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Hearing what the body feels: Auditory encoding of rhythmic movement ☆

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Abstract

Phillips-Silver and Trainor (Phillips-Silver, J., Trainor, L.J., (2005). Feeling the beat: movement influences infants' rhythm perception. *Science,* 308, 1430) demonstrated an early cross-modal interaction between body movement and auditory encoding of musical rhythm in infants. Here we show that the way adults move their bodies to music influences their auditory perception of the rhythm structure. We trained adults, while listening to an ambiguous rhythm with no accented beats, to bounce by bending their knees to interpret the rhythm either as a march or as a waltz. At test, adults identified as similar an auditory version of the rhythm pattern with accented strong beats that matched their previous bouncing experience in comparison with a version whose accents did not match. In subsequent experiments we showed that this effect does not depend on visual information, but that movement of the body is critical. Parallel results from adults and infants suggest that the movement-sound interaction develops early and is fundamental to music processing throughout life.

Keywords: Rhythm; Music; Multisensory; Body movement; Auditory perception; Embodied cognition

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1. Introduction

Hearing music makes us move. But does the movement of our bodies shape what we hear? That there is a cross-modal interaction between body movement and sound is not a new idea. Aristotle (as cited in Helmholtz, 1954) asserted that motion "follows" sound. Synchronized coordination of movement to music has been observed in all known cultures (Brown, 2003). We move our bodies to the rhythms of music by tapping, drumming, plucking, singing, dancing, or rocking an infant (Wallin, Merker, & Brown, 2000). In fact, a disconnect between the body's movement and perceived sound, such as sitting still at a concert, is a recent phenomenon in Western cultures. According to Cross, a "generalizable definition of music would refer to music's two roots in sound and movement" (2003, p. 46).

The relation between auditory rhythm and movement is evident in that people readily tap on the strong beats of rhythm patterns (Drake, Penel, & Bigand, 2000). The organization of beats that allows the music listener to infer a steady succession of rhythmic pulses or strong beats is called meter. Metrical structure takes two principle forms in western music, duple and triple, depending on whether the basic unit of pulse consists of two or three beats (Randel, 1986). In musical traditions across the world, these two forms are manifest in dances such as the march and the waltz.

A century-old theory of music teaching is built on the idea that rhythm is embodied and expressed through movement. The Dalcroze Eurythmics approach teaches that musical knowledge is the result of physical experience (Jaques-Dalcroze, 1921/1980). Musicians study rhythm through time *and* space, utilizing the body's movement to internalize a pattern, and resulting in the product of expressed rhythm (Jaques-Dalcroze, 1920). Imagine stepping in time to music: stepping on the first beat not only marks the initial pulse point, but propels the body into motion towards the second beat and through the entire musical phrase. The musician feels and also hears the movements that she performs and can modify those movements as she produces them. As described by Juntunen, there exists a dynamic partnership in which listening inspires movement, while moving guides and informs listening (Juntunen & Hyvönen, 2004). Although this method of embodied rhythm has long been implemented in advanced music education, there has been no empirical basis for its description of cross-modal perceptual processing. Our aim was to provide empirical evidence for the basic interaction between body movement and auditory perception in feeling the musical beat.

Typically in music, the strong beats of the rhythm pattern are played louder and/or longer (physical accents), and the metrical structure is derived from, and consistent with, these accents. However, what about the case of an ambiguous rhythm pattern in which no physical accents are present: would different movements give rise to different metrical interpretations? An ambiguous sensory stimulus can be interpreted perceptually in two different ways, as in the case of the Rubin face-vase figure (Rubin, 1915) (Fig. 1). At a given time, the visual system determines which form, the pair of faces or the vase, is the figure and which is the ground. An auditory analogy of an ambiguous figure can be made from a sequence of six equally spaced beats, in which the first beat marks the downbeat of each measure. This rhythm figure can be

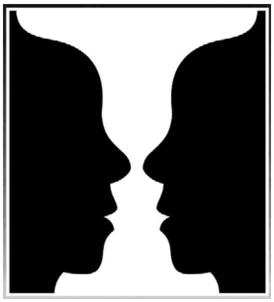

Fig. 1. Ambiguous figure: a visual analogy. Rubin's face-vase illusion can be seen either as a white vase on a black ground or as two black faces on a white ground, but both cannot be seen simultaneously.

subdivided into either three groups of two beats (in which the doublet groups are the figure against the 6-beat ground), which we refer to as duple form, or two groups of three beats (in which the triplet groups are the figure against the 6-beat ground), which we refer to as triple form (Fig. 2). The first beat of each pair or triplet that would normally be accented is without acoustical accent in the ambiguous pattern. In our experiments, we replace the auditory accents with body movements that occur on either every second or every third beat to provide the accent structure. We thus replace 'heard accents' with 'felt accents'. We hypothesized that moving on different beats will give rise to different metrical interpretations, which will then give rise to different auditory representations of the rhythm pattern. In other words, *how we move* will influence *what we hear*.

If this cross-modal process is indeed intrinsic to the human musical experience, we should observe it regardless of age or musical background. Phillips-Silver and Trainor (2005) trained 7-month-old infants with a 2-minute repetition of the rhythm

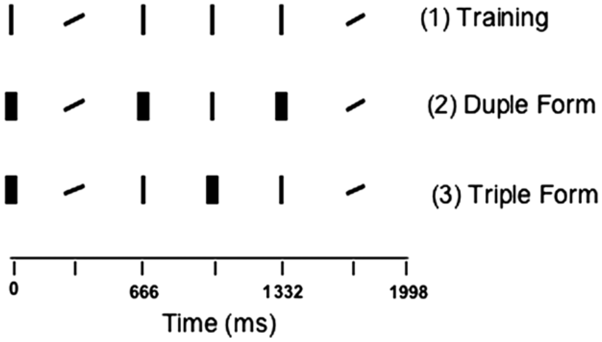

Fig. 2. The stimuli. Vertical lines represent the snare drum sounds of the rhythm patterns and oblique lines represent time-marking slapstick sounds. During training (1) no accents were present. During testing subjects heard the duple form (2) with accents every second beat versus the triple form (3) with accents every third beat. Since the training rhythm (snare drum) sounds were presented at a higher intensity than the microbeat (slapstick) sounds, the rhythm masked the microbeat when the two coincided on beats 1, 3, 4, and 5. As a result, the slapstick alone was audible on beats 2 and 6 (the "rest" beats of the rhythm pattern).

pattern shown in Fig. 2, with all snare drum beats equally loud. This rhythm can be interpreted in either groups of two beats or groups of three beats. Interestingly, these two interpretations sound, and *feel*, very different (like a waltz versus a march), and adults often do not recognize that they consist of an identical sequence of sound event durations (see http://www.sciencemag.org/cgi/content/full/308/5727/1430 to hear experimental stimuli). The infant subject was bounced up and down while held in the arms of the experimenter, either on every second beat to induce perception of the rhythm in duple form, or on every third beat to induce perception of the rhythm in triple form. Thus, both groups heard the same stimulus, but had different movement experiences. After training, infants' preferences (Trainor & Heinmiller, 1998) were tested for an accented version of the auditory pattern in duple form versus an accented version in triple form. Infants who were bounced in twos listened significantly longer to the duple form pattern, while those who were bounced in threes listened significantly longer to the triple form pattern. Furthermore, visual information was not necessary for the effect, but movement of the infant's body was crucial. We concluded that movement influences infants' auditory interpretation of metrical structure. In the present paper, we investigated through four experiments whether movement affects adults' interpretation of auditory rhythm.

2. Experiment 1

2.1. Methods

2.1.1. Participants

The study included 8 (2 males, 6 females) healthy university undergraduate students (aged 18–21, mean age 19.1 years). Subjects in all four studies had no known hearing deficits. Musical training (defined in these four experiments by past or present lessons in musical instruments, voice or dance) ranged from 2 to 10 years (mean 6.8 years). Subjects reported whether or not they participate in any recreational (i.e., without training) music or dancing, either private or public (such as dancing in night clubs): all 8 reported some recreational music activity; 3 of the 8 reported recreational dancing. Procedures were approved by the McMaster University Research Ethics Board and adults in all studies gave written consent to participate. Subjects in each study did not participate in any other study.

2.1.2. Stimuli

The stimuli were identical to those of Phillips-Silver and Trainor (2005), and were constructed and evaluated by musicians so as to be ecologically valid as musical excerpts.

2.1.2.1. Training stimulus. The training stimulus was constructed as follows (see Fig. 2). The *downbeat* (snare drum timbre) was presented at 60 dB in a sound-attenuating chamber with a noise floor of 29 dB, with an SOA of 1994 ms. After four repetitions, a *microbeat* (slapstick timbre) background of sounds with an SOA of

330 ms, presented at 50 dB, began and repeated throughout the rest of the training stimulus presentation. This combination resulted in a six-beat background sequence, with the snare drum sounding on the first beat, followed by five slapstick beats. The presence, and relative loudness, of the snare drum downbeat helped to perceptually divide the microbeat pattern into groups of six (equivalent to one musical bar with either 3/4 or 6/8 metric time signature). This combination was presented for eight repetitions of the six-beat group. Next, the *training rhythm* of interest was superimposed. The training rhythm was the same duration as the six microbeats, and consisted of four snare drum beat sounds with SOAs of 660–330–330–660 ms, presented at 60 dB. It repeated continuously for the remainder of the 2-min training period (for a total of 63 repetitions). SOAs of the beats in all rhythm patterns fell within the optimal range (300–800 ms interonset interval) for tempo discrimination (see Baruch & Drake, 1997; Fraisse, 1982).

2.1.2.2. Test stimuli. Two test stimuli were constructed to be identical to the snare drum training rhythm superimposed on the slapstick microbeat (i.e., the training stimulus minus the downbeat + microbeat introduction), except that the rhythm patterns contained accented sounds that had relatively high intensity. This was achieved by maintaining the “strong beats” (the accented snare drum beats) at the same intensity level (60 dB) as the snare drum beats in the training stimulus, while decreasing the intensity level of the “weak beats” (the unaccented snare drum beats) to 55 dB. The *duple rhythm* stimulus subdivided the rhythmic pattern into three groups of two beats, with every second beat accented (i.e., BEAT–rest–BEAT–beat–BEAT–rest). The *triple rhythm* stimulus subdivided the rhythm pattern into two groups of three beats, with every third beat accented (i.e., BEAT–rest–beat–BEAT–beat–rest).

2.1.3. Apparatus

The auditory stimuli were created using Cakewalk, and recorded as realistic instrumental sounds (i.e., snare drum no. 229, slapstick no. 244) using a Roland 64-Voice Synthesizer Module. Sound files were recorded with Cool Edit 2000, on a personal computer using an AOpen AW-840 4 Channel PCI Sound Card. Stimulus sound files were transferred to a Power Macintosh 7300/180 computer and converted into System 7 sound files for testing. Using a Denon PMA-480R amplifier, sounds were presented from two audiological GSI speakers located inside a large Industrial Acoustics Co. sound attenuated booth. The experiment was run by a custom software program, with a custom interface to an experimenter-controlled button box and lights. The sound booth was set up so that the subject stood or sat between the two speakers, facing the experimenter, both during training and during testing. Auditory stimuli were always presented from both speakers.

2.1.4. Procedure

2.1.4.1. Training. The subject stood between the two speakers, facing the experimenter. The movement was a gentle bouncing up and down by repeatedly bending at the knees on specified beats. The experimenter requested that the subject watch and mirror her movement, imagining that his own "knees were attached" to hers as they bounced. The experimenter extended her hands, palm side up, and the subject rested his hands on top, to assist the subject in following the movement. The experimenter's hands remained at chest-level, so that their movement was aligned with her body movement. All adults began synchronizing their movement almost immediately, after approximately 1–3 bounces. Experimenter and subject bounced throughout the remainder of the 2-min training phase, for 63 repetitions of the training rhythm stimulus. Subjects were assigned to one of two movement conditions in the training phase. In the duple movement condition, bouncing (knee bending) occurred on every second beat (beats 1, 3, and 5). In the triple movement condition, bouncing occurred on every third beat (beats 1 and 4). In other words, during the training phase the bouncing movement provided the accents on the rhythmic strong beats of each subject's respective condition, while the auditory training stimulus was identical in both conditions. Thus, the only difference in the training of the two groups of adults was the beats on which they bounced.

2.1.4.2. Test. Immediately following the training phase the subject was seated between the two loudspeakers, facing the experimenter, and given a two-alternative forced-choice (2AFC) task. Subjects were told to choose the sound that matched what they heard during training; they were never instructed to make their choices based on their movement experience. Thus, the 2AFC task can be considered an implicit measure of whether the subjects' auditory representation of the pattern was biased by the moving experience. The experimenter wore headphones and listened to masking music for the remainder of the experiment. During the testing session sounds were presented to the subject from both speakers. The experimenter pressed a button to begin each test trial. Each trial contained a duple and a triple test stimulus, presented in random order. Presentation of the duple and triple rhythms was counterbalanced for trial 1, so that half of the subjects heard the duple rhythm first, and half heard the triple rhythm first. Eight test trials were presented. Subjects were instructed to choose which of the two stimuli was the same as, or most similar to, the sounds they had heard in the training phase. Subjects were never instructed to recall or match to the movement experience; they were only asked to recall the sound.

2.2. Results and discussion

Adults in the Duple and Triple groups differed significantly in the proportion choosing the duple test stimulus as most similar to what they heard during training, as measured by an independent samples t-test, $t(6) = 4.03$, $p < .003$ (Fig. 3). The two groups did not differ in accuracy; they identified as 'same' the auditory rhythm form that matched their own movement experience, with mean performance accuracy 86%. Thus, bouncing on either every second or every third beat influenced whether adults perceived the ambiguous rhythm in duple or triple form.

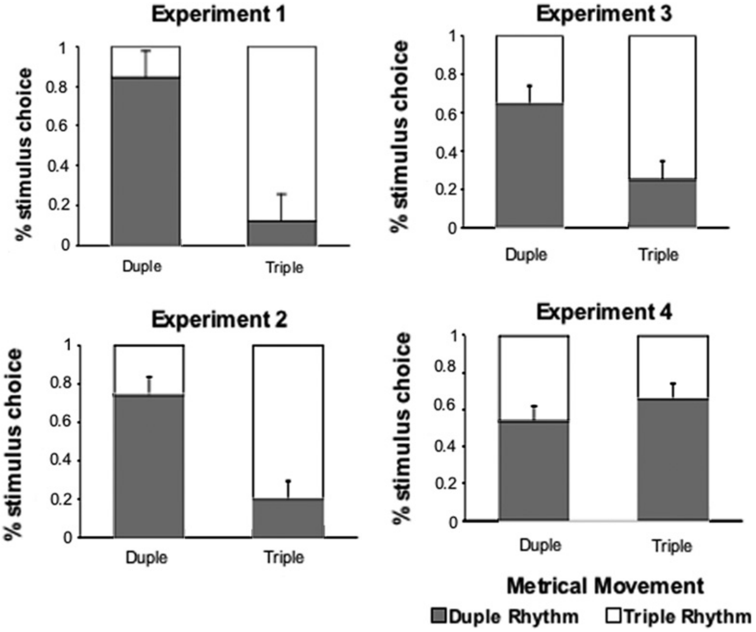

Fig. 3. Results of the four experiments with mean proportion stimulus choice on *y*-axis and movement training on *x*-axis. Experiment 1: adults who bounced while watching and holding the hands of the experimenter identified as 'same' the auditory test stimulus with matching metrical form. Experiment 2: adults who bounced while listening over headphones still identified the matching auditory test stimulus. Experiment 3: adults who bounced while blindfolded still identified the matching auditory test stimulus. Experiment 4: adults who passively observed the experimenter bouncing during training failed to identify the matching auditory test stimulus. Error bars represent the standard error of the mean.

All 8 subjects reported having musical training; however there was no significant correlation between the number of years of musical training and task performance. Because all 8 subjects reported some kind of recreational music activity, no correlations could be performed with this variable. However the correlation between performance accuracy and recreational dance in particular approached significance, $r = .59$, $N = 8$, $p = .06$. Whether recreational dance is a more powerful predictor than musical training of the strength of the auditory-movement interaction needs to be explored further with a larger sample with more variance in musical and dance experience.

It is possible that in Experiment 1 the bouncing of the subject relative to the sound field created by the speakers caused amplitude modulation of the auditory stimulus, providing an acoustical cue to the accented beats. The purpose of Experiment 2 was to control for this possibility by presenting the auditory training stimuli via headphones, rather than from the speakers. The headphones ensured that the subjects experienced no amplitude modulation of the sound while bouncing. If the movement training biases the auditory representation under these circumstances, this would provide strong evidence that the bias was due to the multisensory stimulation.

3. Experiment 2

Experiment 2 was identical to Experiment 1, except that the subjects listened over headphones during training.

3.1. Methods

3.1.1. Participants

The study included 16 (3 males, 13 females) students (aged 18–40, mean age 22.1 years). Musical training ranged from 0 to 15 years (mean 5.4 years). Subjects reported whether or not they participate in any recreational (i.e., without training) music or dancing, either private or public (such as dancing in night clubs): 14 of 16 reported recreational music activity and 8 of 16 reported recreational dancing. One additional adult was excluded due to equipment failure.

3.1.2. Apparatus, stimuli and procedure

The apparatus, stimuli and procedure were the same as in Experiment 1.

3.2. Results and discussion

Adults in the Duple and Triple groups differed significantly in the proportion choosing the duple test stimulus, as measured by an independent samples *t*-test, $t(14) = 3.92$, $p = .001$ (Fig. 3). The two groups did not differ in accuracy; they identified as 'same' the auditory rhythm form that matched their own movement experience with mean performance accuracy 74%. There was no significant difference in performance between Experiments 1 and 2, $t(22) = 1.02$, p(2-tailed) > .1. Thus, the effect of movement on the auditory encoding of the rhythm was not due to amplitude modulation during bouncing. No significant correlations were found between performance accuracy and any of the measures of trained or recreational music or dance activities.

We conclude from Experiments 1 and 2 that the experience of bouncing in either duple or triple form while listening to the ambiguous rhythm pattern influenced whether adults encoded the auditory stimulus as a duple or triple rhythm. Our next question was whether the observed effect in Experiment 1 might be caused by visual cues such as optical flow and object motion. For example, optical flow information can affect balance and perception of self-motion as demonstrated in studies of visual–vestibular interactions in the nervous system (Lakner, 1992). Furthermore, bimodal (i.e. auditory and visual) presentation of a stimulus can enhance perception, both in infants (Bahrick & Lickliter, 2000; Lewkowicz, 2000) and adults (Stein, London, Wilkinson, & Price, 1996; Summerfield, 1979). Thus our aim was to investigate whether removal of such visual cues would inhibit the effect of movement on auditory perception.

Phillips-Silver and Trainor (2005) demonstrated in infants that visual information is not critical to the effect of movement on the auditory encoding of the rhythm pattern. We predicted that adult subjects would be able to identify at test the auditory version of the rhythm pattern that matched the way they had bounced in the absence of visual information.

4. Experiment 3

Experiment 3 was identical to Experiment 1, except that the subject wore a blindfold during training.

4.1. Methods

4.1.1. Participants

The study included 16 (6 males, 10 females) students (aged 18–30, mean age 22.8 years). Musical training ranged from 0 to 15 years (mean 6.3 years). Subjects reported whether or not they participate in any recreational (i.e., without training) music or dancing, either private or public (such as dancing in night clubs): 12 of 16 reported recreational music activity and 7 of 16 reported recreational dancing. Two additional adults were excluded due to failure to follow training or test instructions.

4.1.2. Apparatus, stimuli and procedure

The apparatus, stimuli and procedure were the same as in Experiment 1.

4.2. Results and discussion

Even when blindfolded during training, the adults' body movement significantly affected their auditory encoding. Adults in the Duple and Triple groups differed significantly in the proportion choosing the duple test stimulus, as measured by an independent samples t-test, $t(14) = 2.25, p = .021$ (Fig. 3). The two groups did not differ in accuracy; they identified as 'same' the auditory rhythm form that matched their own movement experience, with mean performance accuracy 70%. There was no significant difference in performance accuracy between Experiments 1 and 3, $t(22) = 1.20$, p(2-tailed) $> .1$. Thus, visual information was not necessary for the effect of movement on auditory encoding. No significant correlations were found between performance accuracy and any of the measures of trained or recreational music or dance activities.

The performance of blindfolded adults corroborated that of blindfolded infants, providing further support for the hypothesis that visual information is not necessary for the encoding effect. This confirms the important role of body movement in the auditory perception of rhythm.

Our infant study demonstrated that while visual information was dispensable in the effect of movement on auditory perception, the subject's own body movement was not (Phillips-Silver & Trainor, 2005). Experiment 4 tested whether adults must experience the actual movement of their own body in order to bias their auditory rhythm perception. The recent discovery of mirror neurons suggests that simple observation of the movement of a conspecific activates representations and memory for the movement (Wilson & Knoblich, 2005). If this mechanism provides a sufficient basis for extracting the metrical structure from observed movement and imposing it on an auditory stimulus, then we should see an effect of observed movement on auditory rhythm perception in adults. Infant subjects did not show such an effect, but the mirror neuron system is reportedly not mature by 6 months of age; the youngest age reported to show evidence of the prediction of action that is purportedly mediated by mirror neurons is 12 months (Falck-Ytter, Gredebäck, & von Hofsten, 2006). On the other hand, if vestibular stimulation is critical for the influence of movement on auditory encoding, then actual movement should be necessary for the cross-modal interaction. This would be consistent with the philosophy of the Dalcroze method: music cognition results from physical experience, and a strong internalization of metrical structure requires the active involvement of the body.

5. Experiment 4

5.1. Methods

5.1.1. Participants

The study included 16 (4 males, 12 females) students (aged 18–30, mean age 21.6 years). Musical training ranged from 0 to 16 years (mean 7.1 years). Subjects reported whether or not they participate in any recreational (i.e., without training) music or dancing, either private or public (such as dancing in night clubs): 11 of 16 reported recreational music activity and 7 of 16 reported recreational dancing. One additional adult was excluded due to failure to follow test instructions.

5.1.2. Procedure

In the training phase subjects were seated in a chair between the two speakers and were instructed to watch the experimenter while listening to the training sounds. The experimenter alone performed the bouncing movement identical to Experiment 1, in either duple or triple form (videotapes of all experimental sessions were recorded to enable the investigators to ensure that the experimenter's movement was equivalent across Experiments 1 through 4). In the test phase, identical to that in Experiment 1, subjects were instructed to choose which of the two test stimuli was the same as, or most similar to, the sounds they had heard in the training phase.

5.2. Results

In contrast with Experiments 1 through 3, no effect of movement on auditory rhythm perception was observed when adults passively watched the experimenter. Adults in the Duple and Triple groups did not differ in the proportion choosing the duple test stimulus, as measured by an independent samples *t*-test, $t(14) = -.72$, p(2-tailed) $= .49$ (Fig. 3). Adults failed to identify an auditory rhythm form matching the movement that they had observed, with performance (mean accuracy 44%) not different from chance. The performance accuracy of bouncing subjects in Experiment 1 was significantly greater than that of seated subjects in Experiment 4, $t(22) = 3.11$,

$p < .003$. Thus, the movement of the subjects' body is critical to biasing auditory perception of the ambiguous rhythm. No significant correlations were found between performance accuracy and any of the measures of trained or recreational music activities.

6. General discussion

In this series of experiments we demonstrated that movement of the body influenced adults' auditory encoding of an ambiguous musical rhythm. We showed that visual information was not necessary for this effect, but that movement of the body was crucial. These results parallel those of our infant studies (Phillips-Silver & Trainor, 2005), and suggest that the strong, early-developing relation between the auditory modality and movement-related sensory inputs is maintained in adulthood.

While the current findings support a strong link between body movement and perception, they challenge the potential influence of mirror neurons in the domain of metrical disambiguation. Recent findings on mirror neurons suggest that mere visual or auditory observation of a conspecific's goal-directed movement (e.g., reaching for an object or hand to mouth action) is sufficient to elicit a neuronal representation of the action (Kohler et al., 2002; Wilson & Knoblich, 2005). Our data, in contrast, show that in the case of extracting the metrical structure from observed body movement, mere observation is not sufficient to strongly bias auditory encoding of the rhythm pattern. Thus, it appears that either this type of rhythmic body movement is not an example of the kind of object-directed action that activates the mirror neuron system (Falck-Ytter et al., 2006; Wilson & Knoblich, 2005), or the information provided by the mirror neurons is not strong enough to influence the later-recalled auditory metrical representation of the rhythm pattern.

The present studies provide an empirical basis for the Dalcroze tradition of movement and embodiment in rhythm theory. A tight link between body and perception is described in the cognition literature as 'embodied' or 'situated' cognition. Lakoff and Johnson (1980, 1999) suggest that our knowledge of concepts, for example the spatial concept of "high" versus "low", is not only inseparable from, but also derives from our bodily experience in the world (see also Barsalou, Simmons, Barbey, & Wilson, 2003; Prinz, 2002). Empirical studies show not only how perceptual and motor representations influence people's cognitive processing, but how sensorimotor representations are tied to symbolic information about the self and the body (Markman & Brendl, 2005; Pecher, Zeelenberg, & Barsalou, 2004). We add our data to this list in support of the idea that sensory perception cannot be separated from the multisensory experience of our bodies. Of course these data do not rule out the possibility that sensory inputs other than those coming from body movement can affect auditory processing, but rather they provide a valuable contribution to the understanding of multisensory perception – namely, of an interaction between auditory and movement systems – with strong evidence that body movement alone can be sufficient to influence auditory encoding of a rhythm stimulus.

To understand the mechanisms underlying rhythmic embodied cognition, future studies might turn to models of attention and memory. For example, Large and Jones' (1999) model of dynamic attending accounts for perception of hierarchical auditory temporal patterns by describing how external rhythm patterns can drive attending and lead to detailed perceptual encoding. Metrical time structure in music is one type of dynamic event hierarchy that elicits attending and entrainment of the perceiver (i.e., "feeling the beat"), making this model a candidate attentional system for extracting the metrical beat from body movement and transferring it to the auditory representation (Jones & Boltz, 1989). Future research might investigate whether this attentional model will extend to our data on meter extraction from body movement and transfer to auditory encoding, in adults as well as in infants. Finally, a model such as Large and Jones' can be used to explore the generalizability of this multisensory interaction to human behaviors other than music, which may integrate auditory perception and body movement, such as speech, mating, and other forms of coordinated action (e.g., Condon & Sander, 1974; Lakin & Chartrand, 2003). Embodiment of rhythm is seen naturally across the world in music, but is by no means necessarily limited to music behavior.

Research on multimodal processing, which has tended to favor audio-visual pairings, provides support for studying music as a multisensory experience. For example, audio-visual interactions have shown auditory dominance for rhythmic, temporal stimuli (Guttman, Gilroy, & Blake, 2005). Yet historical writings on music as well as musical practices and education indicate a strong relation between the movement and auditory modalities in particular. Fraisse (1982) claimed that auditory rhythms are capable of inducing rhythmic action, while visual rhythms are not. Repp and Penel (2004) confirmed this notion by demonstrating that the motor activity of adults' synchronized tapping to a beat is controlled by auditory input, even if attention is focused on visual input. Phillips-Silver and Trainor (2005) showed that when infants feel the beat, their auditory encoding of the rhythm pattern is influenced by movement of their bodies. Here we show that in adults, too, movement can determine the beat that we hear and feel. We therefore characterize musical rhythm processing as a multisensory interaction relying primarily on auditory and movement systems. It has been suggested that we "hear what the eyes see" (Guttman et al., 2005). We have provided evidence that we "hear what the body feels".

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