BEAT PERCEPTION AND PRODUCTION IN MUSICIANS AND DANCERS

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THE ABILITY TO PERCEIVE AND PRODUCE A BEAT IS believed to be universal in humans, but individual ability varies. The current study examined four factors that may influence beat perception and production capacity: 1) *expertise*: music or dance, 2) *training style*: percussive or nonpercussive, 3) *stimulus modality*: auditory or visual, and 4) *movement type*: finger-tap or whole-body bounce. Experiment 1 examined how expertise and training style influenced beat perception and production performance using an auditory beat perception task and a finger-tapping beat production task. Experiment 2 used a similar sample with an audiovisual variant of the beat perception task, and a standing knee-bend (bounce) beat production task to assess whole-body movement. The data showed that: 1) musicians were more accurate in a finger-tapping beat synchronization task compared to dancers and controls, 2) training style did not significantly influence beat perception and production, 3) visual beat information did not benefit any group, and 4) beat synchronization in a full-body movement task was comparable for musicians and dancers; both groups outperformed controls. The current study suggests that the type of task and measured response interacts with expertise, and that expertise effects may be masked by selection of nonoptimal response types.

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MUSIC IS TEMPORAL, UNFOLDING OVER TIME and structured by its temporal features. Processing of certain structural regularities of temporal patterns in music occurs spontaneously, such as perceiving a "beat"—a regularly recurring salient psychological event that arises in response to rhythm (Cooper & Meyer, 1960; Large & Palmer, 2002; Parncutt, 1994).

Beat perception and production abilities, though arising spontaneously, vary across individuals. Individual differences arise from age (McAuley et al., 2006), auditory short term memory capacity (Grahn & Schuit, 2012), cultural exposure (Cameron et al., 2015; Hannon et al., 2012; Soley & Hannon, 2010), music training (Cameron & Grahn, 2014: Grahn & Rowe, 2009; Palmer & Krumhansl, 1990), and can be influenced by stimulus modality (Grahn, 2012; Grahn et al., 2011; McAuley & Henry, 2010). However, other factors remain to be examined. The current study, across two experiments, examines four factors that may influence beat perception and production performance: 1) *expertise*: in music or dance, 2) *training style*: percussive or nonpercussive, 3) *stimulus modality*: auditory or visual, and 4) *movement type*: finger or whole-body.

Music and Dance Experience

Music and dance training are comparable in many respects. Culturally and socially speaking, both are found and often share roots in every known culture and are engaged in by experts and novices alike. Individuals with either music or dance training typically start training at a young age and come from families with similar socioeconomic backgrounds (Pew Research Center, 2015). Moreover, both types of training often focus on the refinement of rhythm processing and sensorimotor synchronization skills—the coordination of movement with an external rhythm or beat (Karpati et al., 2016). However, the types of movement and relation to sound differ for the two training types. Musicians' movements are dependent upon the instrument but are typically isolated to certain body regions (e.g., arms for string instruments). Additionally, the movements are what leads to the creation of sound. Dance movements also vary by style but generally engage more whole-body movements. In dance training sound is added to movements or movements are a response to sound. Because of similarities in their background, comparing musicians and dancers enables us to isolate how their

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different training affects beat perception and production in populations that are otherwise similar.

EFFECTS OF MUSICAL EXPERTISE

Not surprisingly, musicians have more accurate rhythm processing and sensorimotor synchronization performance than nonmusicians. For example, musicians are better at detecting differences in auditory rhythms than nonmusicians (Bailey & Penhune, 2010; Besson & Faita, 1995; Chen et al., 2008; Drake, Penel, & Bigand., 2000; Jongsma et al., 2007). When asked to rate beat saliency in different rhythms, musicians are better able to differentiate beat-based and non-beat-based rhythms (Grahn & Rowe, 2009). Musicians are also better at synchronizing to rhythms (Drake et al., 2000; Repp, 2010; Repp & Doggett, 2007). Musicians synchronize more accurately and are able to tap to a wider range of metrical levels than nonmusicians (Drake et al., 2000). Similarly, when tapping to isochronous sequences with temporal perturbations, musicians generally show smaller asynchronies, lower tapping variability, faster error correction, and greater perceptual sensitivity to timing changes than nonmusicians (Repp, 2010). Music training may provide musicians with a greater range of strategies for processing rhythms (Grahn & Schuit, 2012), or it may enhance sensitivity to underlying temporal structures that make the beat more salient (Bailey & Penhune, 2010). Musicians may perceptually organize events over longer time spans than nonmusicians, thus have a more complete metrical representation of the music, which may give rise to their better synchronization (Drake et al., 2000).

Behavioral differences in rhythm perception between musicians and nonmusicians are paralleled by differences in brain responses: event-related potentials (ERPs), particularly the late positive component (LPC) in the 400–800 ms range elicited by musical incongruities, are larger for musicians than nonmusicians when hearing a rhythmically incongruous musical phrase ending (Besson & Faita, 1995). Moreover, functional magnetic resonance imaging (fMRI) shows that for beat-based rhythms, auditory-motor connectivity is greater in those with music training (Grahn & Rowe, 2009). Thus, behavioral performance may relate to increased auditory-motor coupling, which is important for integrating auditory perception with motor production and may be enhanced by musicians extensive practice using auditory feedback to alter motor production (Chen et al., 2008).

EFFECTS OF DANCE EXPERIENCE

Unlike in music, studies in dance often focus on visual rather than auditory processing (Calvo-Merino, Ehrenberg, Leung, & Haggard, 2010; Lee, Barrett, Kim, Lim, & Lee, 2015; Stevens et al., 2009), and sensorimotor synchronization using whole-body movements rather than finger-tapping (Miura, Kudo, & Nakazawa, 2013; Miura et al., 2011; Miura, Kudo, Ohtsuki, et al., 2013). Dancers are better than nondancers at discriminating between different visual point-light displays of dance movements, recognizing different body configuration, and anticipating dance movements (Calvo-Merino et al., 2010; Hagendoorn, 2004; Stevens et al., 2010). For example, when shown a filmed performance of contemporary dance, dancers' saccades are faster than nondancers' (Stevens et al., 2009), suggesting more accurate expectancies of movements. Viewing dance movements can shape auditory rhythm perception, (Lee et al., 2015), and watching dance movements with a strong visual beat can improve auditory rhythm perception in music (Su & Salazar-López, 2016). Thus, exposure to visual rhythms through dance training may influence the auditory perception of rhythm and beat, but no study to date has directly examined whether dancers and nondancers differ in auditory rhythm processing.

Dancers are better than nondancers at synchronizing to the beat, particularly on tasks that involve whole-body synchronization (Karpati et al., 2016; Miura et al., 2011; Miura et al., 2016; Miura, Kudo, & Nakazawa, 2013; Miura, Kudo, Ohtsuki, et al., 2013). When asked to bounce to the beat by bending at the knees, dancers synchronize more accurately, produce lower variability, and deviate less from the beat time than nondancers (Miura et al., 2011; Miura, Kudo, & Nakazawa, 2013; Miura, Kudo, Ohtsuki, et al., 2013). Similarly, dancers display lower variability in leg movements during a dance synchronization task (Sofianidis et al., 2012), and better coordination with observed dance movements in the presence or absence of auditory cues or music (Washburn et al., 2014). Enhanced synchronization accuracy may be influenced by dancers' better proprioception (Kiefer et al., 2013), better postural control (Rein et al., 2011), greater stability, and stronger interlimb coupling (Buchanan et al., 2007; Sofianidis et al., 2012; Thullier & Moufti, 2004).

Musicians and Dancers

To date, only one study has compared how music and dance training affect performance across a variety of music- and dance-related tasks (Karpati et al., 2016). Behaviorally, on music-related tasks, rhythm synchronization involving finger-tapping, and melody discrimination, musicians outperform dancers (and controls), whereas on dance-related tasks and dance imitation involving whole-body movements, dancers outperform musicians (and controls). Structural MRI studies have shown that both musicians and dancers have increased cortical thickness compared to controls in the superior temporal gyrus, suggesting that auditory neural changes relate to both music and dance (Karpati et al., 2017).

Percussive and Nonpercussive Training

Another factor that may influence beat perception and production ability is what we are terming "training style." Different musical instruments and dance styles can be classified as either percussive or nonpercussive. Here, percussive musical instruments are defined as those played by striking, either directly (e.g., drums) or indirectly (e.g., piano). Percussive styles use sounds and movements with mainly short attack times, whereas nonpercussive styles often use longer attack times. In music, drums or cymbals are classified as percussive, and strings or winds are classified as nonpercussive (Cicchini et al., 2012). In dance, percussive styles involve movements that are "sudden, sharp, choppy, jagged" (Sofras, 2020). such as tap, step-dancing, or hip-hop. Ballet or contemporary are regarded as nonpercussive (Rosenfeld, 2011). Nonpercussive styles may contain percussive movements, but they are not the predominant movement type. Given that percussive training commonly focuses on temporal precision, percussive musicians and dancers may show enhanced rhythm processing and sensorimotor synchronization performance compared to their nonpercussive counterparts.

PERCUSSIVE AND NONPERCUSSIVE MUSIC TRAINING

Percussive musicians perform more accurately on rhythm perception and production tasks than nonpercussive musicians (Cameron & Grahn, 2014; Cicchini et al., 2012; Fujii et al., 2011; Krause et al., 2010; Repp et al., 2013). Percussive musicians, particularly drummers, are better than nonpercussive musicians at perceiving audiovisual asynchrony in point-light displays of drumming movements (Petrini et al., 2009). Percussionists also produce lower variability when synchronizing to isochronous or non-isochronous rhythms (Cameron & Grahn, 2014; Fujii et al., 2011; Krause et al., 2010; Repp et al., 2013), and are more accurate during rhythm reproduction and beat tapping tasks, for both simple and highly complex rhythms (Cameron & Grahn, 2014).

PERCUSSIVE AND NONPERCUSSIVE DANCE TRAINING

No studies to date have directly examined percussive and nonpercussive dancers on the same task. One body of research compared skilled street dancers—a style of dance that is arguably percussive in nature—with nondancers (Miura et al., 2011; Miura, Kudo, & Nakazawa, 2013; Miura, Kudo, Ohtsuki, et al., 2013) and found that dancers deviated less from the intended beat phase compared to nondancers. However, comparing percussive dancers with nondancers is different from comparing percussive dancers with equally trained nonpercussive dancers, hence motivating the current study.

Auditory and Visual Stimulus Modalities

Stimulus modality may influence beat processing. Both music and dance training involve training on auditory and visual rhythm, but music generally relies more on the auditory modality, whereas dance has a greater visual emphasis. Correspondingly, studies have found that musicians are better than nonmusicians at detecting differences in auditory rhythms (Besson & Faita, 1995; Drake et al., 2000; Jongsma et al., 2007), and dancers are better than nondancers at detecting differences of visual dance movements (Calvo-Merino et al., 2010; Hagendoorn, 2004; Stevens et al., 2009). Although musicians and dancers may show a bias towards one modality over the other, auditory and visual integration is fundamental to both music and dance training (Karpati et al., 2016). Music training often requires integrating visual information from reading music with auditory information from one's own and other's output, whereas dance training often requires integrating auditory information from music and visual information from one's own and other's movements (Karpati et al., 2016). In fact, there is evidence to suggest that watching rhythmic visual movement can aid auditory rhythm perception and production (Arrighi et al., 2009; Su, 2014; Su & Salazar-López, 2016).

However, beat processing and sensorimotor synchronization differ for audition and vision. Audition is generally superior to vision for beat perception (Grahn, 2012; Grahn et al., 2011; McAuley & Henry, 2010) and sensorimotor synchronization (Kato & Konishi, 2006; Lorås et al., 2012; Patel et al., 2005). For example, perceiving the beat in auditory rhythms improves subsequent beat perception of visual rhythms, but perceiving a beat in visual rhythms does not affect subsequent beat perception of auditory rhythms (Grahn et al., 2011). Moreover, tap timing is typically less variable when participants synchronize with auditory than visual rhythms (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004). Lastly, when synchronizing to visual rhythms with perturbations, error correction is slower than for auditory rhythms

(Comstock & Balasubramaniam, 2018). According to the *modality appropriateness hypothesis*, different modalities are specialized for different tasks: audition is dominant in temporal processing, whereas vision is dominant in spatial processing (Welch & Warren, 1980). The *modality appropriateness hypothesis* helps explain the auditory dominance observed for beat processing and sensorimotor synchronization, as these processes rely more on temporal than spatial processing.

However, more recent research has challenged the auditory superiority view for rhythm processing. Earlier studies often used spatially static visual stimuli (e.g., a flashing light) that do not provide the rich spatiotemporal information of dynamic visual stimuli may, which may optimize temporal processing (Grondin & McAuley, 2009; Guttman et al., 2005; McAuley & Henry, 2010; Repp & Penel, 2002; Repp & Penel, 2004). Beat perception and sensorimotor synchronization improves with dynamic visual stimuli, such as a rotating line, moving bar, bouncing ball, or a bouncing point-light figure (Grahn, 2012; Hove et al., 2013; Hove & Keller, 2010; Hove et al., 2010; Su, 2014). For example, the tap time variability is lower when synchronizing with visual rhythms derived from apparent motion (i.e., a tapping finger) than those derived from static motion (i.e., a flashing light) (Hove & Keller, 2010). Similarly, asynchrony is lower when synchronizing with a bouncing ball (with a rectified sinusoidal velocity) than a flashing square (Iversen et al., 2015). In fact, synchronizing with a bouncing ball was no more variable than synchronizing with an auditory metronome, suggesting that dynamic stimuli enable better prediction regarding the point (time) of impact.

Effector-Specific and Whole-Body Movements

Musicians and dancers may possess similar sensorimotor synchronization skills (Karpati et al., 2016), but the movements used to execute those skills differ considerably. Musicians often rely on discrete effector-specific movements to produce music, whereas dancers often rely on gross whole-body movements to perform choreography (Karpati et al., 2016). Musicians seem to show advantages in hand and finger movements compared to nonmusicians (Fernandes & de Barros, 2012; Inui & Ichihara, 2001; Verheul & Geuze, 2004), whereas dancers seem to show significantly better proprioception (Kiefer et al., 2013), better postural control (Rein et al., 2011), more stability, and stronger interlimb coupling than nondancers (Buchanan et al., 2007; Sofianidis et al., 2012; Thullier & Moufti, 2004). When musicians and dancers were compared on tasks that involved effector-specific movements (i.e., finger-tapping), musicians outperformed dancers (and controls), but on tasks that involved whole-body movements, dancers outperformed musicians (and controls) (Karpati et al., 2016). Therefore, musicians seem to be more accurate when synchronizing with specific effectors, while dancers seem to be more accurate when synchronizing with the whole body. No studies, to date, have directly compared how music and dance training interact with movement type to affect performance on beat processing or sensorimotor synchronization tasks performed with specific effectors or whole-body movements.

The Current Study

The above-mentioned factors appear to be individually important and can be teased apart but naturalistically are rarely separate. To address the interplay across these factors, we conducted two experiments to investigate their effect on beat perception and production. Experiment 1 examined how percussive and nonpercussive music and dance training influenced beat perception and production. Beat processing performance was measured using the Beat Alignment Test (BAT) taken from the Goldsmiths Musical Sophistication Index (Gold-MSI; Müllensiefen et al., 2014). For the beat perception task, participants made judgments about whether a metronome superimposed onto a piece of music was "on the beat" or "off the beat." For the beat production task, participants tapped in time with the perceived beat of a piece of music. Experiment 2 examined how percussive and nonpercussive music and dance training influenced beat perception and production with an audiovisual variant of the beat perception task, as well as a beat production task that measured bouncing accuracy with motion capture to assess whole-body movements (knee bending).

Experiment 1

The objective of Experiment 1 was to examine how percussive and nonpercussive music and dance training influence performance on the BAT (Müllensiefen et al., 2014). Five groups of participants were tested: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and nonmusician/nondancer controls. We predicted that musicians and dancers would not significantly differ in performance on the beat processing tasks, as both types of training focus on the refinement of rhythm and synchronization skills (Karpati et al., 2016), but that they would outperform

TABLE 1. *Participant Characteristics for Experiment 1*

	Percussive musicians	Nonpercussive musicians	Percussive dancers	Nonpercussive dancers	Controls
n	20	20	20	20	20
Sex	7 females 13 males	10 females 10 males	19 females 1 male	19 females 1 male	16 females 4 males
Age range (years)	18 to 48	18 to 31	18 to 43	18 to 36	18 to 26
Mean age (years ± *SD*)	23.7 ± 6.8	22.0 ± 3.8	25.1 ± 6.7	21.2 ± 4.4	19.4 ± 2.7
Music training (years ± *SD*)	17.0 ± 4.9	13.8 ± 6.4	2.0 ± 2.0	1.5 ± 2.1	1.0 ± 1.3
Dance training (years ± *SD*)	0.6 ± 0.9	0.5 ± 1.0	18.5 ± 7.1	14.6 ± 6.0	0.3 ± 1.0
Starting age in respective expertise (years ± *SD*)	6.1 ± 2.4	9.1 ± 3.7	5.6 ± 3.9	6.6 ± 4.8	-
Weekly practice in respective expertise (hours ± *SD*)	9.2 ± 6.2	11.6 ± 7.5	13.8 ± 6.9	12.3 ± 6.5	-
Weekly music exposure (hours ± *SD*)	16.8 ± 5.2	14.8 ± 6.8	14.3 ± 7.9	13 ± 8.6	12.5 ± 6.6

controls. We also predicted that percussionists would outperform nonpercussionists, as percussive training focuses on perceiving and maintaining a steady and precise beat more than nonpercussive training (Cameron & Grahn, 2014; Cicchini et al., 2012; Petrini et al., 2009).

METHOD

Participants

Five groups of 20 participants each were tested: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and controls. There was total of 100 participants. Participants ranged in age from 18 to 48 years ($M = 22.27$ years, $SD = 5.41$ years). Table 1 summarizes the demographic characteristics of the sample for Experiment 1. For an individual to be classified as a musician or a dancer, they needed at least five years of formal training in either music or dance, and to be currently playing or dancing. Individuals with both music and dance training that exceeded five years were excluded. Musicians whose main instruments were drums or keyboards were classified as percussive musicians, whereas musicians whose main instruments were brass, strings, or winds were classified as nonpercussive musicians (Cicchini et al., 2012). Likewise, dancers whose main dance styles were hip-hop, street, or tap were classified as percussive dancers, whereas dancers whose main dance styles were ballet, contemporary, or lyrical were classified as nonpercussive dancers (Rosenfeld, 2011). Individuals whose main instruments or whose main dance styles could be classified as both percussive and nonpercussive were excluded. Finally, controls must have had less than five years of formal training in music and dance. All participants reported normal hearing and normal or corrected-to-normal vision. Participants received either one research credit or $10.00 (CAD) for their participation. All participants provided informed consent in accordance with the guidelines approved by the University of Western Ontario Psychology Research Ethics Board.

Tasks

Beat processing abilities were tested using the BAT v.1.0 taken from the Gold-MSI (Müllensiefen et al., 2014). The BAT consists of a beat perception and a beat production task. The tasks were administered on a PC laptop using E-Prime (2.0) software (Psychology Software Tools, 2002). All auditory stimuli were delivered through Sennheiser HD 280 headphones at a comfortable volume. The task order was counterbalanced across participants. Each participant completed both tasks in one session. The entire session took approximately 30 mins. All participants were fully debriefed following the study.

Beat Perception Task. Participants listened to 20 short instrumental clips (10 to 16 s long) and decided whether a train of beeps superimposed on top of the music track was "on the beat" or "off the beat." The 20 clips were taken from 12 different musical pieces chosen from three distinct genres which differed stylistically and instrumentally: rock, jazz, and pop orchestral. The tempo of the musical pieces varied between 85 and 165 beats per minute. Nine of the clips were in duple meter while three clips (one from each genre) were in triple meter. For the off-beat trials, there were two possible types of errors: the beeps were either too fast or too slow in tempo either by 2% or 10% relative to the beat of the music track creating a "tempo error," or the beeps were too early or too late either by 10% or 17.5% of the beat period creating a "phase error." There were five "on-beat" trials, nine "off-beat tempo error" trials, and six "off-beat phase error" trials. One clip from each of the three trial types was used as practice, consequently there were 17 test clips (see Müllensiefen et al., 2014, for full documentation on the stimuli). The order of the trials was randomized for each participant. Participants were instructed to not move in any way to keep the beat, and to respond only when prompted.

Beat Production Task. Participants listened to the same instrumental clips (without the superimposed beeps) as those in the Beat Perception Task and tapped in time to the beat on the spacebar of a laptop keyboard. They were to start tapping as soon as they found the beat, and to continue until the end of the trial. Participants were allowed to synchronize to any integer multiple or subdivision of the beat rate to allow for the fact that different participants might synchronize to different levels of the metrical hierarchy. One clip was used as practice, making 13 test clips in total. The order of the trials was randomized for each participant.

Statistical Analyses. Beat perception was analyzed by calculating the proportion of trials correctly identified as having the beeps "on the beat" or "off the beat." Beat production was analyzed using three measures: coefficient of variation (CoV), coefficient of deviation (CDEV), and asynchrony. All measures were analyzed with a 2 (*expertise*: in music and dance) x 2 (*training style*: percussive and nonpercussive) between groups analysis of variance (ANOVA). A 1 x 5 (*group*: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and controls) ANOVA was also conducted to include the control group for all measures, as well as for all group demographics analyses. Post hoc pairwise comparisons were conducted where appropriate and multiple comparisons were accounted for with Bonferroni correction. All hypothesis tests used $\alpha = .05$ for significance. Data were analyzed with SPSS (23.0) software.

Coefficient of Variation. CoV measures the variability of a participant's tapping, independent of the music. To calculate CoV, a participant's interresponse intervals (IRIs) for each trial were calculated, by subtracting the time of each tap response from that of the next tap response. Any IRIs that were less than 0.50 or greater than 1.50 of the mean IRI for that trial were removed. CoV for each trial was then calculated by dividing the standard deviation of the IRIs by the mean IRI for that trial.

$$\mathrm{CoV} = \frac{\mathrm{SD}_{\mathrm{IRI}}}{\mathrm{MEAN}_{\mathrm{IRI}}} \tag{1}$$

The CoV values were then averaged across all 13 trials to obtain a single CoV score for each participant. A lower CoV value indicates less tapping variability, while a higher CoV value indicates more tapping variability.

Coefficient of Deviation. CDEV measures the participant's accuracy in matching their tap timing to the tempo of the music. CDEV was calculated by taking the mean of the absolute difference between each IRI and its corresponding interbeat interval (IBI) in the music, and dividing that difference by the mean IBI for that trial. This normalized the CDEV for the different tempi across trials. Because participants could choose different levels of the metrical hierarchy as the perceived beat, the relevant IBI for the calculation was determined by comparing the mean IRI of the trial to potential IBIs that were multiples of the tempo (i.e., different levels of the metrical hierarchy). This allowed for a meaningful analysis of CDEV regardless of what metrical level the participant chose to tap to.

$$\mathrm{CDEV} = \frac{\mathrm{MEAN}_{|\mathrm{IRI}-\mathrm{IBI}|}}{\mathrm{MEAN}_{\mathrm{IBI}}} \tag{2}$$

The CDEV values were then averaged across all 13 trials to obtain a single CDEV score for each participant. A lower CDEV value indicates less deviation between the response tempo and the beat tempo of the music, indicating better tempo matching.

Asynchrony. Asynchrony measures the participant's ability to match each tap to the corresponding beat in the music. For each tap, it assesses whether participants tapped earlier or later than the beat. To measure asynchrony, the mean of the absolute difference between each response and the nearest beat position in the stimulus was calculated. The mean absolute difference was divided by the mean IBI for that trial to normalize for the different tempi across trials. As for the CDEV, the relevant IBI was selected by comparing the mean IRI to potential IBIs of multiple metrical levels to allow for a meaningful analysis of asynchrony at different metrical levels of synchronization.

$$\mathrm{ASYNCHRONY} = \frac{\mathrm{MEAN}_{|\mathrm{RESPONSE}-\mathrm{BEAT}|}}{\mathrm{MEAN}_{\mathrm{IBI}}} \tag{3}$$

The asynchrony values were then averaged across all 13 trials to obtain a single asynchrony score for each participant. A lower asynchrony value indicates less deviation between the response phase and the beat phase of the music, indicating higher accuracy.

RESULTS

Group Demographics

All means and standard deviations for group demographics can be found in Table 1. One-way (1 x 5) ANOVAs conducted on years of music and dance training revealed significant between group differences for both music, $F(4, 95) = 78.38$, $p < .001$, $\eta^2 = .77$, and dance training, $F(4, 95) = 90.22$, $p < .001$, $\eta^2 = .79$. Post hoc comparisons using Bonferroni corrections confirmed that controls and percussive dancers as well as nonpercussive dancers did not differ in years of music training, $t(38) = 1.96$, $p = .29$ and $t(38) = 1.00$, $p = 1.00$, respectively. Percussive musicians and nonpercussive musicians also did not significantly differ in years of music training, $t(38) = 1.77$, $p = .42$, but did significantly differ from controls: $t(38) = 14.24$, $p < .001$ and $t(38) = 8.71$, $p < .001$, percussive dancers: $t(38) = 12.70$, $p < .001$ and $t(38) = 7.78$, $p < .001$, and nonpercussive dancers: $t(38) = 13.03$, $p < .001$ and $t(38) = 8.07$, $p < .001$, respectively.

Likewise, for years of dance training, post hoc comparisons using Bonferroni corrections confirmed that controls and musicians, both percussive and nonpercussive did not differ, $t(38) = .82$, $p = 1.00$ and $t(38) = .66$, $p = 1.00$, respectively. Percussive dancers and nonpercussive dancers also did not significantly differ in years of dance training, $t(38) = 1.89$, $p = .34$. However, percussive dancers and nonpercussive dancers did significantly differ from controls: $t(38) = 11.42$, $p < .001$ and $t(38) = 10.56$, $p < .001$, percussive musicians: $t(38) = 11.27$, $p < .001$ and $t(38) = 10.38$, $p < .001$, and nonpercussive musicians: $t(38) = 11.30$, $p < .001$ and $t(38) = 10.42$, $p < .001$, respectively.

To determine whether overall training amounts differed between musicians and dancers, independent samples *t*-tests were also conducted on years of training, age of training commencement, and hours of practice per week for each music and dance group's respective expertise. Musicians' years of music training did not significantly differ from dancers' years of dance training, $t(78) = 0.86$, $p = .39$. Musicians and dancers also did not significantly differ in starting age $t(78) = 1.76$, $p = .08$ or number of hours practiced per week, $t(78) = 0.50$, $p = .62$.

To confirm that any differences in performance between musicians and dancers were not due to differences in music exposure, an independent samples *t*-test was conducted on the hours of music exposure per week. There were no significant differences between groups, $\mathrm{t}(78) = 1.30$, $p = .20$.

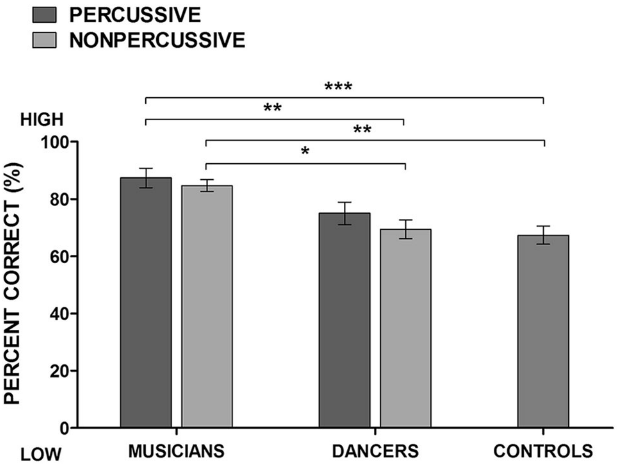

FIGURE 1. Performance on the beat perception task. As a group, musicians were significantly more accurate in identifying whether beeps were "on" or "off" the beat than dancers, but percussionists and nonpercussionists did not differ. Both percussive and nonpercussive musicians were more accurate than controls and nonpercussive dancers, but not percussive dancers, at perceiving the beat. Error bars indicate standard error of the mean. *$p < .05$ **$p < .01$ ***$p < .001$

Beat Perception Task

Percent Correct. Musicians ($M = 86.03\%$, $SE = 1.99\%$) scored better on the beat perception task than dancers ($M = 72.21\%$, $SE = 2.56\%$), $F(1, 76) = 18.08$, $p < .001$, $\eta^2 = .19$. There was no effect of training style, $F(1, 76) = 1.61$, $p = .21$, $\eta^2 = .02$, as percussionists ($M = 81.18\%$, $SE = 2.76\%$) and nonpercussionists ($M = 77.06\%$, $SE = 2.28\%$) performed similarly. The interaction between expertise and training style was also not significant, $F(1, 76) = 0.21$, $p = .65$, $\eta^2 = .003$. In the 1 x 5 between-subjects ANOVA that included controls there was a significant of group, $F(4, 95) = 7.66$, $p < .001$, $\eta^2 = .24$. Post hoc comparisons using Bonferroni corrections indicated that both percussive ($M = 87.35\%$, $SE = 3.42\%$) and nonpercussive musicians ($M = 84.71\%$, $SE = 2.11\%$) were significantly better at the beat perception task than controls ($M = 67.35\%$, $SE = 3.18\%$), $p < .001$ and $p = .00,3$ respectively, and nonpercussive dancers ($M = 69.41\%$, $SE = 3.27\%$), $p = .002$ and $p = .012$, respectively, but not percussive dancers ($M = 75.00\%$, $SE = 3.93\%$), $p = .082$, and $p = .336$, respectively (Figure 1).

Beat Production Task

To assess whether the tap rate (level of metrical hierarchy) at which the different groups chose to synchronize differed, a 1 x 5 between-subjects ANOVA that included controls ($M = 663.45$, $SE = 40.35$), percussive dancers ($M = 602.43$, $SE = 35.61$), nonpercussive dancers ($M = 635.49$, $SE = 35.61$), percussive musicians ($M = 594.18$, $SE = 135.91$), and nonpercussive musicians ($M = 600.80$, $SE = 33.41$) was performed. The results indicated there were no significant differences on the average tap rate across stimuli, $F(4, 95) = 0.70$, $p = .60$, $\eta^2 = .03$. Additionally, a 1 x 3 between-subjects ANOVA with controls, dancers ($M = 618.96$, $SE = 25.07$) and musicians ($M = 597.49$, $SE = 22.30$) similarly indicated no difference on the metrical hierarchy that participants chose to synchronize to when tapping, $F(2, 97) = 1.18$, $p = .31$, $\eta^2 = .02$.

Coefficient of Variation (CoV). The 2 x 2 between-subjects ANOVA on tapping variability revealed a significant main effect of expertise, $F(1, 76) = 14.44$, $p < .001$, $\eta^2 = .16$. Musicians ($M = .047$, $SE = .002$) were less variable than dancers ($M = .061$, $SE = .003$). There was no significant main effect of training style, $F(1, 76) = 0.23$, $p = .63$, $\eta^2 = .03$. Tapping variability did not significantly differ between percussionists ($M = .053$, $SE = .002$) and nonpercussionists ($M = .055$, $SE = .003$). The interaction between expertise and training style was also not significant, $F(1, 76) = 0.01$, $p = .92$, $\eta^2 < .001$. The between-subjects 1 x 5 ANOVA revealed a significant effect of group, $F(4, 95) = 8.32$, $p < .001$, $\eta^2 = .26$. Bonferroni corrected post hoc comparisons indicated that percussive ($M = .046$, $SE = .002$) and nonpercussive musicians ($M = .047$, $SE = .003$) were less variable than controls ($M = .080$, $SE = .007$), $p < .001$ and $p < .001$, respectively. Percussive dancers ($M = .060$, $SE = .005$), $p = .044$, but not nonpercussive dancers ($M = .062$, $SE = .004$), $p = .11$, were also less variable than controls (Figure 2).

Coefficient of Deviation (CDEV). Musicians ($M = .041$, $SE = .002$) tapped to the tempo of the music with greater accuracy (lower mean CDEV) than dancers ($M = .053$, $SE = .004$), $F(1, 76) = 7.49$, $p < .01$, $\eta^2 = .09$. There was no significant main effect of training style, $F(1, 76) = 0.51$, $p = .48$, $\eta^2 = .007$. Percussionists ($M = .046$, $SE = .003$) and nonpercussionists ($M = .049$, $SE = .003$) did not differ in matching their tapping tempo to the beat tempo of the music. The interaction between expertise and training style was also not significant, $F(1, 76) = 0.05$, $p = .83$, $\eta^2 < .01$. The 1 x 5 between-subjects ANOVA conducted to compare tempo matching accuracy in the five groups produced a significant effect of group, $F(4, 95) = 4.87$, $p < .01$, $\eta^2 = .17$. Post hoc comparisons using Bonferroni corrections indicated that percussive ($M = .039$, $SE = .002$) and nonpercussive musicians ($M = .043$, $SE = .005$) tapped to the tempo of the music with greater accuracy than controls ($M = .069$, $SE = .007$) $p = .001$ and $p = .008$, respectively. Tempo matching accuracy was numerically greater for percussive ($M = .052$, $SE = .006$) and nonpercussive dancers ($M = .055$, $SE = .004$) than controls, but the differences were not statistically significant, $p = .29$ and $p = .58$, respectively (Figure 3).

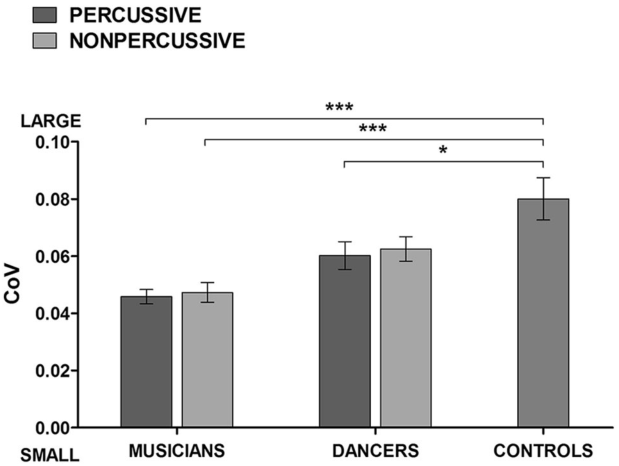

FIGURE 2. Coefficient of variation on the beat production task. As a group, musicians were significantly less variable than dancers, but percussionists and nonpercussionists did not differ. Percussive and nonpercussive musicians, as well as percussive dancers, were significantly less variable than controls. Error bars indicate standard error of the mean. $*p < .05$ $***p < .001$

Asynchrony. The 2 x 2 between subjects ANOVA on tapping accuracy (asynchrony) produced a significant main effect of expertise, $F(1, 76) = 7.41$, $p < .01$, $\eta^2 = .09$. Musicians ($M = .070$, $SE = .006$) produced a smaller mean absolute asynchrony than dancers ($M = .100$, $SE = .009$). There was no significant main effect of training style, $F(1, 76) = 0.95$, $p = .33$, $\eta^2 = .01$. Percussionists ($M = .079$, $SE = .007$) and nonpercussionists ($M = .090$, $SE = .009$) did not differ in their ability to match their tap times to the beat times. The interaction between expertise and training style was also not significant, $F(1, 76) = 0.002$, $p = .97$, $\eta^2 < .001$. The 1 x 5 between-subjects ANOVA on asynchrony produced a significant effect of group, $F(4, 95) = 3.14$, $p < .05$, $\eta^2 = .12$. Post hoc comparisons using Bonferroni corrections indicated that percussive musicians ($M = .064$, $SE = .006$), but not nonpercussive musicians ($M = .075$, $SE = .010$), were significantly better at matching their tapping to the beat than controls, ($M = .111$, $SE = .011$) $p = .04$ and $p = .28$, respectively. However, tapping asynchrony did not significantly differ between

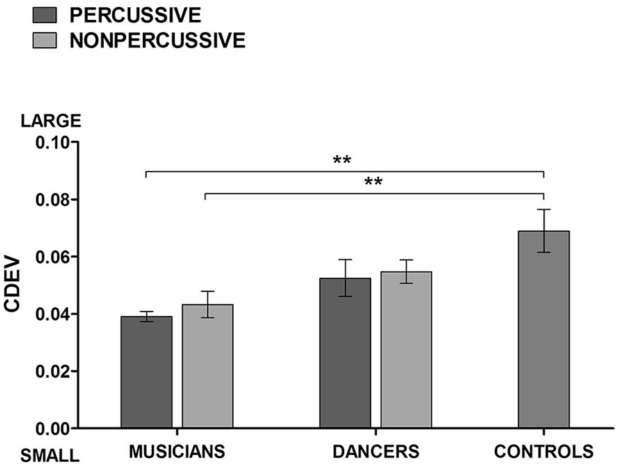

FIGURE 3. Coefficient of deviation (tempo matching) on the beat production task. As a group, musicians were significantly better at matching the tempo than dancers, but percussionists and nonpercussionists did not differ. Relative to controls, only percussive and nonpercussive musicians were significantly more accurate. Error bars indicate standard error of the mean. $^{**}p < .01$

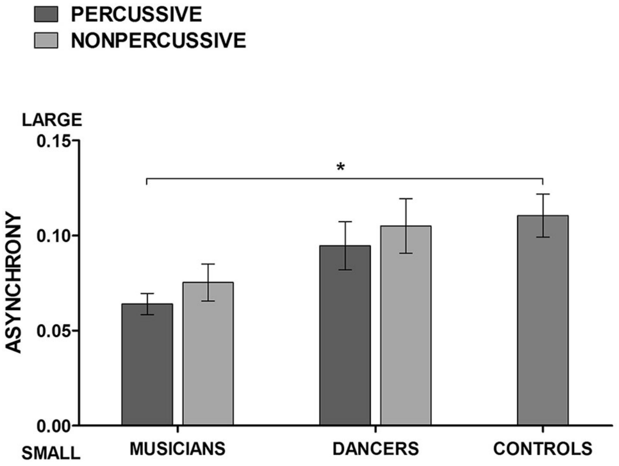

FIGURE 4. Asynchrony performance (as a proportion of the beat interval) on the beat production task. As a group, musicians had a significantly lower mean asynchrony than dancers, but percussionists and nonpercussionists did not differ. Relative to controls, only percussive musicians were significantly better at matching their tapping to the beat. Error bars indicate standard error of the mean. $^{*}p < .05$

percussive dancers ($M = .095$, $SE = .012$) and nonpercussive dancers ($M = .105$, $SE = .014$) compared to controls, $p = 1.00$ and $p = 1.00$, respectively (Figure 4).

Correlations

Pearson correlation coefficients were computed to assess the relationship between beat perception (percent correct) and beat production (CoV, CDEV, and asynchrony). There were significant correlations between percent correct and all three measures of beat production: CoV, $r = -.530$, $p < .001$, CDEV, $r = -.478$, $p < .001$, and asynchrony, $r = -.480$, $p < .001$. In addition, the three beat production measures significantly correlated with each other: CoV and CDEV, $r = .896$, $p < .001$, CoV and asynchrony, $r = .541$, $p < .001$, CDEV and asynchrony, $r = .614$, $p < .001$. Thus, variability in tapping correlated with deviation from the beat tempo and asynchrony, and deviation from the beat tempo correlated with asynchrony. The three measures of beat production assess different, but clearly related, aspects of beat production.

Discussion

Experiment 1 examined how percussive and nonpercussive music and dance training related to beat perception and production. We predicted that musicians and dancers would not significantly differ, as both types of training refine rhythm processing and sensorimotor synchronization skills (Karpati et al., 2016). However, we found that music training was associated with better performance than dance training. On the beat perception task, musicians were more accurate at perceiving whether "beeps" in the music were on or off the beat than dancers and controls. When tapping the beat along to music, musicians had significantly lower variability, lower mean absolute asynchrony, and better tempo matching than dancers and controls. Dancers performed better than controls, but not significantly so. Thus, on these tasks, music but not dance training was related to better performance.

We also predicted that percussionists would outperform nonpercussionists, as percussive training focuses on steady and precise beat timing (Cameron & Grahn, 2014). However, percussive training did not significantly alter beat processing performance: on all measures of beat perception and production, performance was similar for percussionists and nonpercussionists. Other work suggests that percussionists have enhanced beat processing compared to nonpercussionists (Cameron & Grahn, 2014; Petrini et al., 2009; Repp, 2005). Although we excluded individuals whose *primary* instruments or dance styles could be classified as both percussive and nonpercussive, we did not exclude individuals who had limited training outside their category (e.g., a percussionist may have had limited nonpercussive training in addition to their primary percussion training). Therefore, the lack of significant difference may have been because the distinction between the two groups was not strong or extreme enough.

It is possible that musicians' better performance may be task specific. Arguably, the tasks used in Experiment 1 were more music-relevant than dance-relevant. Specifically, auditory stimuli and a finger-tapping task were used, which may be more related to music training activities (Fernandes & de Barros, 2012; Repp, 2010; Verheul & Geuze, 2004). Compared to music, dance relies on visual stimuli in addition to auditory, as well as whole-body—not just finger—movements (Karpati et al., 2016; Miura et al., 2011; Miura et al., 2016). Therefore, in Experiment 2, we used a beat perception and production task that were more dance-relevant, that may be more sensitive to the effect of dance training.

Experiment 2

One limitation for Experiment 1 may have been that the distinction between percussive and nonpercussive groups was not strong enough. As long as the participant's primary instrument or dance style was percussive, they were considered a percussionist, and vice versa for participants whose main instrument or dance style was nonpercussive. The classification did not exclude those who had experience outside their primary domain. To address this limitation, in Experiment 2, only musicians and dancers whose training was exclusively percussive or nonpercussive were recruited, excluding any participants with both percussive and nonpercussive training.

The tasks were also changed in Experiment 2. Beat perception and production were tested using an audiovisual variant of the BAT and whole-body movements (i.e., knee bending), respectively. Both music and dance training focus on the processing of auditory and visual rhythms, but dance may rely more on the visual modality. Therefore, the additional visual information in the audiovisual BAT may be more beneficial to dancers. Moreover, musicians often rely on discrete effector-specific movements to produce music, whereas dancers often rely on gross whole-body movements to perform choreography (Karpati et al., 2017). Therefore, it may be that musicians' beat production is more accurate with ecologically valid effector-specific movements, but dancers' beat production will be more accurate with ecologically valid whole-body movements.

For the audiovisual beat perception task, participants made perceptual judgements of audiovisual stimuli (a music sample plays while they watched a visual bouncing stick figure). See Figure 5 for a depiction of the stimuli. For the beat production task, participants listened to short instrumental clips while standing, and bounced (by bending their knees) in time to the beat while motion capture equipment measured whole-body movement timing. The beat point was defined as the lowest point of the bounce and was used to determine whether the bounce was in time with the beat for both the perception and production task. Five groups of participants, as defined by the above stricter classification, were tested: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and controls.

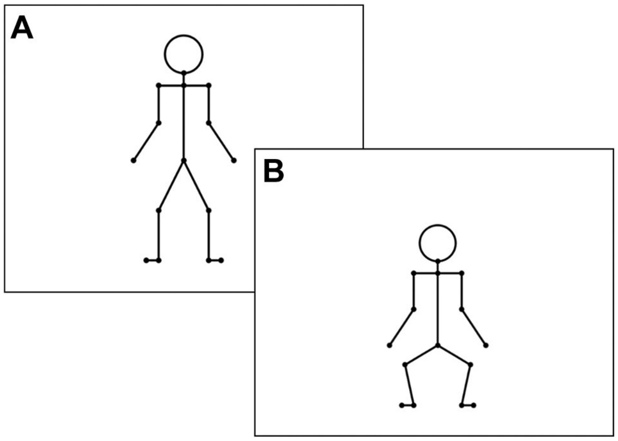

FIGURE 5. Visual representation of the bouncing stick figure. A) depicts the stick figure in the most upright position. B) depicts the stick figure in the most bent position.

If the musicians' better performance in Experiment 1 was not task specific, then the musicians should outperform the dancers in both the audiovisual beat perception and the bouncing beat production tasks. If, however, the musicians' better performance in Experiment 1 was task specific, then the dancers should outperform the musicians, or perform comparably. We also predicted that musicians and dancers would outperform controls on both tasks (Karpati et al., 2016), and that percussionists would outperform nonpercussionists (Cameron & Grahn, 2014; Cicchini et al., 2012; Petrini et al., 2009).

METHOD

Participants

Five groups of participants were tested: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and controls. There were 20 participants in each group, for a total of 100 participants. Participants ranged between the ages of 18 and 44

TABLE 2. *Participant Characteristics for Experiment 2*

	Percussive musicians	Nonpercussive musicians	Percussive dancers	Nonpercussive dancers	Controls
n	20	20	20	20	20
Sex	14 females 6 males	13 females 7 males	16 females 4 male	19 females 1 male	16 females 4 males
Age range (years)	19 to 36	19 to 26	18 to 35	18 to 35	18 to 44
Mean age (years ± *SD*)	23.2 ± 4.8	22.1 ± 2.5	22.4 ± 3.9	23.0 ± 4.3	22.6 ± 6.9
Music training (years ± *SD*)	15.5 ± 6.3	12.8 ± 3.8	1.4 ± 1.9	1.6 ± 2.2	1.3 ± 1.8
Dance training (years ± *SD*)	1.3 ± 2.2	0.3 ± 1.1	14.9 ± 6.6	15.6 ± 4.6	0.3 ± 0.7
Starting age in respective expertise (years ± *SD*)	7.0 ± 2.1	8.9 ± 3.6	7.5 ± 5.0	5.4 ± 3.6	-
Weekly practice in respective expertise (hours ± *SD*)	8.6 ± 8.6	11.5 ± 8.2	8.4 ± 6.4	10.0 ± 7.9	-
Weekly music exposure (hours ± *SD*)	12.1 ± 7.4	16.0 ± 7.7	14.3 ± 6.8	14.0 ± 7.0	14.3 ± 7.0

years ($M = 22.64$ years, $SD = 4.64$ years). Table 2 summarizes the demographic characteristics of the sample. The participant criteria for Experiment 2 was identical to participant criteria for Experiment 1, except that only musicians and dancers whose training was exclusively percussive or nonpercussive were recruited. Individuals with more than five years of training in any instruments or dance styles that could be classified as both percussive and nonpercussive were excluded from the study. These stricter criteria for training style were imposed to better distinguish the percussionist and nonpercussionist groups. All participants reported normal hearing and normal or corrected-to-normal vision. Participants received either one research credit or $10.00 (CAD) for their participation. All participants provided informed consent in accordance with the guidelines approved by the University of Western Ontario Psychology Research Ethics Board.

Tasks

The perception and production tasks were administered on a PC laptop using E-Prime (2.0) software (Psychology Software Tools, 2002). Auditory stimuli for the perception task was delivered through Sennheiser HD 280 headphones at a comfortable volume. The task order was counterbalanced across participants: either perception followed production, or vice versa. Each participant completed both tasks in one session. The entire session took approximately 30 mins. All participants were fully debriefed following the study.

Audiovisual Beat Perception Task. Participants watched 20 short video clips (10 to 16 seconds long) of a stick figure bouncing to music (see Figure 5) and decided whether the figure was bouncing "on the beat" or "off the beat." The bouncing stick figure was programmed in MATLAB R2014a (The MathWorks Inc., Natick, MA). All stimuli videos used for this task can be found at http://www.jessicagrahn.com/NguyenSidhu Everlingetal.html. The timing of the bounces was generated from the IBIs of each musical piece and the movement trajectory was programmed according to the average timing trajectory recorded from a dancer who bounced to each clip five times while undergoing motion capture. The 20 video clips were generated using the 12 different musical pieces from the study in Experiment 1. For the off-beat trials, there were two possible types of errors: the bounces were either too fast or too slow in tempo relative to the beat of the music, creating a "tempo error," or the bounces were too early or too late relative to the beat onset creating a "phase error". To make the "off-beat" trials easy enough to perceive (as determined by piloting), any clips with a $\frac{4}{4}$. time signature were offset by 33% of the IBI and any clips with a $\frac{3}{4}$ time signature were offset by 25% of the IBI. Asynchronous audiovisual information may still be perceived as simultaneous if onsets occur within approximately 100 ms, therefore the "off-beat" trials had audio-visual offsets between 100 and 132 ms. There were five "on-beat" trials, nine "off-beat tempo error" trials, and six "off-beat phase error" trials. One clip from each of the three trial types was used as practice, consequently there were 17 test clips. The order of the trials was randomized for each participant. Participants were instructed to not move in any way to keep the beat, and to respond only when prompted.

Bouncing Beat Production Task. The bouncing beat production task was identical to that used in Experiment 1, except that participants were standing, and instructed to bounce to the beat by bending their knees, ensuring that the bottom of their bounces were synchronized with the beat. They were to start bouncing as soon as they perceived the beat, and to continue until the end of the trial. Participants were not required to synchronize to any specific metrical level, allowing for the fact that different participants might synchronize to different levels of the metrical hierarchy. Their movements were recorded by a three-camera optoelectronic recording system (Optotrak, Northern Digital Inc., Waterloo, Canada). The system captured the three-dimensional (3D) positions of infrared-emitting diodes (IREDs) attached to black foam knee pads (two IREDs on each knee) worn by the participant. Using custom in-house software (OTCollect, programmed by Haitao Yang), the 3D positions of each IRED were recorded at 250 Hz as the participant bounced, and used to calculate the spatial displacement of the knees. The motion capture was time locked to the start of the trial. Each trial was recorded for 20 s. One clip was used as practice, so there were 13 test clips in total. The practice trial for each participant was always the same, while the order of the test trials was randomized.

Statistical Analyses. Beat perception was analyzed by calculating the proportion of trials correctly identified as "on the beat" or "off the beat." Beat production was analyzed using three measures: CoV, CDEV, and asynchrony. Custom in-house software (OTDisplay, programmed by Haitao Yang) was used to calculate the IRIs, which were the times from the onset of one bounce to the onset of the subsequent bounce. IRIs were calculated for each of the four IREDs, and then averaged to get one set of IRIs for each trial. The IRIs for each of the trials were used to calculate CoV, CDEV, and asynchrony, as in Experiment 1. All measures were analyzed with a 2 (*expertise*: in music and dance) x 2 (*training style*: percussive and nonpercussive) between groups ANOVA. A 1 x 5 (*group*: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and controls) ANOVA was also conducted to include the control group for all measures, as well as for group demographics analyses. Post hoc pairwise comparisons were conducted where appropriate and corrected for multiple comparisons using Bonferroni correction. All hypothesis tests used $\alpha = .05$ for significance. Data were analyzed with SPSS (23.0) software.

RESULTS

Group Demographics

One-way (1 x 5) ANOVAs were conducted on years of music and dance training with group (percussive musicians, nonpercussive musicians, percussive dancers, and nonpercussive dancers, controls) as the between groups variables. Means and standard errors for group demographics can be found in Table 2. Years of training significantly differed between groups for both music, $F(4, 95) = 76.05$, $p < .001$, $\eta^2 = .76$, and dance training, $F(4, 95) = 91.63$, $p < .001$, $\eta^2 = .79$. Bonferroni corrected post hoc comparisons confirmed that controls and dancers, percussive and nonpercussive, did not differ in years of music training, $t(38) = 0.17$, $p = 1.00$ and $t(38) = 0.54$, $p = 1.00$, respectively. Percussive musicians and nonpercussive musicians also did not significantly differ in years of music training, $t(38) = 1.68$, $p = .51$. However, percussive musicians and nonpercussive musicians did significantly differ from controls: $t(38) = 9.80$, $p < .001$ and $t(38) = 12.23$, $p < .001$, percussive dancers: $t(38) = 9.71$, $p < .001$ and $t(38) = 12.04$, $p < .001$, and nonpercussive dancers: $t(38) = 9.38$, $p < .001$ and $t(38) = 11.35$, $p < .001$, respectively.

Similarly, for years of dance training, post hoc comparisons using Bonferroni corrections confirmed that controls and musicians, percussive and nonpercussive, did not significantly differ, $t(38) = 1.83$, $p = .37$ and $t(38) = .17$, $p = 1.00$, respectively. Percussive dancers and nonpercussive dancers also did not significantly differ in years of dance training, $t(38) = 0.42$, $p = 1.00$, but did significantly differ from controls: $t(38) = 9.78$, $p < .001$ and $t(38) = 14.68$, $p < .001$, percussive musicians: $t(38) = 8.71$, $p < .001$ and $t(38) = 12.53$, $p < .001$, and nonpercussive musicians: $t(38) = 9.73$, $p < .001$ and $t(38) = 14.45$, $p < .001$, respectively.

Independent samples *t*-tests were conducted on years of training, starting age of training, and hours of practice per week for each group's respective expertise with musicians, dancers, and controls. Training style was collapsed across groups because no effect of percussive versus nonpercussive training style was found. Musicians and dancers did not significantly differ in the years of training in their respective expertise, $t(78) = 0.86$, $p = .39$. Musicians and dancers also did not significantly differ on the starting age of their respective training, $t(78) = 1.76$, $p = .08$. Likewise, musicians and dancers did not significantly differ on the number of hours they practiced per week, $t(78) = 0.50$, $p = .62$.

To confirm that any differences in performance between groups were not due to differences in music exposure, an independent samples t-test on the hours of music exposure per week was conducted. All participants had similar exposure to music, regardless of expertise $t(78) = 1.30$, $p = .94$.

Audiovisual Beat Perception Task

Percent Correct. Neither expertise, $F(1, 76) = 1.41$, $p = .24$, $\eta^2 = .02$, nor training style, $F(1, 76) = 0.10$, $p = 0.92$, $\eta^2 < .001$, produced any significant results in the 2 x 2 between subjects ANOVA. Musicians ($M = 61.47\%$, $SE = 2.20\%$) and dancers ($M = 57.94\%$, $SE = 2.04\%$) performed similarly on the audiovisual beat perception task. Percussionists ($M = 59.85\%$, $SE = 2.07\%$) and nonpercussionists ($M = 59.56\%$, $SE = 2.20\%$) also performed similarly on the task. The interaction between expertise and training style was also not significant, $F(1, 76) = 3.54$, $p = .64$, $\eta^2 = .05$. In the 1 x 5 between-subjects ANOVA that included controls there was a significant effect of group, $F(4, 95) = 2.58$, $p < .05$, $\eta^2 = .10$. Post hoc comparisons using Bonferroni corrections indicated that nonpercussive musicians ($M = 64.12\%$, $SE = 3.25\%$), but not percussive musicians ($M = 58.83\%$, $SE = 2.93\%$) were significantly better at perceiving a beat compared to controls ($M = 51.77\%$, $SE = 3.24\%$), $p = .048$ and $p = 1.00$, respectively. Percussive ($M = 60.88\%$, $SE = 3.00\%$) and nonpercussive dancers ($M = 55.00\%$, $SE = 2.67\%$) also did not differ from controls, $p = .36$ and $p = 1.00$, respectively (Figure 6).

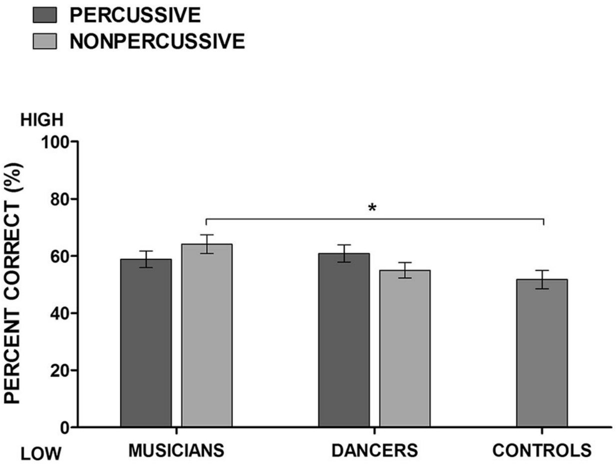

FIGURE 6. Performance on the audiovisual beat perception task measured using percent correct. Musicians and dancers performed similarly on the audiovisual beat perception task. Percussionists and nonpercussionists also performed similarly on the task. Relative to controls, only nonpercussive musicians were significantly better at perceiving the beat. Error bars indicate standard error of the mean. $^*p < .05$.

Bouncing Beat Production Task

The bounce rate (level of metrical hierarchy) at which the different groups chose to synchronize to did not differ as no group effect was found in a 1 x 5 between-subjects ANOVA that included controls ($M = 957.61$, $SE = 43.68$), percussive dancers ($M = 928.82$, $SE = 42.74$), nonpercussive dancers ($M = 884.85$, $SE = 35.29$), percussive musicians ($M = 925.58$, $SE = 44.96$), and nonpercussive musicians ($M = 946.22$, $SE = 43.50$), $F(4, 95) = 0.43$, $p = .79$, $\eta^2 = .02$. Additionally, a 1 x 3 between-subjects ANOVA with controls, dancers ($M = 906.84$, $SE = 27.58$), and musicians ($M = 935.90$, $SE = 30.92$) similarly indicated no difference on the metrical hierarchy that participants chose to synchronize to when bouncing, $F(2, 97) = 0.54$, $p = .58$, $\eta^2 = .01$.

Coefficient of Variation (CoV). The 2 x 2 between-subjects ANOVA on bouncing variability did not produce a significant main effect of expertise, $F(1, 76) = 0.12$, $p = .73$, $\eta^2 = .002$. Musicians ($M = .042$, $SE = .002$) and dancers bounced with similar variability ($M = .043$, $SE = .002$). There was also no significant main effect of training style, $F(1, 76) = 0.02$, $p = .88$, $\eta^2 < .001$, as bouncing variability did not significantly differ between percussionists ($M = .042$, $SE = .002$) and nonpercussionists ($M = .042$, $SE = .002$). The interaction between expertise and training style was also not significant, $F(1, 76) = 3.29$, $p = .74$, $\eta^2 = .04$. However, the 1 x 5 between subjects ANOVA produced a significant effect of group on bouncing variability, $F(4, 95) = 5.27$, $p < .01$, $\eta^2 = .18$. Post hoc comparisons using Bonferroni corrections indicated that percussive ($M = .044$, $SE = .003$) and nonpercussive musicians ($M = .039$, $SE = .002$) bounced with lower variability than controls ($M = .058$, $SE = .005$), $p = .033$ and $p = .001$, respectively. Percussive dancers ($M = .040$, $SE = .002$), but not nonpercussive dancers ($M = .045$, $SE = .004$), also bounced with lower variability than controls, $p = .002$ and $p = .078$ respectively (Figure 7).

Coefficient of Deviation (CDEV). The participants' ability to match their bouncing tempo to the beat tempo of the music did not significantly differ for expertise, $F(1, 76) = 0.20$, $p = .66$, $\eta^2 = .003$. Musicians ($M = .042$, $SE = .003$) and dancers ($M = .044$, $SE = .004$) bounced to the tempo of the music with similar accuracy (similar mean CDEV). Tempo matching accuracy also did not

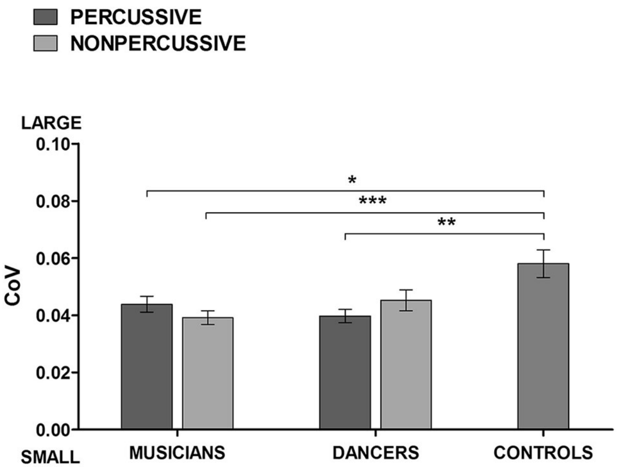

FIGURE 7. Performance on the bouncing beat production task measured using CoV. Bouncing variability did not significantly differ between musicians and dancers, or between percussionists and nonpercussionists. Percussive and nonpercussive musicians, as well as percussive dancers, bounced with significantly lower variability than controls. Error bars indicate standard error of the mean. $^*p < .05$ $^{**}p < .01$ $^{***}p < .001$

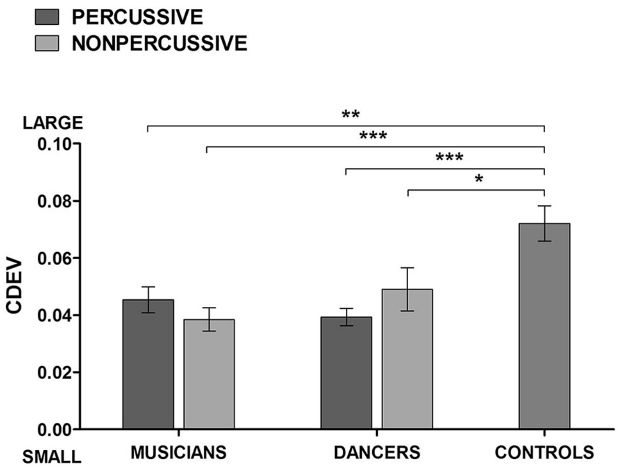

FIGURE 8. Performance on the bouncing beat production task measured using CDEV. Musicians and dancers bounced to the tempo of the music with similar accuracy. Tempo matching accuracy also did not differ between percussionists and nonpercussionists. Relative to controls, percussive and nonpercussive musicians, as well as percussive and nonpercussive dancers bounced to the tempo of the music with significantly greater accuracy. Error bars indicate standard error of the mean. $^*p < .05$ $^{**}p < .01$ $^{***}p < .001$

significantly differ for training style, $F(1, 76) = 0.07$, $p = .79$, $\eta^2 = .001$. Percussionists ($M = .042$, $SE = .003$) and nonpercussionists ($M = .044$, $SE = .004$) did not differ in their ability to match their bouncing tempo to the beat tempo of the music. The interaction between expertise and training style was also not significant, $F(1, 76) = 2.66$, $p = .11$, $\eta^2 = .03$. However, the 1 x 5 between-subjects ANOVA conducted to compare tempo matching accuracy in the five groups produced a significant effect of group, $F(4, 95) = 6.60$, $p < .001$, $\eta^2 = .22$. Bonferroni corrected post hoc comparisons indicated that percussive ($M = .045$, $SE = .005$) and nonpercussive musicians ($M = .038$, $SE = .004$) bounced to the tempo of the music with greater accuracy than controls ($M = .072$, $SE = .006$), $p = .006$ and $p < .001$, respectively. Tempo matching accuracy was also significantly greater for percussive ($M = .039$, $SE = .003$) and nonpercussive dancers ($M = .049$, $SE = .008$) compared to controls, $p < .001$ and $p = .029$, respectively (Figure 8).

Asynchrony. The 2 x 2 between-subjects ANOVA on bouncing accuracy (asynchrony) did not produce a significant main effect of expertise, $F(1, 76) = 3.07$, $p = .08$, $\eta^2 = .04$. Musicians ($M = .096$, $SE = .005$) and dancers ($M = .108$, $SE = .005$) bounced to the beat with similar accuracy (similar mean absolute asynchrony). There was also no significant main effect of training style, $F(1, 76) = 2.08$, $p = .15$, $\eta^2 = .03$. Percussionists ($M = .097$, $SE = .004$) and nonpercussionists ($M = .107$, $SE = .006$) did not differ in their ability to match their bouncing to the beat. The interaction between expertise and training style was also not significant, $F(1, 76) = 0.41$, $p = .52$, $\eta^2 = .005$. Finally, the 1 x 5 between-subjects ANOVA on bouncing accuracy also did not produce a significant effect of group, $F(4, 95) = 1.91$, $p = .12$, $\eta^2 = 0.07$. Bouncing accuracy did not significantly differ between percussive ($M = .093$, $SE = .005$) and nonpercussive musicians ($M = .098$, $SE = .008$) as well as percussive ($M = .101$, $SE = .006$) and nonpercussive dancers ($M = .115$, $SE = .008$), compared to controls ($M = .114$, $SE = .008$) $p = .38$, $p = 1.00$, $p = 1.00$, and $p = 1.00$, respectively (Figure 9).

Correlations. To assess the relationship between beat perception (percent correct) and beat production (CoV, CDEV, and asynchrony), Pearson correlation coefficients were computed. There was a negative correlation between percent correct and measures of beat production: CoV, $r = -.538$, $p < .001$, CDEV, $r = -.476$, $p < .001$, and asynchrony, $r = -.390$, $p < .001$. Better performance on the audiovisual beat perception task (higher scores) was correlated with better performance on the bouncing beat production task (lower scores). The results confirmed that good beat perceivers tend to also be good synchronizers. Pearson correlation coefficients for beat production measures showed a positive correlation between CoV and CDEV, $r = .814$, $p < .001$, CoV and

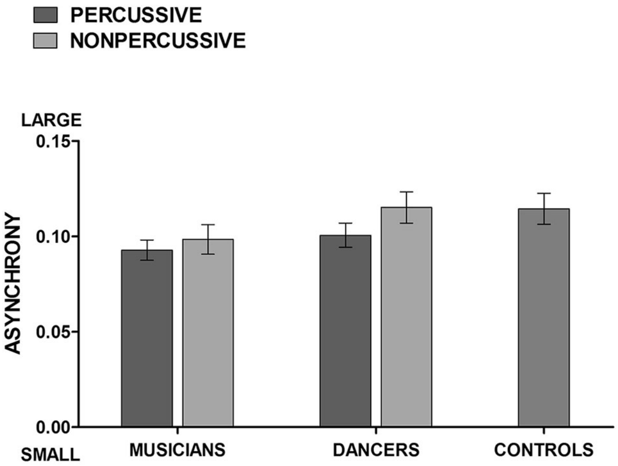

FIGURE 9. Performance on the bouncing beat production task measured using asynchrony. Musicians and dancers, as well as percussionists and nonpercussionists, bounced to the beat with similar mean asynchrony. Relative to controls, neither musicians or dancers significantly differed. Error bars indicate standard error of the mean.

asynchrony, $r = .552$, $p < .001$, CDEV and asynchrony, $r = .889$, $p < .001$. Thus, smaller variability in bouncing was correlated with smaller deviation from the beat tempo and smaller asynchrony scores. Smaller deviation from the beat tempo was also correlated with smaller asynchrony scores. The results were not surprising as the three measures of beat production assess different, but related aspects of beat production.

Discussion

Experiment 2 examined how percussive and nonpercussive music and dance training influenced beat perception and production, using an audiovisual variant of the BAT and a knee-bending task, respectively. Musicians and dancers did not significantly differ on any measures of beat perception or production, but significantly outperformed the controls on the beat production (but not perception) task. The results suggest that dancers' beat production abilities are comparable to that of musicians' when they are tested with whole-body movements.

We predicted that percussionists would outperform nonpercussionists on both tasks (Cameron & Grahn, 2014; Cicchini et al., 2012; Petrini et al., 2009). However, as in Experiment 1, percussive training did not significantly affect performance, despite using a stricter criteria for training style to better distinguish the percussionist and nonpercussionist groups. As this was the first study to use percussive vs nonpercussive classifications for dancers it is possible there is not a clear enough distinction between the training styles as some dance styles may include both percussive and nonpercussive elements. For musicians, although expert percussionists have previously shown enhanced timing abilities, this appears to be mainly when compared to nonexpert musicians (Cameron & Grahn, 2014; Petrini et al., 2009).

Performance on the audiovisual beat perception task did not significantly differ between the three groups. It is interesting that the nonpercussive musicians performed better than controls, but the percussive musicians did not. Performance overall was low, ranging from 51–67% correct. This poorer performance may be caused by the larger integration window for audiovisual information than for auditory-only information. Auditory and visual onsets occurring within about 100 ms of each other may be perceived as simultaneous (Andersen & Mamassian, 2008; Meredith, Nemitz, & Stein, 1987; Shams et al., 2002). Here, the offset between the visual beat and auditory beat was in the range of 100 and 132 ms, which may have been difficult to perceive. Additionally, the poor performance could have been a result of increased perceptual load due to the need to integrate the audiovisual information, as this may result in performance deficits (Allerdissen et al., 2017; Lee et al., 2015).

In general, music production relies more on discrete effector-specific movements, whereas dancing relies more on gross whole-body movements (Karpati et al., 2017). In Experiment 1, beat production was tested using a finger-tapping (effector-specific movement) task, and musicians outperformed dancers. When beat production was tested in Experiment 2 with a knee bending (whole-body movement) task (Miura et al., 2011; Miura, Kudo, & Nakazawa, 2013; Miura, Kudo, Ohtsuki, et al., 2013), dancers and musicians were similarly accurate, and more accurate than controls. Thus, when tested with movements that are more ecologically valid for their training, dancers exhibit enhanced beat production abilities compared to controls.

General Discussion

The current study examined four factors that may influence beat perception and production performance. These were: 1) *expertise*: in music and dance, 2) *training style*: percussive and nonpercussive, 3) *stimulus modality*: auditory and visual, and 4) *movement type*: effector-specific or whole-body. Broadly, the data showed that: 1) beat processing differs among musicians, dancers, and controls; 2) training style did not significantly influence beat perception and production, as performance did not significantly differ between percussionists and nonpercussionists; 3) the addition of visual information on the audiovisual beat perception task in Experiment 2 did not specifically benefit dancers, however, it is possible that the task was difficult for all three groups; and 4) when tested with movements that were more ecologically valid with respect to their training, dance training is associated with better beat production.

In Experiment 1, percussionists performed numerically better than the nonpercussionists, but the difference was not significant. Other studies have found that percussive musicians have enhanced temporal precision in both perception and production tasks compared to nonpercussive musicians (Cameron & Grahn, 2014; Cicchini et al., 2012; Fujii et al., 2011; Krause et al., 2010; Repp et al., 2013). However, little is known about the difference between percussive and nonpercussive dancers. Here, dancers with percussive training did not have a significant advantage over dancers with nonpercussive training, possibly because the foundations of their training are similar (Rosenfeld, 2011), or perhaps because the tasks were not sensitive enough to detect differences related to percussive vs nonpercussive training. A limitation of Experiment 1 was that percussionists and nonpercussionists were classified on the basis of their primary style of training, but could have some degree of experience in the other style. To better distinguish the percussionist and nonpercussionist groups, in Experiment 2, only musicians and dancers whose training was exclusively percussive or nonpercussive were recruited, excluding any participants with both percussive and nonpercussive training. However, the percussionists and nonpercussionists still did not differ in performance. Therefore, across both experiments, training style did not significantly affect beat perception or production, despite efforts to make the two groups as distinct as possible.

In Experiment 2, beat perception was measured using audiovisual stimuli rather than auditory only stimuli to examine whether the addition of visual information would be beneficial to dancers. However, performance did not significantly differ among musicians, dancers, or controls. In fact, it was difficult for participants to judge whether the figure was in synchrony or not with the music, as performance on the task was low. Although effort was made to make the beat easy to visually perceive by offsetting any clips with a $\frac{4}{4}$ time signature by 33% of the IBI, and any clips with a $\frac{3}{4}$ time signature by 25% of the IBI, some of these offsets lie within the temporal window of audiovisual integration, where the auditory and visual stimuli are perceived as simultaneous (Andersen & Mamassian, 2008; Meredith et al., 1987; Shams et al., 2002). Therefore, the offset between the auditory and visual stimuli may not have been large enough, making it difficult for participants to perceive whether the bouncing stick figure (visual) was bouncing "on the beat" or "off the beat" (auditory). The lack of group differences on the audiovisual beat perception task is thus difficult to interpret.

In Experiment 2, beat production was measured with knee-bending rather than finger-tapping to examine whether expertise (in music or dance) that favors effector-specific or whole-body movement affects beat production. Performance on the task did not significantly differ between musicians and dancers, although musicians and dancers did significantly outperform controls. Thus, musicians' better production performance in Experiment 1 appears to be task specific and may be because musicians have more experience with auditory-finger movement coupling compared with auditory-leg movement coupling. For knee-bending and finger-tapping, CoV, CDEV, and asynchrony scores for musicians and controls were comparable for both types of movements. Dancers, however, only performed worse than musicians when tapping along with just their finger but had comparable performance when bouncing to the beat, possibly because dance training involves performing whole-body movements in synchrony with auditory stimuli (Karpati et al., 2016).

The knee-bending task was meant to better represent movements that dancers make compared to musicians; however, not every style of dance involves these movements. For example, percussive dancing styles like hip-hop involve whole-body movements, while tap localizes movement to the ankles and feet while suppressing bouncing movements. In addition, some percussive instruments, such as the drums, do involve knee movements and coordinating movement across the body. Due to the novelty of this study, knee-bending was a first step at choosing a general whole-body movement that would be easy for nondancers to achieve, and be easy to quantify relative to the beat. Further differences may have been found if we had used metrics that were unique to different dance style movements (e.g., flaps, a basic step for tap dancers). Additionally, extra markers could be used to obtain measures of the rhythmicity of the movement, such as at the hip level as a measure of centre of mass, or at the head level, where the movement is perceived.

With the current study we validated a new audiovisual task and examined whether it could be sensitive to expertise differences. To start we focused on percussive and nonpercussive music and dance training as a broad classification. As previously mentioned, the distinction between percussive and nonpercussive may have not been sufficient to produce two completely separate training styles. Therefore, dance and music could be examined with other distinctions based on the different styles/instruments to tease apart the effects of various facets of training on beat perception and production abilities.

Taken together, the current studies described for the first time how music and dance training interact with training style, stimulus modality, and movement type to influence beat processing abilities. Beat processing differs between musicians, dancers, and controls. Training style did not significantly influence beat perception and production, as performance did not significantly differ between percussionists and nonpercussionists. On the audiovisual beat perception task in Experiment 2, the addition of visual information did not benefit dancers, but it is possible that the task was too difficult for all groups. Finally, the results show that if musicians and dancers are tested with movements that are more ecologically valid with respect to their training, music and dance training does influence beat production.

It cannot be said that differences in training *caused* the group differences. Other factors may have accounted for the results, although great effort was made to recruit individuals with similar backgrounds, with the exception of their training backgrounds. Participants were similar in age and education and were recruited within the university community. Furthermore, differences in music exposure, which might influence beat processing (Bläsing et al., 2012; Drake, 1998; Tillmann, 2008), were not significant between groups. Musicians and dancers did not significantly differ in the number of years of training, starting age of their training, or the number of hours they practiced per week.

Conclusions

Experiment 1 demonstrated that music training was associated with better beat perception and production performance relative to dance training, but percussive training compared to nonpercussive training did not have a significant effect in either musicians or dancers. Experiment 2 demonstrated that dance training and music training can elicit similar beat production performance when dancers are tested with movements that are more ecologically valid with respect to their training. The findings from both experiments suggest that music and dance training can have implications in motor accuracy for beat production that extend beyond specific instruments or dance training. Additionally, the results suggest that tailoring methods, techniques, and materials to accommodate individual is important in temporal processing research.

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