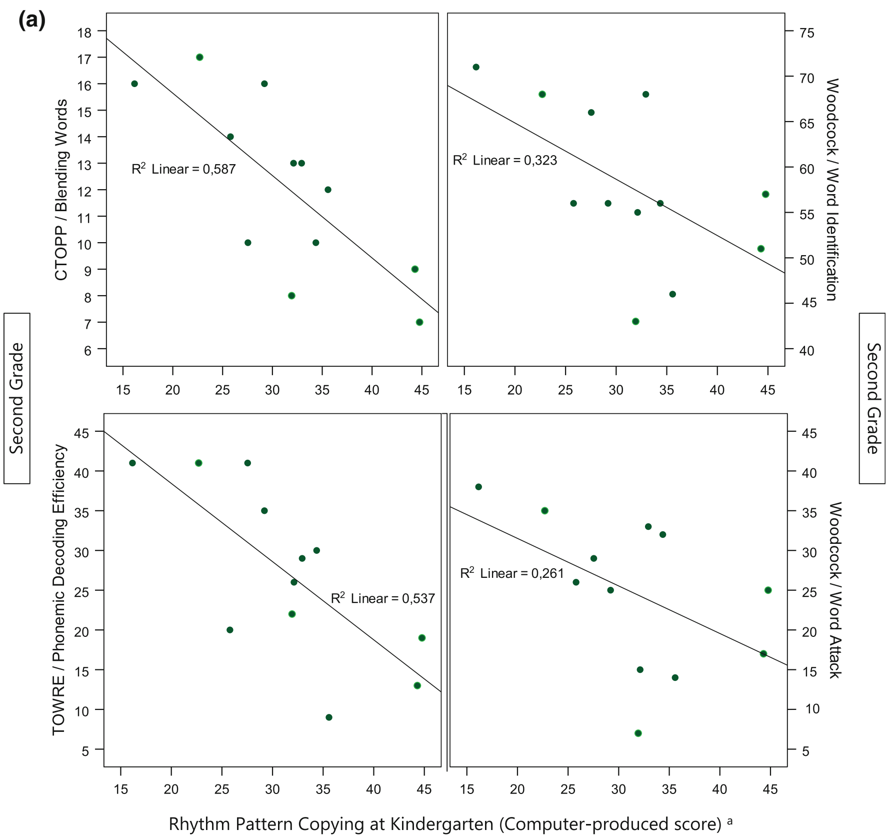

Fig. 2 **a** Scatterplots of the statistically significant correlations between rhythm pattern copying skills at the beginning of kindergarten and measures of phonological awareness and reading skills in second grade (see also Table 7). [a]Higher scores in the rhythm pattern copying test indicate worse performance. Therefore, the negative slope of the regression lines illustrate a positive relationship between rhythm pattern copying accuracy and the measures of phonological awareness and reading skills in second grade displayed in these graphs. **b** Scatterplots of the statistically significant correlations between rhythm pattern copying skills at the beginning of kindergarten and measures of phonological awareness in second grade (see also Table 7). [b]Higher scores in the rhythm pattern copying test indicate worse performance. Therefore, the negative slope of the regression lines illustrate a positive relationship between rhythm pattern copying accuracy and the measures of phonological awareness in second grade displayed in these graphs. **c** Scatterplots of the statistically significant correlations between rhythm pattern discrimination skills at the beginning of kindergarten and measures of phonological awareness in second grade (see also Table 7). [c]Higher scores in the rhythm pattern discrimination test indicate better performance

Discussion

A few prior studies have shown that children's rhythm ability, a component skill of music, may be connected to their PA (e.g., Anvari et al., 2002; David et al., 2007; Douglas & Willats, 1994; Overy et al., 2003). A small number of prior experimental studies with control groups have also indicated that musical training may enhance reading acquisition, comprehension, or verbal abilities (e.g., Fisher, 2001; Hurwitz

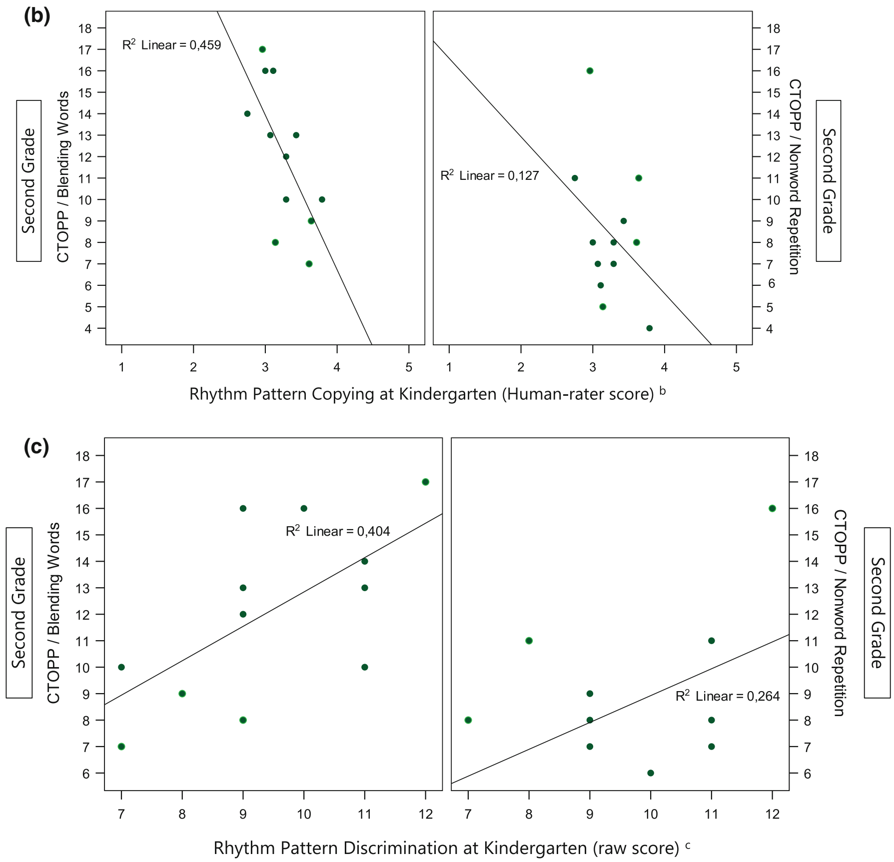

Fig. 2 continued

et al., 1975). We hypothesized that overall rhythm sensitivity is a pre-cursor skill to development of PA, and that musical rhythm and many phonological tasks are connected because both types of tasks require the children to perceive and manipulate patterns of time intervals between sounds in sound streams. We explored connections between kindergartners' rhythm and PA skills and whether intensive musical training contributed to their having more PA skill at the end of the year than children who had less musical training (Study 1). We also conducted a follow-up investigation (Study 2) into whether kindergartners' rhythm ability was connected to their PA and reading ability in second grade.

Significant and marginally-significant correlational results in Study 1 showed that kindergartners' PA ability across segmentation tasks, including words, syllables, and phonemes, was positively related to their rhythm ability. Wilcoxon signed-rank analyses demonstrated that children who received intensive music training improved in more phonological tasks, including segmentation and rhyming tasks, by the end of the year than kindergartners who received less music training. Study 2

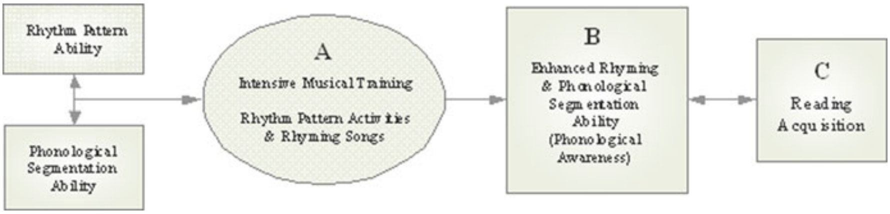

Fig. 3 Proposed chain of relationships between musical training, phonological awareness, and reading acquisition, expanding on an earlier model proposed by Overy (2003)

produced significant correlational results illustrating that kindergartners' rhythm abilities are connected to blending words, nonword repetition, non-word decoding, and non-word decoding automaticity in second grade. These tasks rely heavily on phonological skills, both in oral and print contexts. Study 2 also found a connection between kindergarten rhythm ability and second grade real-word decoding, a reading task that relies on phonological ability but also involves other skills. No significant correlations were found between kindergarten rhythm skills and second grade real-word reading automaticity or reading comprehension, perhaps because these latter activities require many additional underlying skills of reading that go beyond phonological processing.

The results of Study 1 suggest a pathway by which musical training in young children could bolster reading acquisition: (1) rhythm pattern ability is linked to phonological segmentation ability; (2) exposure to rhythmic pattern activities and rhyming song lyrics through intensive musical instruction are connected to enhanced PA in the form of rhyming and phonological segmentation skills; and (3) PA facilitates reading acquisition in a reciprocal manner. This pathway is depicted in Fig. 3. [This study's pathway expands on an earlier model presented by Overy (2003) by including initial, pre-training correlations between rhythm and phonological skills.] Study 1 provided support for the underlying links between rhythm pattern abilities and phonological segmentation skills in kindergarten, and for the link between musical training (A) and enhanced PA (B). Decades of prior research support the link shown (B) between PA and reading acquisition (C) (Adams, 1990; National Reading Panel, 2000).

Relationships between rhythm and phonological awareness—kindergarten fall data

PA skills were significantly or marginally correlated to rhythm pattern copying (varied pattern copying) in the fall of the kindergarten year in a sample combining all the children in the study. Both types of rhythm pattern copying scores, computer-produced and human-rater scores, were marginally correlated to measures of the children's ability to segment sentences into words. Rhythm pattern copying, computer-produced score, was also significantly or marginally correlated to segmentation of syllables and ability to delete word and syllable parts from compound and multi-syllabic words. Rhythm pattern copying, human-rater score, was marginally correlated to ability to isolate initial phonemes. The concurrence of the two scoring systems, with their different strengths and weaknesses, regarding links to sentence segmentation, and the overall results linking rhythm pattern ability to a range of segmentation abilities including words, syllables, and phonemes supported our hypothesis that PA and rhythm ability are related. These results expand on prior research by Anvari et al. (2002) who found significant correlations in rhythm and phonological processing macro-variables in 5-year-olds. Through the use of more controlled testing methods than those that may have been available to Anvari et al. (e.g., our use of computer-produced drum sound stimuli vs. Anvari and colleagues' use of voice-produced stimuli in the rhythm pattern copying tests; and our two scoring systems), the results of the present study build on Anvari et al.'s earlier findings. Our results, along with those of Anvari et al., suggest that the relationships found by Montague (2002) between rhythm pattern copying abilities and PA skills in 8-year-olds and by Holliman et al. (2010) in 6- and 7-year-olds are present in younger children.

As hypothesized, a significant correlation was also found between tempo copying (equal-interval pattern copying), computer-produced score, and the ability to segment words in a sentence. This single finding with tempo copying versus the multiple findings with rhythm pattern copying summarized above suggests that varied time-interval rhythm pattern copying ability has a stronger connection than equal time-interval pattern copying to a range of speech segmentation tasks. We speculate that this may be due to the fact that the flow of speech in English is characterized by varied time intervals between sound amplitude onsets; therefore, varied-rhythm pattern copying ability may be more relevant to speech segmentation than equal-interval pattern copying. Interestingly, the varied patterning of vocalic and intervocalic time intervals in English has recently been demonstrated to reflect rhythm patterns commonly used in English music (Patel & Daniele, 2003). These observations are also in line with current theories of English phonetics and phonology which argue against the proposal that stresses in spoken English occur at roughly equal time intervals—a proposal that connects directly to the concept of strict isochrony in speech rhythm—and further support the view that characteristic rhythm patterns of spoken utterances are among the major cues that listeners rely on in order to segment continuous speech (Cutler, 1991; Ramus, Nespor, & Mehler, 1999).

Relationships between rhythm and phonological awareness—kindergarten fall to spring data

The kindergartners' improvement in PA from fall to spring was measured on six segmentation and rhyming tests. Wilcoxon signed-rank analyses showed that both the experimental and control groups improved significantly in tests of segmentation of sentences, syllables, initial phonemes, and compounds/syllables. However, the experimental group had larger effect sizes (*r* values) in their improvement scores versus the considerably smaller medium effect sizes for improvements in the same tests by the control group. The experimental group also improved in both rhyming discrimination and production skills, whereas the control group did not improve in either rhyming skill. In sum, the experimental group significantly improved in *all* measures of PA whereas the control group improved in four of six areas, and to a lesser extent.

The experimental group also showed significant improvement from fall to spring in its rhythm pattern copying and discrimination abilities, but the control group's rhythm skills did not improve significantly. Because we hypothesize that rhythm skills are pre-cursors to the acquisition of language skills, we argue that the experimental group's improvement in rhythm ability contributed to its large-effect improvements in phonological segmentation ability and improvements in rhyming ability not found in the control group.

That said, the use of language in the music lessons must be considered. The experimental group received daily music lessons that involved both singing familiar songs and creating new songs with rhyming lyrics. As Fisher and McDonald (2001) suggested, singing is an excellent way to make children aware of the individual sounds in speech. Sung as lyrics, words and syllables are lengthened, repeated, and stressed in ways that provide "a captivating entrance to the world of phonemes" (p. 109). Furthermore, Wolf et al. (2000) emphasized the importance of *engagement* in learning. The level of the children's engagement in the music lessons, as observed during a comparison of lessons at both schools, was greater at the experimental school than at the control school. In addition, the experimental school music teacher assured that children knew the words to the songs whereas the control school music teacher did not routinely monitor the children's knowledge of the lyrics. Two factors, therefore, could be related to the experimental group's improvement in rhyming ability at the end of the year: greater rhythm pattern copying ability, with its apparent connection to phonological segmentation skill shown in the fall data, and considerably more exposure to rhyming lyrics in music lessons that actively engaged the children's attention and energy throughout their kindergarten year.

The work of Bryant, Bradley, Maclean, and Crossland (1989) is relevant to the present study. These researchers found that children's knowledge of nursery rhymes at 3 years old predicted their reading ability at six. Their study showed that the connection between the preschoolers' nursery rhyme knowledge and their later reading ability was not direct, but came indirectly through the children's increased rhyming and phoneme detection ability in the years from three to six. They concluded that nursery rhyme knowledge was connected to enhanced PA which, in turn, enhanced reading acquisition.

In their research, Bryant et al. (1989) did not address the rhythmic quality of nursery rhymes as a contributor to PA. Their test scores were based on whether the children knew the words to the nursery rhymes, not whether they used rhythmic prosody in saying the rhymes. Nevertheless, one can speculate that in saying a nursery rhyme such as *Humpty Dumpty*, children would employ its rhythmic structure which puts emphasis on the rhyming words at the ends of the lines (e.g., "sat on a *wall*" and "had a great *fall*"). Extrapolating from Fisher and McDonald's (2001) argument about singing's effects on PA, we speculate that the rhythmic structure helped the children segment the nursery rhyme's words and syllables and understand that the concluding words in the lines rhyme. Analogously, in our study both rhythm pattern activities and the emphasis on rhyming song lyrics in children's music lessons may have contributed to improvements in rhyming production and discrimination ability found in the experimental group kindergartners at the end of the year.

The results of Study 1 may offer some explanation for the discrepancy in outcomes of prior studies into the connection between musical training and language skills. Costa-Giomi (2004) found that 3 years of weekly piano lessons, starting in fourth grade, had no effect on the children's language skills. In contrast, Hurwitz et al.'s (1975) and Fisher's (2001) research showed that musical training was connected to reading acquisition in first graders. This present study suggests that musical training enhances PA. PA is most important for children in kindergarten to third grade when the ability to make grapheme-sound correspondences in written words is critical for learning to read (Stanovich, 1986). By fourth grade, as children enter the reading-to-learn phase, reading performance is more dependent on children's knowledge of syntax, grammar, morphology, and their inferential skills and less on the decoding of individual words through use of their basic phonological processing skills (Wolf, 2007).

Relationships between rhythm and phonological awareness—kindergarten to second grade

As hypothesized, Study 2 showed that kindergartners' rhythm ability was connected to their PA in second grade and to decoding skills that rely most heavily on application of phonological skills. Specifically, the kindergartners' fall skills in rhythm pattern copying (both computer-produced and human-rater scores) and rhythm pattern discrimination were significantly correlated to their PA in blending words in second grade. Kindergarten fall rhythm pattern copying (human-rater score) and rhythm pattern discrimination were both highly correlated to second grade nonword repetition, and rhythm pattern copying (computer-produced score) was also correlated to second grade non-word decoding, non-word decoding automaticity, and real-word decoding. Blending words and nonword repetition require PA in the speech context while non-word decoding, non-word decoding automaticity, and real-word decoding require the ability to apply phonological skills in the print context, indicating that the relationship between rhythm ability and PA extends into the reading context. Although the sample was small (12 children from the original kindergarten study), the large size of the significant correlations suggest a strong relationship between kindergarten rhythm ability and second grade PA and non-word decoding skills. Interestingly, given Study 1's results, all significant correlations with second grade phonological ability were to kindergarten ability in producing or discriminating rhythm patterns with varied time intervals. There were no significant correlations to kindergarten tempo copying, that is, ability to produce patterns with equal time intervals between the sounds. Again, we speculate that this is because varied time interval musical rhythm patterns are more closely related to the varied time interval patterns characteristic of speech.

Kindergarten rhythm ability was correlated to second grade real-word decoding, but not correlated to second grade skills in sight word decoding automaticity or reading comprehension. We suggest that these latter abilities involve many underlying skills beyond PA, such as orthographic, semantic, syntactical, morphological and inferential skills, and thus may be less directly connected to rhythm ability.

In conclusion, the exploratory study results in both our studies give considerable support to, but they do not prove our theory that rhythm sensitivity is a pre-cursor skill of PA. The limitations of our studies include small sample sizes and the typical problems of quasi-experimental research in school settings. There were possible confounding factors including different schools and teachers for the experimental and control groups, very similar but not identical literacy programs between the schools, and music lessons that included songs with lyrics which therefore mixed music and language activities into the same lessons. Future research should employ larger sample sizes and have greater control over these factors.

Implications

The significant and marginally-significant correlations we found between rhythm ability and PA both in the kindergartens' fall scores and over time in the connections between kindergarten rhythm and second grade phonological skills suggest that future research with large samples may find that kindergarten rhythm abilities can predict phonological awareness in second grade. Because problems with PA are present in the majority of children with reading disability (Morris et al., 2010), early rhythm ability measures could then serve as screening tests for pre-reading children at risk of later reading disability because of weakness in phonological ability. Rhythm testing is not language-based—the same test can be administered to pre-readers of any language background. Rhythm testing is therefore especially attractive as the diversity of our pre-school populations increases.

Further, the improvement over the kindergarten year in six tests of PA of the experimental group children who received intensive musical training versus improvement in four areas for the control group points to exciting possibilities. The first possibility, suggested in our present study, is that music activity may bolster PA in pre-readers and, therefore, facilitate their reading acquisition. Early music training may also provide teachers with engaging and play-like ways to respond to the increasing pressure to teach academic skills in the pre-school years. The second possibility, suggested in prior work by Overy (2003), is that music activity focused on rhythm may help school-aged students who have already begun reading but are experiencing difficulties to overcome some problems in their phonological skills. These possibilities present promising directions for future research.

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