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Examining the Differences in Beat Perception and Production Between Musicians and Dancers

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Abstract

The ability to perceive and produce a beat is believed to be universal in humans, but there are factors that may give rise to individual differences. The research presented in this dissertation examined four factors that may influence beat processing and sensorimotor synchronization performance: 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. Chapter 2 examined how percussive and nonpercussive music and dance training influence beat perception and production performance using an auditory beat perception task and a finger tapping beat production task. Chapter 3 also examined how percussive and nonpercussive music and dance training influence beat perception and production performance, but using an audiovisual variant of the beat perception task, and a knee bending beat production task recorded with motion capture to assess whole-body movements. Chapters 4 and 5 examined how music and dance training interact with the auditory and visual modalities to influence audiovisual integration measured using a just-noticeable-difference task, and audiovisual synchronization measured using a bimodal target-distractor synchronization task. In Chapter 4, sensorimotor synchronization was tested with finger tapping, whereas in Chapter 5 sensorimotor synchronization was tested with knee bending. Broadly, the data showed that 1) beat processing and sensorimotor synchronization performance differ among musicians, dancers, and their non-musician/non-dancer counterparts, 2) training style did not significantly influence beat perception and production, as performance did not significantly differ between percussionists and nonpercussionists, 3) musicians were biased toward the auditory modality, whereas dancers were biased toward the visual modality when synchronizing to bimodal sequences, and 4) musicians performed better with finger movements, while dancers performed better with whole-body movements. The research presented in this dissertation demonstrate how music and dance—similar, yet different types of training—may affect beat processing and sensorimotor synchronization abilities.

Keywords

audiovisual integration, auditory modality, beat perception, beat production, bimodal target-distractor synchronization task, dancers, finger tapping, just-noticeable-difference task, motion capture, musicians, nonpercussionists, percussionists, sensorimotor synchronization, visual modality, whole-body movements

Co-Authorship Statement

The following is a list of co-authors that contributed to the research presented in this dissertation:

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“Sometimes it’s not about the journey or the destination, but about the people you meet along the way.” – Nishan Panwar

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“Mentoring is a brain to pick, an ear to listen, and a push in the right direction.”

– John C. Crosby

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“There are friends, there is family, and then there are friends that become family.”

– Unknown

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"The best way out is always through." – Robert Frost

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Simply –

Thank you!

– Tram Nguyen, PhD

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3-D	3-dimensional
A-V	auditory target-visual distractor
A0	audio-leading track with the audio and the video in perfect synchrony
A50	audio-leading track with the audio advanced by 50% relative to the video
ANOVA	analysis of variance
BAASTA	Battery for the Assessment of Auditory Sensorimotor and Timing Abilities
BAT	beat alignment test
CAD	Canadian dollar
CDEV	coefficient of deviation
CoV	coefficient of variation
ERP	event-related potentials
fMRI	functional magnetic resonance imaging
Gold-MSI	Goldsmiths Musical Sophistication Index
IBI	inter-beat-interval
IOI	inter-onset interval
IRED	infrared-emitting diodes
IRI	inter-response-interval
LPC	late positive component
M	mean
MRI	magnetic resonance imaging
ms	millisecond
PD	Parkinson's disease
s	second
SD	standard deviation
SE	standard error
V-A	visual target-auditory distractor
V0	video-leading track with the audio and the video in perfect synchrony
V50	video-leading track with the video advanced by 50% relative to the audio

Chapter 1

1 General Introduction

Music is a universal feature of the human experience. It is temporal in nature because it unfolds over time and is structured using many timing features such as rhythm, tempo, and beat to elicit many behavioural responses. Processing of temporal patterns in music appear to be human-specific (Cook, Rouse, Wilson, & Reichmuth, 2013; Fitch, 2013; Hagmann & Cook, 2010; Honing, Merchant, Háden, Prado, & Bartolo, 2012; Merchant & Honing, 2014), particularly the ability to perceive and produce the beat—a regular recurring salient psychological event (Cooper & Meyer, 1960; Large & Palmer, 2002; Parncutt, 1994). The ability to perceive and produce the beat is referred to as beat perception and beat production, respectively.

1.1 Beat Perception and Production

A musical rhythm is a pattern of sounds characterized by the temporal intervals between the sound onsets, termed inter-onset intervals (IOIs). Listening to a musical rhythm often gives rise to a sense of beat. The beat is a series of regularly recurring, salient psychological events (Cooper & Meyer, 1960; Large & Palmer, 2002; Parncutt, 1994). It is a psychological event because it is not stimulus driven, even though it usually arises in response to a musical rhythm (Benjamin, 1984; Lerdahl & Jackendoff, 1983; Palmer & Krumhansl, 1990). The psychological internalizing of the beat is why it can be sensed even when music is rhythmically complex or has notes occurring off the beat. Individual beats are frequently perceived to possess different degrees of accents, or stress, which gives rise to meter. Meter (or metrical hierarchy) is the grouping or temporal organization of beats, in which some beats are perceived as more salient than others (Figure 1). For example, in a march rhythm, every other beat is accented (strong-weak-strong-weak), whereas in a waltz, the first of every third beat is accented (strong-weak-weak-strong-weak-weak). Different levels of the metrical hierarchy correspond to different intervals, which may result in individual listeners synchronizing to different rates. Thus, beat perception and production allows for individual variability.

Figure 1: Illustration of a musical rhythm and its associated beat and meter (taken from Cameron & Grahn, 2014a). A rhythm is a pattern of sounds characterized by the temporal intervals between the sound onsets. The vertical lines show where the sounds occur and the horizontal lines in between show the silent periods between the sounds. The beat is a series of regularly recurring, salient time positions that are perceived in the rhythm. Meter is the temporal organization of beats, in which some beats are perceived as more salient than others.

There are many factors that may give rise to individual differences in beat perception and production. Such factors include, but are not limited to: age (McAuley, Jones, Holub, Johnston, & Miller, 2006), auditory short term memory (Grahn & Schuit, 2012), cultural differences (Cameron, Bentley, & Grahn, 2015; Hannon, Soley, & Ullal, 2012; Soley & Hannon, 2010), musical training (Cameron & Grahn, 2014b; Grahn & Rowe, 2009; Palmer & Krumhansl, 1990), and stimulus modality (Grahn, 2012; Grahn, Henry, & McAuley, 2011; McAuley & Henry, 2010). However, there are other factors that remain to be examined. The research presented in this dissertation focuses on four factors that may influence beat perception and production: 1) *expertise*: in music and dance, 2) *training style*: percussive and nonpercussive, 3) *stimulus modality*: auditory and visual, and 4) *movement type*: effector-specific and whole-body. This dissertation addresses a gap in the existing literature, focusing on how the effects of music and dance training are similar or different from each other with regards to beat perception and production.

1.2 Music and Dance Experience

One factor that may influence beat perception and production ability is music or dance experience. Music and dance training are comparable in many respects: culturally, socially, economically, and technically. Culturally and socially speaking, both forms of art are found in every known culture throughout the world, shared, and enjoyed by all (experts and novices). From an economical and technical perspective, individuals with music or dance training typically start training at a young age and are reared 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, Giacosa, Foster, Penhune, & Hyde, 2016). Because of their specialized training, musicians and dancers are suitable populations to examine how training affects beat perception and production.

1.2.1 Musicians and Non-Musicians

In general, musicians appear to have more accurate rhythm processing and sensorimotor synchronization performance than non-musicians. Perceptually, musicians are better at detecting even subtle differences in auditory rhythms than non-musicians (Bailey & Penhune, 2010; Besson & Faita, 1995; Chen, Penhune, & Zatorre, 2008; Drake, Penel, & Bigand, 2000; Jongsma, Meeuwissen, Vos, & Maes, 2007). For example, musicians are better than non-musicians at identifying familiar and unfamiliar musical phrases, and determining whether the terminal note of the phrase ends either congruously or with a rhythmic violation (Besson & Faita, 1995). Moreover, when asked to rate beat saliency for both non-beat- and beat-based rhythms, musicians are better than non-musicians at differentiating that beat-based rhythms have a strong beat and that non-beat-based rhythms have a weak beat (Grahn & Rowe, 2009). One explanation for the differences in performance between musicians and non-musicians is that music training provides musicians with a range of strategies necessary for accurate processing of auditory rhythms that non-musicians do not possess (Grahn & Schuit, 2012). Another explanation is that musical training enhances musicians' sensitivity to underlying temporal structures that may make the beat more salient when they are listening to rhythms (Bailey & Penhune, 2010).

Musicians are also better at synchronizing to the beat than non-musicians (Drake et al., 2000; Repp, 2010; Repp & Doggett, 2007). When asked to tap in time with mechanically synthesized and expressively performed music, musicians synchronize more accurately, tap more slowly, and tap to a wider range of metrical levels than non-musicians (Drake et al., 2000). Musicians may perceptually organize events over longer time spans than non-musicians, thus have a more complete metrical representation of the music, which may give rise to their better synchronization (Drake et al., 2000). Similarly, when asked to tap along to isochronous auditory sequences containing temporal perturbations, musicians generally produce smaller asynchronies, lower tapping variability, faster error correction, and show greater perceptual sensitivity to timing changes than non-musicians (Repp, 2010). The enhanced ability of musicians to synchronize to timed sequences may relate to increased auditory-motor coupling, which is important for integrating auditory perception with motor production, and musicians may have greater auditory-motor integration because of their extensive practice at using auditory feedback to alter motor production (Chen et al., 2008).

1.2.2 Dancers and Non-Dancers

Unlike in music, studies in dance often examine rhythm processing from a visual perspective (Calvo-Merino, Ehrenberg, Leung, & Haggard, 2010; Lee, Barrett, Kim, Lim, & Lee, 2015; Stevens et al., 2010), and sensorimotor synchronization using whole-body movements (Miura, Kudo, & Nakazawa, 2013; Miura, Kudo, Ohtsuki, & Kanehisa, 2011; Miura, Kudo, Ohtsuki, Kanehisa, & Nakazawa, 2013). In fact, no study to date has directly examined how dancers and non-dancers differ in processing of auditory rhythms. However, there is evidence to suggest that extracting a visual beat when watching dance movements can parallel auditory rhythm perception in music (Su & Salazar-López, 2016). In terms of visual rhythms, dancers have better rhythm processing performance than non-dancers. For example, dancers are better than non-dancers 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). Moreover, there is evidence to suggest that viewing dance movements can shape sound perception, particularly meter perception and where strong and weak beats occur (Lee et al., 2015). The literature on rhythm processing may not be as abundant for dance as it is for music, but there is some evidence to suggest that dance training may influence the perception of rhythm and beat.

Dancers are also better than non-dancers at synchronizing with auditory and visual rhythms, particularly if the task involves whole-body synchronization (Karpati et al., 2016; Miura et al., 2011; Miura, Fujii, Okano, Kudo, & Nakazawa, 2016; Miura, Kudo, & Nakazawa, 2013; Miura, Kudo, Ohtsuki, et al., 2013). For example, when asked to bounce to a metronome by bending at the knees, dancers generally produce lower variability and deviate less from the metronome than non-dancers (Miura et al., 2011; Miura, Kudo, & Nakazawa, 2013; Miura, Kudo, Ohtsuki, et al., 2013). Moreover, dancers are better than non-dancers at coordinating with observed dance movements in the presence or absence of auditory cues or music (Washburn et al., 2014). In general, dance training is associated with better proprioception (Kiefer et al., 2013), better postural control (Rein, Fabian, Zwipp, Rammelt, & Weindel, 2011), more stability, and stronger inter-limb coupling (Buchanan, Zihlman, Ryu, & Wright, 2007; Sofianidis, Hatzitaki, Grouios, Johannsen, & Wing, 2012; Thullier & Moufti, 2004), which may make dancers better synchronizers compared to non-dancers.

1.2.3 Musicians and Dancers

Although there are similarities between musicians and dancers, little research has directly compared these two populations. In fact, 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). Behaviourally, on the music-related tasks (rhythm synchronization and melody discrimination), musicians outperform dancers (and controls), whereas on the dance-related task (dance imitation), dancers outperform musicians (and controls). Neural correlates of music and dance suggest that similar gray matter structures in the superior temporal gyrus are activated for musicians and dancers, and that the activation is correlated with performance on the music- and dance-related tasks (Karpati, Giacosa, Foster, Penhune, & Hyde, 2017). Although the aforementioned studies demonstrate how the effects of music training and the effects of dance training are similar and different from each other, it still remains to be elucidated how music and dance training may influence other processes in music cognition, such as beat perception and production.

1.3 Percussive and Nonpercussive Training

Another factor that may influence beat perception and production ability is training style. Different musical instruments and dance styles can be classified as either percussive or nonpercussive. The classification between percussive and nonpercussive is defined based on the attack time of the sound or movement produced by the musician or dancer, respectively. Attack time refers to the time it takes from the onset to the completion of the sound or movement. Percussionists often produce a sound or movement with a short attack time, whereas nonpercussionists often produce a sound or movement with a long attack time. Therefore, in music, individuals that play drums or cymbals are often classified as percussive musicians. By contrast, individuals that play strings or winds are often classified as nonpercussive musicians (Cicchini, Arrighi, Cecchetti, Giusti, & Burr, 2012). In dance, individuals whose dance styles are tap or hip-hop are regarded as percussive dancers, whereas individuals whose dance styles are ballet or contemporary are regarded as nonpercussive dancers (Rosenfeld, 2011). Given that percussive training commonly focuses on temporal precision, percussionists are likely to show enhanced rhythm processing and sensorimotor synchronization performance compared to nonpercussionists.

1.3.1 Percussive and Nonpercussive Musicians

Indeed, percussive musicians have enhanced temporal precision in rhythm perception and production tasks compared to nonpercussive musicians (Cameron & Grahn, 2014b; Cicchini et al., 2012; Fujii et al., 2011; Krause, Pollok, & Schnitzler, 2010; Repp, London, & Keller, 2013). Perceptually, percussive musicians, particularly drummers, are better than nonpercussive musicians at perceiving audiovisual asynchrony in point-light displays of drumming movements (Petrini et al., 2009). In terms of rhythm production, percussionists also consistently outperform nonpercussionists (Cameron & Grahn, 2014b; Cicchini et al., 2012; Fujii et al., 2011; Krause et al., 2010; Repp et al., 2013). For example, percussionists generally produce lower variability regardless of whether they are synchronizing to isochronous or non-isochronous rhythms (Fujii et al., 2011; Krause et al., 2010; Repp et al., 2013). Moreover, percussionists are more accurate and less variable during rhythm reproduction and beat tapping regardless of rhythm complexity or beat structure (Cameron & Grahn, 2014b). Superior performance by percussive musicians on many perception and production tasks may be a result of their specialized training, as percussive training commonly focuses on temporal precision and the ability to maintain a steady and precise beat (Cameron & Grahn, 2014b).

1.3.2 Percussive and Nonpercussive Dancers

No studies, to date, have directly examined percussive and nonpercussive dancers on the same task. Therefore, little is known about the difference between percussionists and nonpercussionists with respect to dance. One body of research has compared skilled street dancers—a style of dance that is arguably percussive in nature—with non-dancers (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 non-dancers. However, comparing percussive dancers with non-dancers is different than comparing percussive dancers with equally trained nonpercussive dancers. Given the lack of research comparing between percussive and nonpercussive dancers, it is unclear how training style, particularly in dance, may influence beat perception and production.

1.4 Auditory and Visual Modalities

Stimulus modality is another factor that may influence beat perception and production ability. Beat processing and sensorimotor synchronization significantly differ for audition and vision. Audition is superior compared to vision with regards to beat perception (Grahn, 2012; Grahn et al., 2011; McAuley & Henry, 2010), and sensorimotor synchronization (Kato & Konishi, 2006; Lorås, Sigmundsson, Talcott, Öhberg, Stensdotter, 2012; Patel, Iversen, Chen, & Repp, 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, the variability of tap times is typically lower when participants are asked to synchronize with auditory than with visual rhythms (Chen, Repp, & Patel, 2002; Repp & Penel, 2002; Repp & Penel, 2004). More specifically, when participants tap in synchrony with isochronous auditory (tones) and visual (flashes) sequences, asynchrony scores are much lower for auditory compared to visual sequences (Repp & Penel, 2004). 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* may explain the auditory dominance observed for beat processing and sensorimotor synchronization, as these processes rely more on temporal than spatial processing.

More recent research, however, has challenged the auditory superiority view for rhythm processing. Many earlier studies often used spatially static visual stimuli (e.g., a flashing light) that do not provide the rich spatiotemporal information that dynamic visual stimuli may, in order to optimize temporal processing (Grondin & McAuley, 2009; Guttman, Gilroy, & Blake, 2005; McAuley & Henry, 2010; Repp & Penel, 2002; Repp & Penel, 2004). There is evidence that beat processing and sensorimotor synchronization improves substantially if the visual stimuli are dynamic rather than static, such as a moving bar, a bouncing ball, or a bouncing point-light figure (Grahn, 2012; Hove, Iversen, Zhang, Repp, 2013; Hove & Keller, 2010; Hove, Spivey, & Krumhansl, 2010; Su, 2014). For example, the variability of taps is lower when synchronizing with visual rhythms derived from apparent motion (i.e., a tapping finger) than with visual rhythms derived from static motion (i.e., a flashing light) (Hove & Keller, 2010). Along the same vein, asynchrony scores are lower when synchronizing with a bouncing ball (with a rectified sinusoidal velocity) than with a flashing square (Iversen, Patel, Nicodemus, & Emmorey, 2012). 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.

Sensorimotor synchronization with multimodal rhythms, in which sequences from different modalities are combined, is an important skill for musicians and dancers. Musicians often integrate visual information (e.g.; reading music or following a conductor) with auditory information (e.g., the sound of their instrument) to execute a movement to produce a sound, whereas dancers often integrate auditory information (e.g.; music or counts) with visual information (e.g., choreography) to execute a movement for a dance (Karpati et al., 2016). Yet to date, no studies have used multimodal rhythms to compare the sensorimotor synchronization performance of musicians and dancers. One way to test sensorimotor synchronization with multimodal rhythms is by using the bimodal target-distractor synchronization paradigm (Repp, 2005), which requires participants to synchronize with a target sequence in one modality and regard the simultaneous sequence in the other modality as a distractor. Many earlier sensorimotor synchronization studies using the bimodal target-distractor synchronization paradigm have used musically trained individuals who seem to favour the auditory modality (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004), thus further perpetuating the auditory superiority view. To date, only one study has directly compared auditory experts (musicians) and visual experts (video gamers and ball players) using the bimodal target-distractor synchronization paradigm. For the auditory experts, the auditory distractors (auditory metronome) were more distracting than the visual distractors (bouncing ball). For the visual experts, the visual distractors were more distracting than the auditory distractors. Nevertheless, synchronization was still less variable with auditory than with visual rhythms for both groups (Hove et al., 2013). Yet, a more comparable visual expert population to musicians may be dancers, as both music and dance training focus on synchronization with auditory and visual rhythms, but music perhaps focuses more on auditory while dance perhaps focuses more on visual. However, musicians and dancers have yet to be compared using the bimodal target-distractor synchronization paradigm.

1.5 Effector-Specific and Whole-Body Movements

Musicians and dancers possess similar sensorimotor synchronization skills because of their training (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 non-musicians (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 inter-limb coupling than non-dancers (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 effector-specific movements, while dancers seem to be more accurate when synchronizing with whole-body movements.

However, most sensorimotor synchronization studies in the literature have frequently focused on standard tapping tasks. For example, beat processing performance are often measured using production tasks, in which individuals tap in time with the perceived beat of the music. Moreover, studies that have used the bimodal target-distractor synchronization paradigm have exclusively assessed sensorimotor synchronization with finger tapping. No studies, to date, have compared how music and dance training interact with movement type to affect beat processing or sensorimotor synchronization performance. Thus, it is unclear whether expertise in one or the other type of movement affects beat perception and production.

1.6 Dissertation Objectives

Although the ability to perceive and produce the beat is believed to be universal in humans, there are factors that may give rise to individual differences. The objective of this dissertation is to examine the various factors that may influence beat processing and sensorimotor synchronization abilities. The four experimental chapters that follow present research designed to investigate how music and dance training affects beat processing and sensorimotor synchronization performance.

Chapter 2 examines how percussive and nonpercussive music and dance training influence beat perception and production. Beat processing performance are measured using the Beat Alignment Test (BAT) taken from the Goldsmiths Musical Sophistication Index (Gold-MSI). Beat perception is measured using a perception task: participants make judgments about whether a metronome superimposed onto a piece of music is "on the beat" or "off the beat". Beat production is measured using a production task: participants tap in time with the perceived beat of a piece of music. Chapter 3 examines how percussive and nonpercussive music and dance training influence beat perception and production using an audiovisual variant of the beat perception task, as well as a bouncing beat production task recorded with motion capture to assess whole-body movements.

Chapter 4 examines how music and dance training interact with modality (auditory and visual) to influence audiovisual integration and synchronization. Audiovisual integration is measured using a variant of the "flash-beep" just-noticeable-difference task: participants make judgments about whether a stick figure is bouncing on or off the auditory tone. Audiovisual synchronization is measured using the bimodal target-distractor synchronization paradigm: participants tap in synchrony with an isochronous auditory or visual target sequence while a distractor sequence is presented in the other modality at one of nine temporal offsets. Chapter 5 examines how music and dance training interact with modality to influence audiovisual integration and synchronization using motion capture to assess whole-body movements. Instead of tapping, here, participants bounce in synchrony with the target sequence in one modality while regarding the other sequence in the other modality as a distractor. This dissertation aims to provide a novel understanding of how music and dance training affect beat processing and sensorimotor synchronization performance.

Chapter 2

2 Examining the Differences in Beat Perception and Production between Percussive and Nonpercussive Musicians and Dancers

2.1 Introduction

Listening to a musical rhythm often gives rise to a sense of beat. The beat is a series of regularly recurring, equivalent psychological events (Cooper & Meyer, 1960; Large & Palmer, 2002; Parncutt, 1994). It is psychological because it is not defined as a stimulus property, even though it generally arises in response to a musical rhythm (Benjamin, 1984; Lerdahl & Jackendoff, 1983; Palmer & Krumhansl, 1990). The psychological internalizing of the beat is why it can be sensed even when music is rhythmically complex or has notes occurring off the beat. The ability to perceive and produce the beat is referred to as beat perception and beat production, respectively. Beat perception and production are believed to be universal in humans, but there are factors that may give rise to individual differences.

2.1.1 Music and Dance Training

One factor that may influence beat perception and production ability is music or dance experience. Both forms of art 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). For example, music training commonly focuses on the perception and production of a beat using discrete effector-specific movements (Karpati et al., 2016). Similarly, dance training commonly focuses on the perception and production of a beat using gross whole-body movements (Karpati et al., 2016). Because of their specialized training, musicians and dancers are suitable populations to examine how training affects beat perception and production.

Compared to their non-musician/non-dancer counterparts, musicians and dancers have more accurate rhythm processing and sensorimotor synchronization performance. For example, musicians are better at detecting even subtle differences in auditory rhythms than non-musicians (Besson & Faita, 1995; Drake et al., 2000; Jongsma et al., 2007). Specifically, musicians are better than non-musicians at identifying familiar and unfamiliar musical phrases, and determining whether the terminal note of the phrase ends either congruously or with a rhythmic violation (Besson & Faita, 1995). In fact, behavioural difference in rhythm perception between musicians and non-musicians is paralleled by the difference in brain responses: event-related potentials (ERPs), particularly the late positive components (LPCs) in the 400- to 800-ms range elicited by musical incongruities, are larger for musicians than non-musicians when listening to incongruous musical phrase ending (Besson & Faita, 1995). Furthermore, performances on other rhythm perception tasks are also influenced by music training (Bailey & Penhune, 2010; Chen et al., 2008; Grahn & Rowe, 2009). For example, when asked to rate beat saliency for both non-beat- and beat-based rhythms, musicians are better than non-musicians at differentiating that beat-based rhythms have a strong beat and that non-beat-based rhythms have a weak beat (Grahn & Rowe, 2009). Moreover, functional magnetic resonance imaging (fMRI) showed that for the beat-based rhythms, the auditory-motor connectivity is modulated by musical training (Grahn & Rowe, 2009). One explanation for the differences in performance between musicians and non-musicians is that music training provides musicians with a range of strategies necessary for accurate processing of auditory rhythms that non-musicians do not possess (Grahn & Schuit, 2012). Another explanation is that musical training enhances musicians' sensitivity to underlying temporal structures that may make the beat more salient when they are listening to rhythms (Bailey & Penhune, 2010).

Likewise, dancers are better than non-dancers 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, saccades of dancers are significantly faster than saccades of non-dancers (Stevens et al., 2010). The difference in saccades suggests that dancers have more accurate expectancies of movements than non-dancers. There is also evidence to suggest that dance training and familiarity with performing a dance may enhance discrimination of metrical positions and the perception of auditory rhythms (Lee et al., 2015; Su, 2014; Su & Salazar-López, 2016). For example, viewing dance movements can shape sound perception, particularly meter perception and where strong and weak beats occur (Lee et al., 2015). Moreover, simply watching dance movements with a strong visual beat can improve auditory rhythm perception in music (Su & Salazar-López, 2016). Thus, there is evidence to suggest that dance training may influence the perception of rhythm and beat.

In terms of beat production, musicians are also better at synchronizing to the beat than non-musicians (Drake et al., 2000; Repp, 2010; Repp & Doggett, 2007). When asked to tap in time with mechanically synthesized and expressively performed music, musicians synchronize more accurately, tap more slowly, and tap to a wider range of metrical levels than non-musicians (Drake et al., 2000). Musicians may perceptually organize events over longer time spans than non-musicians, thus have a more complete metrical representation of the music, which may give rise to their better synchronization (Drake et al., 2000). Similarly, when asked to tap along to isochronous auditory sequences containing temporal perturbations, musicians generally produce smaller asynchronies, lower tapping variability, faster error correction, and show greater perceptual sensitivity to timing changes than non-musicians (Repp, 2010). The enhanced ability of musicians to synchronize to timed sequences may relate to increased auditory-motor coupling, which is important for integrating auditory perception with motor production, and musicians may have greater auditory-motor integration because of their extensive practice at using auditory feedback to alter motor production (Chen et al., 2008).

Dancers are also better than non-dancers 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 non-dancers (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 than non-dancers (Sofianidis et al., 2012). Dancers are also better than non-dancers at coordinating with observed dance movements in the presence or absence of auditory cues or music (Washburn et al., 2014). The enhanced ability of dancers to synchronize to the beat are likely influenced by the characteristics associated with dance training. For example, dance training is associated with better proprioception (Kiefer et al., 2013), better postural control (Rein et al., 2011), more stability, and stronger inter-limb coupling (Buchanan et al., 2007; Sofianidis et al., 2012; Thullier & Moufti, 2004), which may make dancers better synchronizers compared to non-dancers.

Separately, the behavioural effects of music and dance training on beat processing performance have been well studied. However, little research has directly compared the two types of training. 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). On more music-related tasks, rhythm synchronization involving finger tapping and melody discrimination, musicians outperform dancers (and non-musician/non-dancer controls), whereas on the more dance-related task, dance imitation involving whole-body movements, dancers outperform musicians (and non-musician/non-dancer controls). Moreover, MRI showed that musicians and dancers have increased cortical thickness compared to non-musician/non-dancer controls in the superior temporal gyrus, suggesting that the superior temporal gyrus is important in both music- and dance-related tasks (Karpati et al., 2017). While this body of work was the first to demonstrate how the effects of music training and the effects of dance training are similar and different from each other, it still remains to be elucidated how music and dance training may influence other processes in music cognition, such as beat perception and production.

2.1.2 Percussive and Nonpercussive Training

The other factor that may influence beat perception and production ability is training style. Different musical instruments and dance styles can be classified as either percussive or nonpercussive. The classification between percussive and nonpercussive is defined based on the attack time of the sound or movement produced by the musician or dancer, respectively. Attack time refers to the time it takes from the onset to the completion of the sound or movement. Percussionists often produce a sound or movement with a short attack time, whereas nonpercussionists often produce a sound or movement with a long attack time. Therefore, in music, individuals that play drums or cymbals are often classified as percussive musicians. By contrast, individuals that play strings or winds are often classified as nonpercussive musicians (Cicchini et al., 2012). In dance, individuals whose dance styles are tap or hip-hop are regarded as percussive dancers, whereas individuals whose dance styles are ballet or contemporary are regarded as nonpercussive dancers (Rosenfeld, 2011). Given that percussive training commonly focuses on temporal precision, percussionists are likely to show enhanced rhythm processing and sensorimotor synchronization performance compared to nonpercussionists.

With regards to music, percussionists have better temporal precision in rhythm perception and production tasks compared to nonpercussionists (Cameron & Grahn, 2014b; Petrini et al., 2009; Repp, 2005), perhaps due to the rhythmic focus on their training. In terms of rhythm perception, percussionists, particularly drummers, are better than nonpercussionists at perceiving audiovisual asynchrony in point-light displays of drumming movements (Petrini et al., 2009). In terms of rhythm production, percussionists also consistently outperform nonpercussionists (Cameron & Grahn, 2014b; Cicchini et al., 2012; Fujii et al., 2011; Krause et al., 2010; Repp et al., 2013). For example, percussionists generally produce lower variability regardless of whether they are synchronizing to isochronous or non-isochronous rhythms (with or without a complex beat structure) (Cameron & Grahn, 2014b; Cicchini et al., 2012; Fujii et al., 2011; Krause et al., 2010; Repp et al., 2013). Superior performance by percussionists on many rhythm perception and production tasks may be a result of their specialized training, as percussive training commonly focuses on temporal precision and the ability to maintain a steady and precise beat (Cameron & Grahn, 2014b).

With regards to dance, less is known about the differences between percussive and nonpercussive dancers. One body of research has compared skilled street dancers—a style of dance that is arguably percussive in nature—with non-dancers (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 non-dancers. However, no studies, to date, have directly examined percussive and nonpercussive dancers on the same task. Given the lack of research comparing percussive and nonpercussive dancers, it is unclear how training style, particularly in dance, may influence beat perception and production.

2.1.3 The Current Study

Although there is experimental support that expertise and training style influences beat processing abilities, no studies, to date, has examined how expertise (in music and dance) and training style (percussive or nonpercussive) interact to influence beat perception and production. Thus, the objective of the current study was to examine how percussive and nonpercussive music and dance training influence beat processing performance. Beat perception and production were tested using the BAT taken from the Gold-MSI. The BAT consists of two parts: the first part tests beat perception, while the second part tests beat production. For the beat perception task, participants listened to short instrumental clips, and decided whether a train of beeps superimposed on top of the music track was "on the beat" or "off the beat". For the beat production task, participants listened to short instrumental clips, and tapped in time to the beat on the spacebar of a laptop keyboard. To fully understand the interaction between expertise and training style on beat perception and production, five groups of participants were tested: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and non-musician/non-dancer controls. The non-musician/non-dancer control group was tested to compare beat perception and production between individuals with and without music and dance training.

It was 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 processing and sensorimotor synchronization skills (Karpati et al., 2016). However, it was predicted that musicians and dancers would outperform their non-musician/non-dancer counterparts on both the beat perception and production tasks (Karpati et al., 2016). It was also predicted that percussionists would outperform nonpercussionists on the beat processing tasks, as percussive training focuses more on the ability to perceive and maintain a steady and precise beat than nonpercussive training (Cameron & Grahn, 2014b; Cicchini et al., 2012; Petrini et al., 2009). Finally, it was predicted that the effect of expertise and training style would interact to influence beat perception and production:

percussive musicians and dancers would outperform nonpercussive musicians and dancers.

2.2 Methods

2.2.1 Participants

Five groups of participants were tested: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and non-musician/non-dancer controls. There were 20 participants in each group, for a total of 100 participants. Participants ranged between the ages of 18 and 48 years (M = 22.27 years, SD = 5.41 years). Table 1 summarizes the demographic characteristics of the sample. 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, non-musician/non-dancer 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.

Table 1: Participant characteristics

	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)	23.65±6.82	22.00±3.78	25.10±6.66	21.20±4.44	19.40±2.72
music training (years ± SD)	17.45±6.51	12.20±4.84	2.00±2.03	1.50±2.12	0.95±1.28
dance training (years ± SD)	0.55±0.94	0.50±0.95	18.50±7.06	14.60±5.98	0.30±0.98

2.2.2 Tasks

Beat processing abilities were tested using the BAT v.1.0 taken from the Gold-MSI. The BAT consists of two parts: the first part tests beat perception, while the second part tests beat production. The tasks were administered on a PC laptop using E-Prime (2.0) software (Psychology Software Tools, 2002). All auditory stimuli for the tasks were 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 minutes. All participants were fully debriefed following the study.

2.2.2.1 Beat Perception Task

Participants listened to 20 short instrumental clips (10 to 16 seconds 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, Gingras, Musil, & Stewart, 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.

2.2.2.2 Beat Production Task

Participants listened to the same instrumental clips (without the 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 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. One clip was used as practice, so there were 13 test clips in total. The order of the trials was randomized for each participant.

2.2.3 Statistical Analyses

Beat perception was analyzed by calculating the number 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 non-musician/non-dancer controls) ANOVA was also conducted to include the control group for all measures, as well as all group demographics analyses. Post hoc pairwise comparisons were conducted where appropriate and corrected for multiple comparisons using Bonferroni correction. All hypothesis tests used α = .05 for significance. Data were analyzed with SPSS (23.0) software.

2.2.3.1 Coefficient of Variation (CoV)

CoV measures the variability of a participant's response independent of the music. To measure CoV, a participant's inter-response intervals (IRIs) for each trial were calculated. 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 divided by the mean IRI for that trial.

$$\text{CoV} = \frac{\text{SD}_{\text{IRI}}}{\text{MEAN}_{\text{IRI}}}$$

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 response variability, while a higher CoV value indicates more response variability.

2.2.3.2 Coefficient of Deviation (CDEV)

CDEV measures the participant's ability to match their response to the tempo of the music. CDEV was calculated by taking the mean of the absolute difference between each IRI (calculated using the same criteria specified for the CoV measure) and its corresponding inter-beat interval (IBI) and dividing it by the mean IBI for that trial to normalize for the different tempi across the stimuli. The IBI was determined by comparing the mean IRI to potential IBIs that were multiples of the tempo, allowing for a meaningful analysis of CDEV regardless of what metrical level the participant chose to tap to.

$$\text{CDEV} = \frac{\text{MEAN}_{|\text{IRI}-\text{IBI}|}}{\text{MEAN}_{\text{IBI}}}$$

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 higher accuracy.

2.2.3.3 Asynchrony

Asynchrony measures the participant's ability to match their response to the beat period of the music. To measure asynchrony, the mean of the absolute difference between each response and its nearest beat position was calculated and divided by the mean IBI for that trial to normalize for the different tempi across the stimuli. Beat positions for at each time point were determined by comparing the mean IRI to potential IBIs at multiple metrical levels to allow for a meaningful analysis of asynchrony at different metrical levels of synchronization.

$$\text{ASYNCHRONY} = \frac{\text{MEAN}_{|\text{RESPONSE}-\text{BEAT}|}}{\text{MEAN}_{\text{IBI}}}$$

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.

2.3 Results

2.3.1 Group Demographics

One-way ANOVAs conducted on years of music and dance training revealed significant differences for both music, $F(4, 95) = 78.38$, $p < .001$, $\eta^2 = .77$, and dance training, $F(4, 95) = 90.22$, $p < .001$, $\eta^2 = .79$, between the groups. Post hoc comparisons confirmed that controls ($M = .95$ years, $SE = .29$ years) and dancers, percussive ($M = 2.00$ years, $SE = .45$ years) and nonpercussive ($M = 1.50$ years, $SE = .47$ years), did not differ in years of music training, $t(38) = 1.96$, $p = .06$ and $t(38) = 1.00$, $p = .33$, respectively. Percussive musicians ($M = 16.95$ years, $SE = 1.09$ years) and nonpercussive musicians ($M = 13.75$ years, $SE = 1.44$ years) also did not significantly differ in years of music training, $t(38) = 1.77$, $p = .08$, 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 confirmed that controls (M = .30 years, SE = .22 years) and musicians, percussive (M = .55 years, SE = .21 years) and nonpercussive (M = .50 years, SE = .21 years) did not differ, $t(38) = .82$, $p = .42$ and $t(38) = .66$, $p = .52$, respectively. Percussive dancers (M = 18.50 years, SE = 1.58 years) and nonpercussive dancers (M = 14.60 years, SE = 1.34 years) also did not significantly differ in years of dance training, $t(38) = 1.89$, $p = .07$. 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.

One-way ANOVAs were also conducted on years of training, starting age of training, and hours of practice per week for each group's respective expertise with musicians and dancers as the between subject variables and training style collapsed across groups because no effect of percussive versus nonpercussive training style was found. Musicians (M = 15.35 years, SE = .93 years) and dancers (M = 16.55 years, SE = 1.07 years) did not significantly differ in the years of training in their respective expertise, $F(1, 78) = .72$, $p = .40$, $\eta^2 = .009$. Musicians (M = 7.55 years old, SE = .54 years) and dancers (M = 6.08 years old, SE = .69 years) also did not significantly differ on the starting age of their respective training, $F(1, 78) = 2.83$, $p = .10$, $\eta^2 = .04$. Furthermore, musicians (M = 10.38 hours/week, SE = 1.09 hours/week) and dancers (M = 13.05 hours/week, SE = 1.06 hours/week) did not significantly differ on the number of hours they practiced per week, $F(1, 78) = 3.11$, $p = .08$, $\eta^2 = .04$.

To confirm that any differences in performance between groups were not due to differences in music exposure, a one-way ANOVA on the hours of music exposure per week was conducted. The ANOVA was conducted with controls (M = 12.50 hours/week, SE = 1.47 hours/week), musicians (M = 15.75 hours/week, SE = .96 hours/week), and dancers (M = 13.65 hours/week, SE = 1.30 hours/week) as the between groups variable.

The ANOVA confirmed that there were no significant differences between groups, $F(2, 97) = 1.65$, $p = .20$, $\eta^2 = .03$. All participants had similar exposure to music. Therefore, any differences in performance between the groups are unlikely due to differences in music exposure.

2.3.2 Beat Perception Task

2.3.2.1 Percent Correct

Performance on the beat perception task significantly differed for expertise, $F(1, 76) = 18.08$, $p < .001$, $\eta^2 = .19$. Musicians (*M* = 86.03%, *SE* = 1.99%) were better at perceiving the beat compared to dancers (*M* = 72.21%, *SE* = 2.56%). However, performance did not significantly differ for training style, $F(1, 76) = 1.61$, $p = .21$, $\eta^2 = .02$. Percussionists (*M* = 81.18%, *SE* = 2.76%) and nonpercussionists (*M* = 77.06%, *SE* = 2.28%) performed very similarly on the task. The interaction between expertise and training style was also not significant, $F(1, 76) = .21$, $p = .65$, $\eta^2 = .003$. In the one-way between subjects ANOVA that included non-musician/non-dancer controls, both percussive (*M* = 87.35%, *SE* = 3.42%) and nonpercussive musicians (*M* = 84.71%, *SE* = 2.11%) were significantly better at perceiving the beat compared to controls (*M* = 67.35%, *SE* = 3.18%), and nonpercussive dancers (*M* = 69.41%, *SE* = 3.27%), but not percussive dancers (*M* = 75.00%, *SE* = 3.93%), $F(4, 95) = 7.66$, $p < .001$, $\eta^2 = .24$ (Figure 2).

To examine the difference in performance on the beat perception task broken down into the different trial types, a 3 (*group*: musicians, dancers, and non-musician/non-dancer controls) x 3 (*trial type*: “on-beat” “off-beat tempo error”, “off-beat phase error” trials) mixed ANOVA was conducted, with group as the between groups variable and trial type as the within groups variable. Training style was collapsed across groups because no effect of percussive versus nonpercussive training style was found. Performance on the beat perception task significantly differ for trial type, $F(2, 194) = 117.30$, $p < .001$, $\eta^2 = .55$. Participants were significantly more accurate on the “on-beat” trials (*M* = 93.00%, *SE* = 1.55%) than on the “off-beat tempo error” (*M* = 82.13%, *SE* = 1.81%) and the “off-

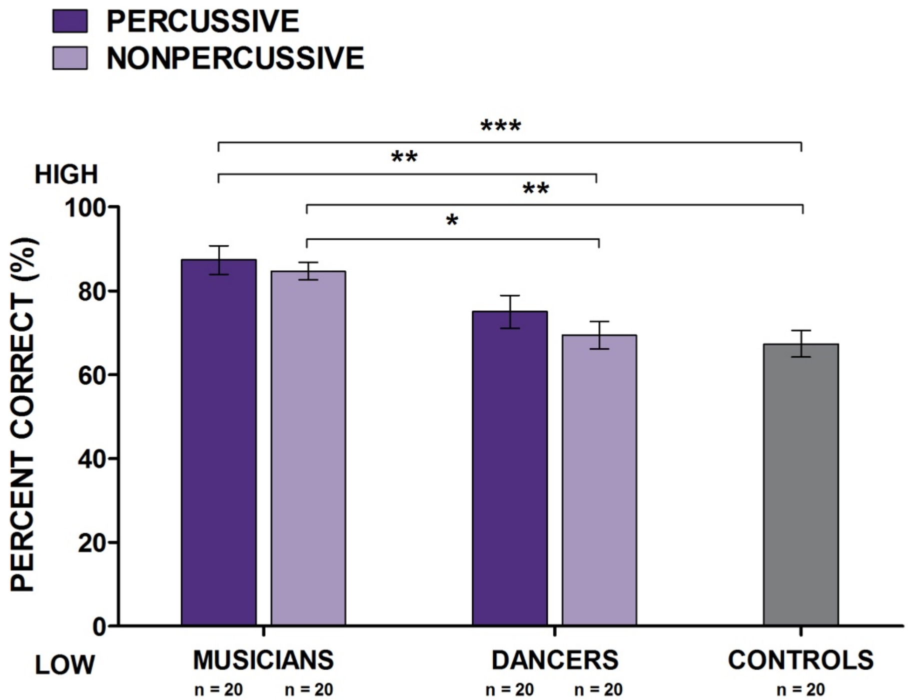

Figure 2: Performance on the beat perception task measured using percent correct. Musicians were significantly better at perceiving the beat compared to dancers, but percussionists and nonpercussionists did not differ. Both percussive and nonpercussive musicians were more accurate than controls and nonpercussive dancers, but not percussive dancers, at perceiving the beat. Error bars indicate standard error of the mean. * p < .05, ** p < .01, *** p < .001.

beat phase error" trials (M = 55.20%, SE = 2.93%), $t(99) = 5.62$, $p < .001$ and $t(99) = 12.79$, $p < .001$, respectively. Participants were also significantly more accurate on the "off-beat tempo error" trials than the "off-beat phase error" trials, $t(99) = 10.23$, $p < .001$. The interaction between group and trial type was also significant, $F(4, 194) = 5.04$, $p < .01$, $\eta^2 = .09$ (Figure 3). Musicians ("on-beat": M = 98.75%, SE = .87%; "off-beat tempo error": M = 88.75%, SE = 2.52%; "off-beat phase error": M = 71.50%, SE = 3.98%) were significantly more accurate than controls ("on-beat": M = 88.75%, SE = 3.84%; "off-beat tempo error": M = 70.00%, SE = 4.29%; "off-beat phase error": M = 46.00%, SE = 5.25%), regardless of trial types. Dancers ("on-beat": M = 89.38%, SE = 3.09%; "off-beat tempo error": M = 81.56%, SE = 2.65%; "off-beat phase error": M = 43.50%, SE =

4.52%) were only significantly more accurate than controls for the “off-beat tempo error” trials. Lastly, the comparison between musicians and dancers was significant for all trial types, see Table 2 for all pairwise comparisons between the groups for the three different trial types.

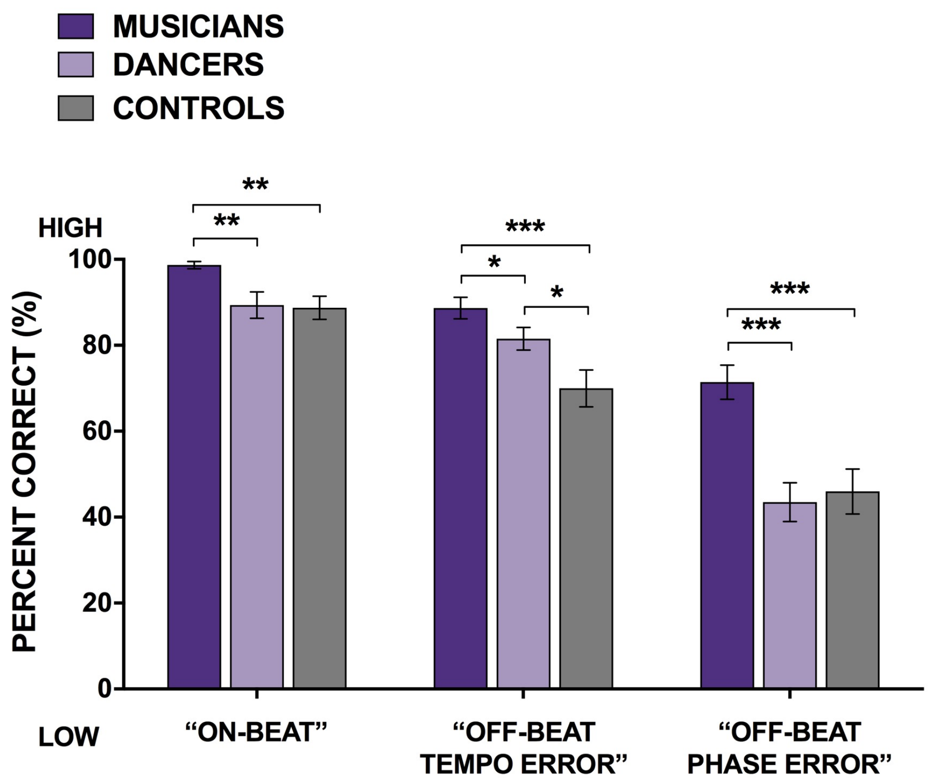

Figure 3: Interaction between group and trial types for the beat perception task. Musicians were significantly more accurate than dancers and controls on the beat perception task, regardless of trial types. Dancers were only significantly more accurate than controls for the “off-beat tempo error” trials. Error bars indicate standard error of the mean. * p < .05, ** p < .01, *** p < .001.

Table 2: Pairwise comparisons between expertise for trial types for the beat perception task

Pairwise Comparisons	"on-beat" trials		"off-beat tempo error" trials		"off-beat phase error" trials	
	t(58)	*p*-value	*t*(58)	*p*-value	*t*(58)	*p*-value
musicians – controls	**3.38**	**< .01**	**4.01**	**< .001**	**3.78**	**< .001**
dancers – controls	.12	.91	**2.40**	**< .05**	-.34	.74
	t(78)	*p*-value	*t*(78)	*p*-value	*t*(78)	*p*-value
musicians – dancers	**2.92**	**< .01**	**1.97**	**< .05**	**4.65**	**< .001**

2.3.3 Beat Production Task

2.3.3.1 Coefficient of Variation (CoV)

The two-way between subjects ANOVA on tapping variability produced a significant main effect of expertise, $F(1, 76) = 14.44$, $p < .001$, $\eta^2 = .16$. Musicians ($M = .047$, $SE = .002$) tapped with lower variability than dancers ($M = .061$, $SE = .003$). However, there was no significant main effect of training style, $F(1, 76) = .23$, $p = .63$, $\eta^2 = .03$. 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, $F(1, 76) = .01$, $p = .92$, $\eta^2 < .001$. The one-way between subjects ANOVA produced a significant effect of group on tapping variability, $F(4, 95) = 8.32$, $p < .001$, $\eta^2 = .26$. Post hoc comparisons indicated that percussive ($M = .046$, $SE = .002$) and nonpercussive musicians ($M = .047$, $SE = .003$) tapped with lower variability than dancers and controls ($M = .080$, $SE = .007$). Percussive dancers ($M = .060$, $SE = .005$), but not nonpercussive dancers ($M = .062$, $SE = .004$), also tapped with lower variability than controls (Figure 4).

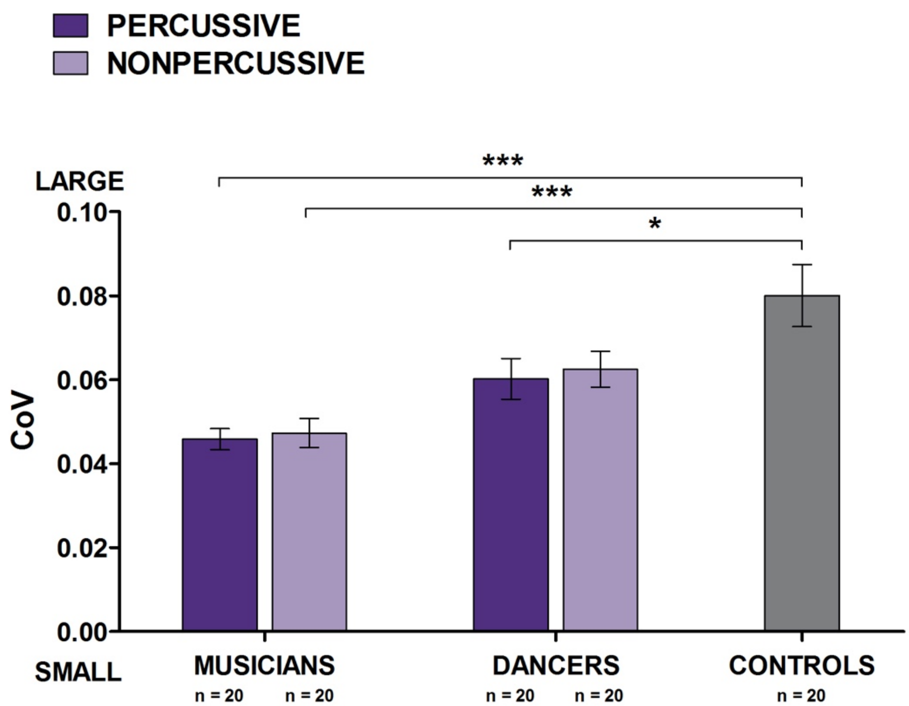

Figure 4: Performance on the beat production task measured using CoV. Musicians tapped with significantly lower variability than dancers, but percussionists and nonpercussionists did not differ. Percussive and nonpercussive musicians, as well as percussive dancers, tapped with significantly lower variability than controls. Error bars indicate standard error of the mean. * *p* < .05, * *p* < .001.**

2.3.3.2 Coefficient of Deviation (CDEV)

The participant's ability to match their tapping tempo to the beat tempo of the music significantly differed for expertise, $F(1, 76) = 7.49$, $p < .01$, $\eta^2 = .09$. Musicians (M = .041, SE = .002) tapped to the tempo of the music with greater accuracy (lower mean CDEV) than dancers (M = .053, SE = .004). However, tempo matching accuracy did not significantly differ for training style, $F(1, 76) = .51$, $p = .48$, $\eta^2 = .007$. Percussionists (M = .046, SE = .003) and nonpercussionists (M = .049, SE = .003) did not differ in their ability to match their tapping tempo to the beat tempo of the music. The interaction between expertise and training style was also not significant, $F(1, 76) = .05$, $p = .83$, $\eta^2 < .01$. The one-way 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, $\eta^2 = .17$. Percussive ($M = .039$, $SE = .002$) and nonpercussive musicians ($M = .043$, $SE = .005$) tapped to the tempo of the music with greater accuracy than controls ($M = .069$, $SE = .007$). Tempo matching accuracy was also greater for percussive ($M = .052$, $SE = .006$) and nonpercussive dancers ($M = .055$, $SE = .004$) compared to controls, but the differences were not statistically significant (Figure 5).

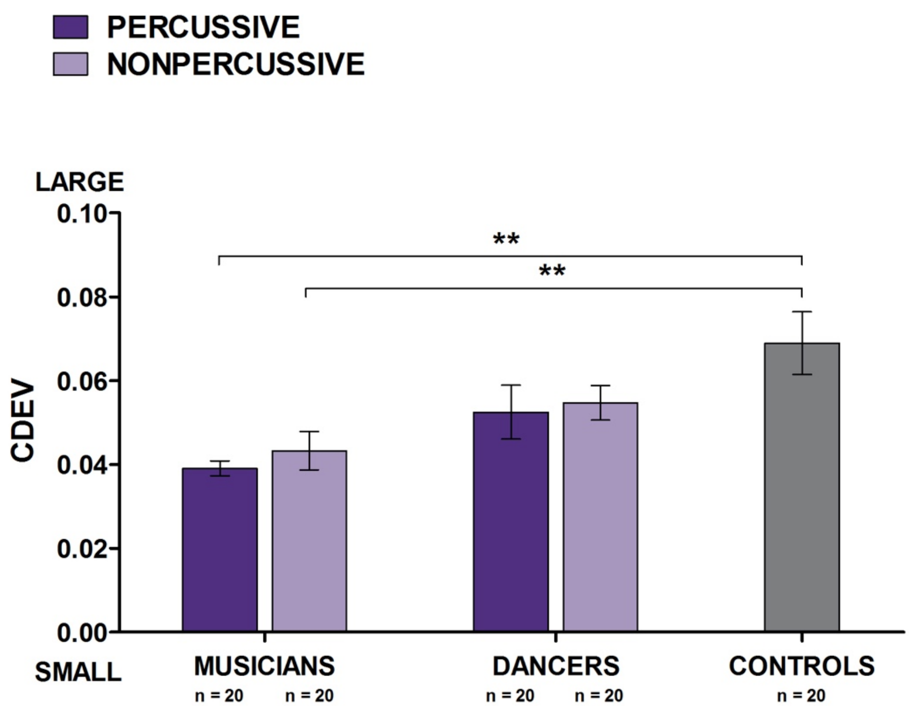

Figure 5: Performance on the beat production task measured using CDEV. Musicians tapped to the tempo of the music with significantly greater accuracy than dancers, but percussionists and nonpercussionists did not differ. Relative to controls, only percussive and nonpercussive musicians tapped to the tempo of the music with significantly greater accuracy. Error bars indicate standard error of the mean. ** p < .01.

2.3.3.3 Asynchrony

The two-way 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 ($M = .070$, $SE = .006$) tapped to the beat with greater accuracy (smaller mean absolute asynchrony) than dancers (*M* = .100, *SE* = .009). However, there was no significant main effect of training style, $F(1, 76) = .95$, $p = .33$, $\eta^2 = .01$. Percussionists (*M* = .079, *SE* = .007) and nonpercussionists (*M* = .090, *SE* = .009) did not differ in their ability to match their tapping to the beat. The interaction between expertise and training style was also not significant, $F(1, 76) = .002$, $p = .97$, $\eta^2 < .001$. The one-way between subjects ANOVA on tapping accuracy produced a significant effect of group, $F(4, 95) = 3.14$, $p < .05$, $\eta^2 = .12$. Post hoc comparisons 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). However, tapping accuracy was not significantly different for percussive dancers (*M* = .095, *SE* = .012) and nonpercussive dancers (*M* = .105, *SE* = .014) compared to controls (Figure 6).

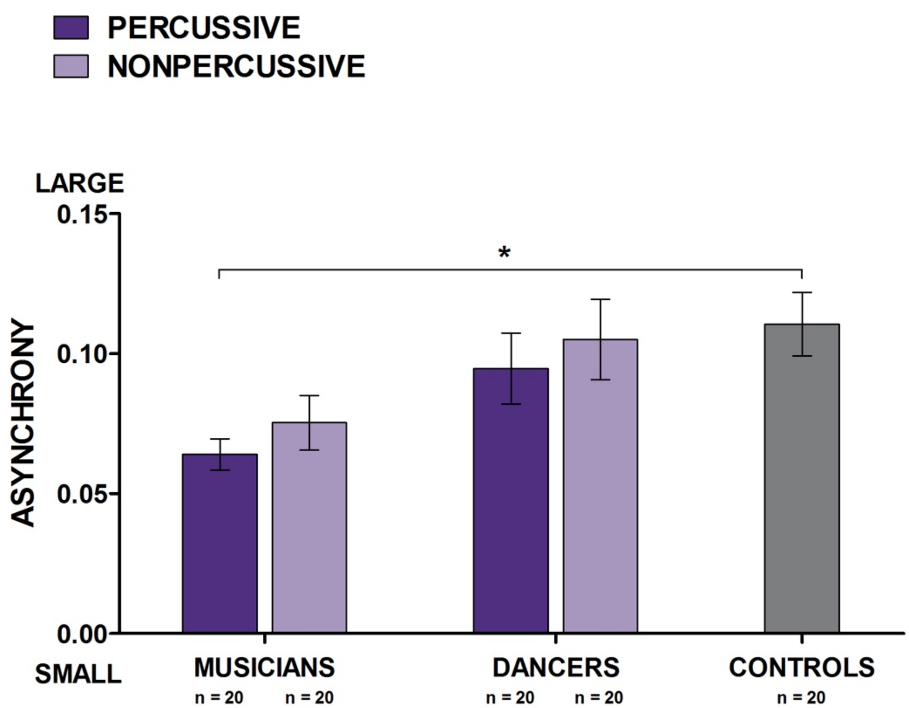

Figure 6: Performance on the beat production task measured using asynchrony. Musicians tapped to the beat with significantly lower mean asynchrony than dancers, but percussionists and nonpercussionists did not differ. Relative to controls, only percussive musicians were significantly better at matching their tapping to the beat. Error bars indicate standard error of the mean. * p < .05.

2.4 Discussion

The current study examined how percussive and nonpercussive music and dance training influenced beat perception and production. It was 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 processing and sensorimotor synchronization skills (Karpati et al., 2016). However, the results indicated that music training was associated with better beat processing compared to dance training. On the beat perception task, musicians were more accurate at perceiving the beat compared to dancers and controls, regardless of trial type. On the beat production task, musicians tapped with significantly lower variability, smaller mean absolute asynchrony, and were more accurate at matching their tapping to the tempo of the music, compared to dancers and controls. Dancers performed better than controls, albeit not significantly so. Thus, the results suggest that music training, but not dance training, influences beat processing performance.

For training style, it was predicted that percussionists would outperform nonpercussionists on the beat processing tasks, as percussive training focuses more on the ability to perceive and maintain a steady and precise beat (Cameron & Grahn, 2014b). However, relative to nonpercussive training, percussive training did not significantly affect beat processing performance. On all measures of beat perception and production, performance was similar for both percussionists and nonpercussionists. Taken together, the results suggest that music training was associated with better beat perception and production relative to dance training, but percussive training compared to nonpercussive training did not have a significant effect.

There is evidence in the literature to suggest that percussionists are more likely to have enhanced beat processing abilities compared to nonpercussionists (Cameron & Grahn, 2014b; Petrini et al., 2009; Repp, 2005). However, the results showed that percussionists and nonpercussionists did not significantly differ on performance of the beat perception or production tasks. Here, musicians and dancers were classified as percussionists or nonpercussionists based on the attack time of the sound or movement they were likely to produce with their instrument or dance style, respectively. Although individuals whose main instruments or whose main dance styles could be classified as both percussive and nonpercussive were excluded from the study, the sample was rather limited with a narrow range of participants with exclusively percussive or nonpercussive training. As such, as long as the participant's main instrument or dance style was percussive, they were considered a percussionist, and vice versa for participants whose main instrument or dance style was nonpercussive. Therefore, the lack of a significant difference between percussionists and nonpercussionists may have been because the distinction between the two groups was not strong enough. Future studies may yield an effect of training style by testing musicians and dancers whose training are intensively and exclusively percussive or nonpercussive.

It is unsurprising that musicians performed better on the beat perception and production tasks compared to controls, as there is strong experimental support that musicians are better at beat processing than non-musicians (Besson & Faita, 1995; Drake et al., 2000; Jongsma et al., 2007; Repp, 2010; Repp & Doggett, 2007). Dancers also performed better on the beat perception and production tasks than controls, albeit the differences in performance were not significant. It seems likely that non-musician/non-dancer controls would have inferior performance compared to their trained counterpart because of their lack of specialized music or dance training. However, it has been suggested that due to their training, musicians and dancers may have had more exposure to music than controls and that mere exposure to music, particularly music with beat-based patterns, may affect beat processing performance (Bläsing et al., 2012; Drake, 1998; Tillmann, 2008). To examine the mere exposure effect of music, participants reported how many hours a week they listened to music, including practicing time. The results confirmed that there were no significant differences in music exposure between musicians, dancers, and controls. Therefore, the differences in performance between musicians and controls are unlikely due to differences in music exposure.

As it was predicted that musicians and dancers would not differ in performance, it was surprising to find that musicians had better beat processing performance than dancers. Other than differences in their training, other possibilities that may account for their performance differences are the differences in quantity or quality of their respective training. However, great effort was made to recruit individuals that were comparable with regards to their respective training. 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. The other possibility is a difference in quality of training. Expertise, here, was quantified by the number of years of training, so it can only be assumed that years of training would positively correlated with expertise. However, it cannot be confirmed for certain as an independent measure of expertise was not assessed. It is unlikely, however, that individuals with comparable years of training in their respective expertise are vastly different in skill levels.

Beat processing performance between musicians and dancers may have significantly differed because of sex differences. In the musician groups, participants were evenly split between male and female, whereas in dancer groups, participants were predominantly female (one male in each group). While male and female dancers were recruited equally, more female dancers met the inclusion criteria. Although this sex difference should not be dismissed, it is unlikely that it is a significant factor influencing beat perception and production. There is no evidence in the literature to suggest that males and females differ in their abilities to process temporal information. Nonetheless, future studies may want to assess whether sex differences might exist.

Musicians' better beat processing performance compared to dancers may also be task specific. Arguably, the tasks used in the current study were more music-relevant than dance-relevant. Specifically, auditory stimuli were used to measure beat perception, and a finger tapping task was used to measure beat production. Musicians' superior performance may have been enhanced by their focused training with auditory stimuli and the use of effector-specific movements (i.e.; hand or finger tapping) (Fernandes & de Barros, 2012; Repp, 2010; Verheul & Geuze, 2004). Compared to music, dance relies more on both auditory and visual stimuli and whole-body movements (Karpati et al., 2016; Miura et al., 2011; Miura et al., 2016). Consequently, musicians' superior performance may arise from the music-specific nature of the tasks. Therefore, future studies may want to try tasks that are more dance-relevant. Perhaps using auditory and visual stimuli together to measure beat perception, and whole-body movements to test beat production, the effect of dance training on beat perception and production may be more evident.

2.5 Conclusions

The current study 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. Musicians showed a significant advantage over dancers and controls on both beat processing tasks. On the beat perception task, musicians were more accurate at perceiving the beat compared to dancers and controls. On the beat production task, musicians tapped with significantly lower variability, smaller mean absolute asynchrony, and were more accurate at matching their tapping to the tempo of the music compared to dancers and controls. On both tasks, performance was similar for percussionists and nonpercussionists. While the current study is not the first to demonstrate that the effects of music and dance training differ from each other, it is the first to examine how music or dance training and percussive or nonpercussive style interact.

Chapter 3

3 Examining the Differences in Beat Perception and Production between Percussive and Nonpercussive Musicians and Dancers using Motion Capture

3.1 Introduction

There is evidence that musicians may have better beat processing abilities than dancers (see Chapter 2). However, it remains to be elucidated whether musicians outperform dancers on the beat processing tasks because they have better beat processing abilities, or because the tasks are biased toward musicians. In Chapter 2, beat perception was measured using auditory stimuli, and beat production was measured using a finger tapping task, both of which are arguably music-related. Thus, musicians' superior performance on the beat perception and production tasks may have been biased by their auditory training and the use of effector-specific movements (i.e.; hand or finger tapping) (Fernandes & de Barros, 2012; Repp, 2010; Verheul & Geuze, 2004). The objective of the current study was to re-examine how percussive and nonpercussive music and dance training influence beat processing performance, but using an audiovisual variant of the BAT, as well as a knee bending task recorded with motion capture to assess whole-body movements.

3.1.1 Percussive and Nonpercussive Training

As previously mentioned, given that percussive training commonly focuses on temporal precision, percussionists are likely to show enhanced rhythm processing and sensorimotor synchronization performance compared to nonpercussionists (Cameron & Grahn, 2014b; Cicchini et al., 2012; Fujii et al., 2011; Krause et al., 2010; Repp et al., 2013). However, the results in Chapter 2 showed that percussionists and nonpercussionists did not significantly differ on the beat perception or production tasks. Although training style did not have a significant effect on beat processing performance for musicians or dancers, the effect of percussive and nonpercussive training on beat perception and production was re-examined here. A limitation of Chapter 2 was that percussionists and nonpercussionists were made up of musicians and dancers whose main instrument or dance style were classified as percussive or nonpercussive, respectively. As long as the participant's main instrument or dance style was percussive, they were considered a percussionist, and vice versa for participants whose main instrument or dance style was nonpercussive. Therefore, the lack of a significant difference between percussionists and nonpercussionists may have been because the distinction between the two groups was not strong enough. To address this limitation, here, only musicians and dancers whose training was exclusively percussive or nonpercussive were recruited, excluding any participants with both percussive and nonpercussive training.

3.1.2 Auditory and Visual Modalities

Both music and dance training focus on the processing of auditory and visual rhythms, but music may rely more on the auditory modality, whereas dance may rely more on the visual modality. For example, musicians are better than non-musicians at detecting differences in auditory rhythms (Besson & Faita, 1995; Drake et al., 2000; Jongsma et al., 2007), whereas dancers are better than non-dancers at detecting differences of visual dance movements (Calvo-Merino et al., 2010; Hagendoorn, 2004; Stevens et al., 2010). 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, Marini, & Burr, 2009; Su, 2014; Su & Salazar-López, 2016). More specifically, visual information combines with auditory information to optimize rhythm perception (Su & Salazar-López, 2016). Therefore, it is unclear whether musicians' superior beat processing abilities (see Chapter 2) will generalize to a beat perception task that is an audiovisual variant of the original (audio only) BAT, or whether the additional visual information will be more beneficial to dancers.

3.1.3 Effector-Specific and Whole-Body Movements

Musicians and dancers possess similar sensorimotor synchronization skills because of their training (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., 2017). For example, when asked to synchronize with music by tapping with their finger, musicians synchronize more accurately, tap more slowly, and tap to a wider range of metrical levels than non-musicians (Drake et al., 2000). Similarly, when asked to synchronize with a metronome by bending at the knees, dancers synchronize more accurately, produce lower variability, and deviate less from the beat time than non-dancers (Miura et al., 2011; Miura, Kudo, & Nakazawa, 2013; Miura, Kudo, Ohtsuki, et al., 2013). Musicians seem to show advantages in hand and finger movements compared to non-musicians (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 inter-limb coupling than non-dancers (Buchanan et al., 2007; Sofianidis et al., 2012; Thullier & Moufti, 2004). Moreover, when musicians and dancers are compared, on tasks that involve finger tapping, musicians outperform dancers (and controls), but on tasks that involve whole-body movements, dancers outperform musicians (and controls) (Karpati et al., 2016). Therefore, it may be that musicians' beat production is more accurate with ecologically valid effector-specific movements, but dancers' beat production is more accurate with ecologically valid whole-body movements.

3.1.4 The Current Study

In the current study, beat perception and production were tested using an audiovisual variant of the BAT and whole-body movements (i.e., knee bending), respectively. For the beat perception task, participants made perceptual judgements of audiovisual stimuli (an auditory train of beeps heard while they watched a visual bouncing stick figure). For the beat production task, participants listened to short instrumental clips, and bounced in time to the beat while motion capture measured the timing of their whole-body movements.

Five groups of participants were tested: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and non-musician/non-dancer controls. The non-musician/non-dancer control group was tested to compare beat perception and production between individuals with and without music and dance training.

If the musicians' superior performance in Chapter 2 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' superior performance in Chapter 2 was task specific, then the dancers should outperform the musicians, or perform comparably, in both the audiovisual beat perception and the bouncing beat production tasks. Furthermore, it was predicted that musicians and dancers would outperform their non-musician/non-dancer counterparts on both tasks (Karpati et al., 2016), and that percussionists would outperform nonpercussionists (Cameron & Grahn, 2014b; Cicchini et al., 2012; Petrini et al., 2009).

3.2 Methods

3.2.1 Participants

Five groups of participants were tested: percussive musicians, nonpercussive musicians, percussive dancers, nonpercussive dancers, and non-musician/non-dancer controls. There were 20 participants in each group, for a total of 100 participants. Participants ranged between the ages of 18 and 44 years (M = 22.64 years, SD = 4.64 years). Table 3 summarizes the demographic characteristics of the sample. The participant criteria for the current study is identical to participant criteria for the study in Chapter 2, except that individuals with training in any instruments or dance styles that could be classified as both percussive and nonpercussive were excluded from the study. 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.

Table 3: Participant characteristics

	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 males	19 females 1 male	14 females 6 males
age range (years)	19 to 36	19 to 26	18 to 35	18 to 35	18 to 44
mean age (years ± SD)	23.20±4.81	22.10±2.53	22.35±3.88	23.00±4.34	22.55±6.90
music training (years ± SD)	15.55±6.26	12.80±3.81	1.35±1.90	1.60±2.23	1.67±1.95
dance training (years ± SD)	1.25±2.22	0.25±1.12	14.85±6.62	15.60±4.62	0.30±0.65

3.2.2 Tasks

Beat processing abilities were tested using an audiovisual variant of the beat perception task and a bouncing beat production task recorded by a motion capture system. The tasks were administered on a PC laptop using E-Prime (2.0) software (Psychology Software Tools, 2002). All auditory stimuli for the tasks were 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 minutes. All participants were fully debriefed following the study.

3.2.2.1 Audiovisual Beat Perception Task

Participants watched 20 short video clips (10 to 16 seconds long), and decided whether a stick figure bouncing to the beat of the music track was "on the beat" or "off the beat". The bouncing stick figure was programmed in MATLAB R2014a (The MathWorks Inc., Natick, MA, USA), generated from the IBIs of each musical piece and moved according to a dancer's bouncing trajectory derived from piloted motion capture data (Figure 7). The 20 video clips were generated using the 12 different musical pieces from the study in Chapter 2. For the off-beat trials, there were two possible types of errors: the beeps were either too fast or too slow in tempo relative to the beat of the music, creating a "tempo error", or the beeps 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. 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.

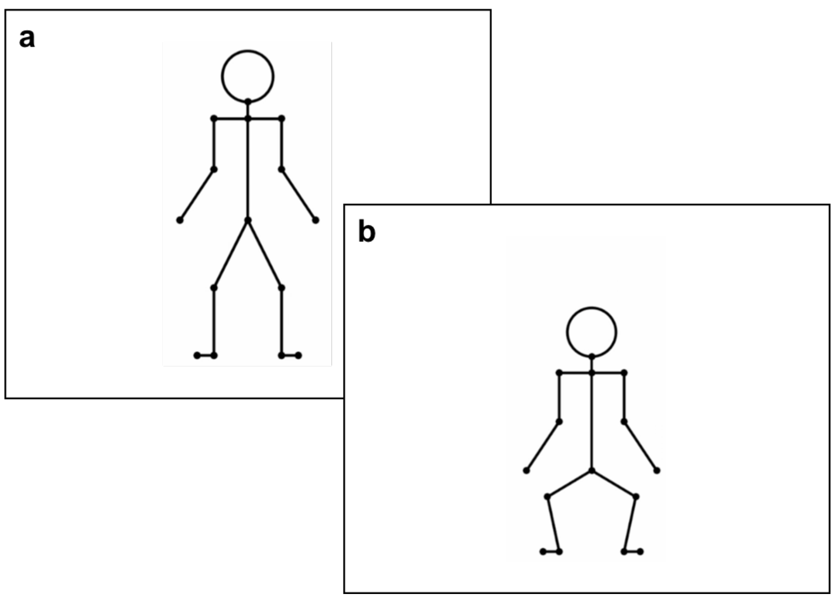

Figure 7: Visual representation of the bouncing stick figure. a) depicts the stick figure in the most upright position. b) depicts the stick figure in the most bent position.

3.2.2.2 Bouncing Beat Production Task

The bouncing beat production task was identical to that used in Chapter 2, except that participants were instructed to bounce to the beat by bending their knees, ensuring that the bottom of their bounces synchronized with the beat. They were to start bouncing as soon as they found 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 (3-D) 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 3-D 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 order of the trials was randomized for each participant.

3.2.3 Statistical Analyses

Beat perception was analyzed by calculating the number of trials correctly identified as having the stick figure bounce “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 is 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 trial were then used to calculated CoV, CDEV, and asynchrony, the same way as it was calculated in Chapter 2. 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 non-musician/non-dancer controls) ANOVA was also conducted to include the control group for all measures, as well as all 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.

3.3 Results

3.3.1 Group Demographics

One-way 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 variable. Years of training were significantly different for both music, $F(4, 95) = 76.05$, $p < .001$, $\eta^2 = .76$, and dance training, $F(4, 95) = 91.63$, $p < .001$, $\eta^2 = .79$, between the groups. Post hoc comparisons confirmed that controls ($M = 1.25$ years, $SE = .41$ years) and dancers, percussive ($M = 1.35$ years, $SE = .42$ years) and nonpercussive ($M = 1.60$ years, $SE = .50$ years), did not differ in years of music training, $t(38) = .17$, $p = .87$ and $t(38) = .54$, $p = .59$, respectively. Percussive musicians ($M = 15.55$ years, $SE = 1.40$ years) and nonpercussive musicians ($M = 12.80$ years, $SE = .85$ years) also did not significantly differ in years of music training, $t(38) = 1.68$, $p = .10$. 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 confirmed that controls ($M = .30$ years, $SE = .15$ years) and musicians, percussive ($M = 1.25$ years, $SE = .50$ years) and nonpercussive ($M = .25$ years, $SE = .25$ years), did not significantly differ, $t(38) = 1.83$, $p = .07$ and $t(38) = .17$, $p = .86$, respectively. Percussive dancers ($M = 14.85$ years, $SE = 1.48$ years) and nonpercussive dancers ($M = 15.60$ years, $SE = 1.03$ years) also did not significantly differ in years of dance training, $t(38) = .42$, $p = .68$, 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.

One-way ANOVAs were also conducted on years of training, starting age of training, and hours of practice per week for each group’s respective expertise with musicians and dancers as the between-subject variables. Training style were collapsed across groups because no effect of percussive versus nonpercussive training style was found. Musicians

(M = 14.18 years, SE = 1.19 years) and dancers (M = 15.23 years, SE = 1.26 years) did not significantly differ in the years of training in their respective expertise, $F(1, 78) = .74$, $p = .39$, $\eta^2 = .01$. Musicians (M = 7.95 years old, SE = .69 years) and dancers (M = 6.45 years old, SE = .99 years) also did not significantly differ on the starting age of their respective training, $F(1, 78) = 3.09$, $p = .08$, $\eta^2 = .04$. Likewise, musicians (M = 10.05 hours/week, SE = 1.89 hours/week) and dancers (M = 9.18 hours/week, SE = 1.60 hours/week) did not significantly differ on the number of hours they practiced per week, $F(1, 78) = .25$, $p = .62$, $\eta^2 = .003$.

To confirm that any differences in performance between groups were not due to differences in music exposure, a one-way ANOVA on the hours of music exposure per week was conducted. The ANOVA was conducted with controls (M = 14.30 hours/week, SE = 1.57 hours/week), musicians (M = 14.03 hours/week, SE = 1.73 hours/week), and dancers (M = 14.15 hours/week, SE = 1.53 hours/week) as the between groups variable. The ANOVA confirmed that there were no significant differences between groups, $F(2, 97) = .01$, $p = .99$, $\eta^2 < .001$. All participants had similar exposure to music, regardless of expertise. Therefore, any differences in performance between the groups are unlikely due to differences in music exposure.

3.3.2 Audiovisual Beat Perception Task

3.3.2.1 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 two-way 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 one-way between subjects ANOVA that included non-musician/non-dancer controls, 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%), $F(4, 95) = 2.58$, p <

.05, η^2 = .10. Percussive (*M* = 60.88%, *SE* = 3.00%) and nonpercussive dancers (*M* = 55.00%, *SE* = 2.67%) also did not differ from controls (Figure 8).

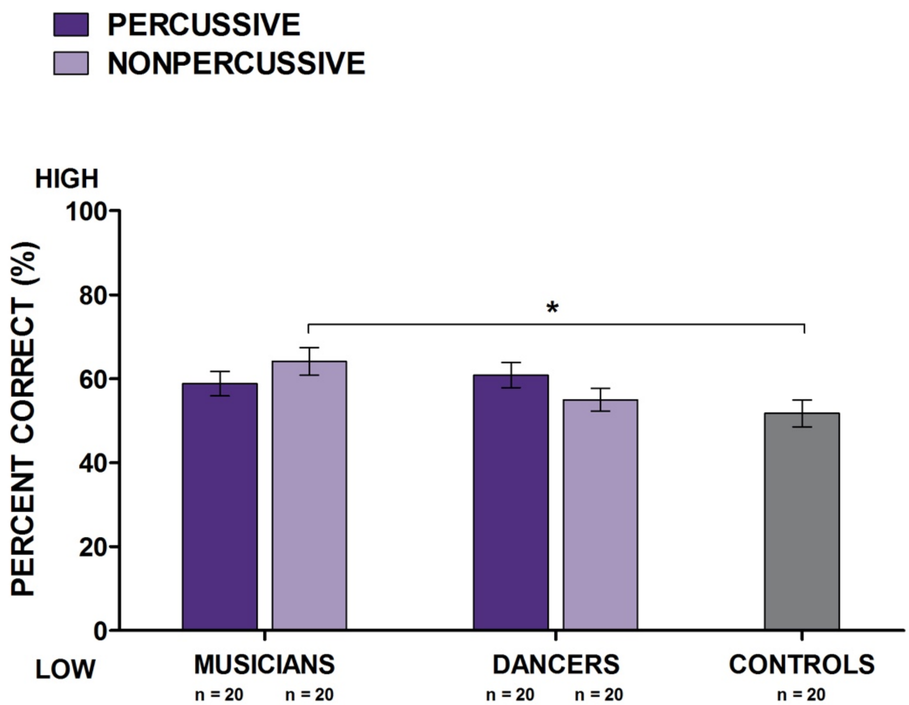

Figure 8: Performance on the audiovisual beat perception task measured using percent correct. Musicians and dancers performed similarly on the audiovisual beat perception task. Percussionists and nonpercussionists also performed similarly on the task. Relative to controls, only nonpercussive musicians were significantly better at perceiving the beat. Error bars indicate standard error of the mean. * p < .05.

To examine the difference in performance on the audiovisual beat perception task broken down into the different trial types, a 3 (*group*: musicians, dancers, and non-musician/non-dancer controls) x 3 (*trial type*: “on-beat” “off-beat tempo error”, “off-beat phase error” trials) mixed ANOVA was conducted, with group as the between groups variable and trial type as the within groups variable. Training style was collapsed across groups because no effect of percussive versus nonpercussive training style was found. Performance on the audiovisual beat perception task significantly differ for trial type, $F(2, 194) = 16.02$, $p < .001$, $\eta^2 = .14$. Participants were significantly more accurate on the "on-beat" (*M* = 62.92%, *SE* = 2.59%) and the "off-beat tempo error" trials (*M* = 62.29%, *SE* = 2.21%) than on the "off-beat phase error" trials (*M* = 44.00%, *SE* = 2.63%), $t(99) = 4.71$, $p < .001$ and $t(99) = 4.91$, $p < .001$, respectively. However, performance on the "on-beat" and the "off-beat tempo error" trials did not significantly differ, $t(99) = .28$, $p = .78$. The interaction between group and trial type was also not significant, $F(2, 194) = .59$, $p = .67$, $\eta^2 = .01$ (Figure 9). Regardless of trial type, musicians ("on-beat": *M* = 64.38%, *SE* = 4.19%; "off-beat tempo error": *M* = 68.75%, *SE* = 3.38%; "off-beat phase error": *M* = 47.50%, *SE* = 4.16%), dancers ("on-beat": *M* = 66.88%, *SE* = 3.40%; "off-beat tempo error": *M* = 60.00%, *SE* = 3.86%; "off-beat phase error": *M* = 47.50%, *SE* = 4.03%), and controls ("on-beat": *M* = 57.50%, *SE* = 7.28%; "off-beat tempo error": *M* = 58.13%, *SE* = 3.77%; "off-beat phase error": *M* = 37.00%, *SE* = 6.20%) all performed similarly, see Table 4 for all pairwise comparisons between the groups for the three different trial types.

Table 4: Pairwise comparisons between expertise for trial types for the audiovisual beat perception task

Pairwise Comparisons	"on-beat" trials		"off-beat tempo error" trials		"off-beat phase error" trials	
	t(58)	*p*-value	*t*(58)	*p*-value	*t*(58)	*p*-value
musicians – controls	.88	.38	1.94	.06	1.43	.16
dancers – controls	1.34	.19	.31	.76	1.46	.15
	t(78)	*p*-value	*t*(78)	*p*-value	*t*(78)	*p*-value
musicians – dancers	-.46	.64	1.71	.09	.00	1.00

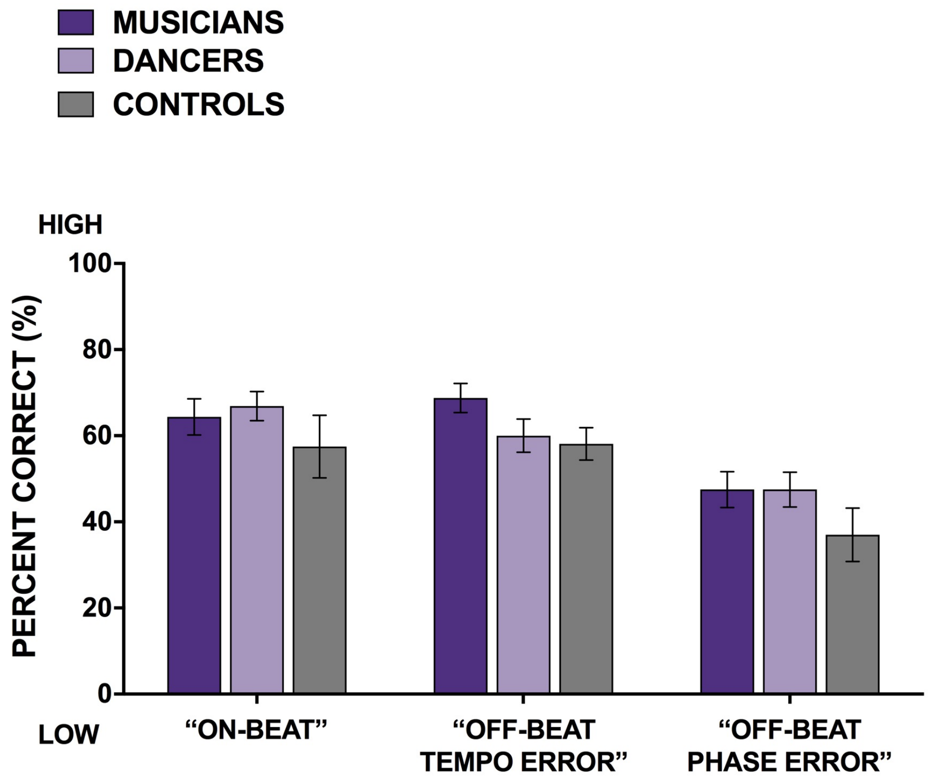

Figure 9: Interaction between group and trial types for the audiovisual perception task. Participants were significantly more accurate on the "on-beat" and the "off-beat tempo error" trials than on the "off-beat phase error" trials. However, performance on the "on-beat" and the "off-beat tempo error" trials did not significantly differ. The interaction between group and trial type was not significant. Musicians, dancers, and controls all performed similarly regardless of trial type. Error bars indicate standard error of the mean.

3.3.3 Bouncing Beat Production Task

3.3.3.1 Coefficient of Variation (CoV)

The two-way between subjects ANOVA on bouncing variability did not produce a significant main effect of expertise, $F(1, 76) = 0.12$, $p = 0.73$, $\eta^2 = 0.002$. 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, $F(1, 76) = 0.02$, $p = 0.88$, $\eta^2 <$ .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, $F(1, 76) = 3.29$, $p = 0.74$, $\eta^2 = 0.04$. However, the one-way between subjects ANOVA produced a significant effect of group on bouncing variability, $F(4, 95) = 5.27$, $p < .01$, $\eta^2 = 0.18$. Post hoc comparisons indicated that percussive ($M = .044$, $SE = .003$) and nonpercussive musicians ($M = .039$, $SE = .002$) bounced with lower variability than controls ($M = .058$, $SE = .005$). Percussive dancers ($M = .040$, $SE = .002$), but not nonpercussive dancers ($M = .045$, $SE = .004$), also bounced with lower variability than controls (Figure 10).

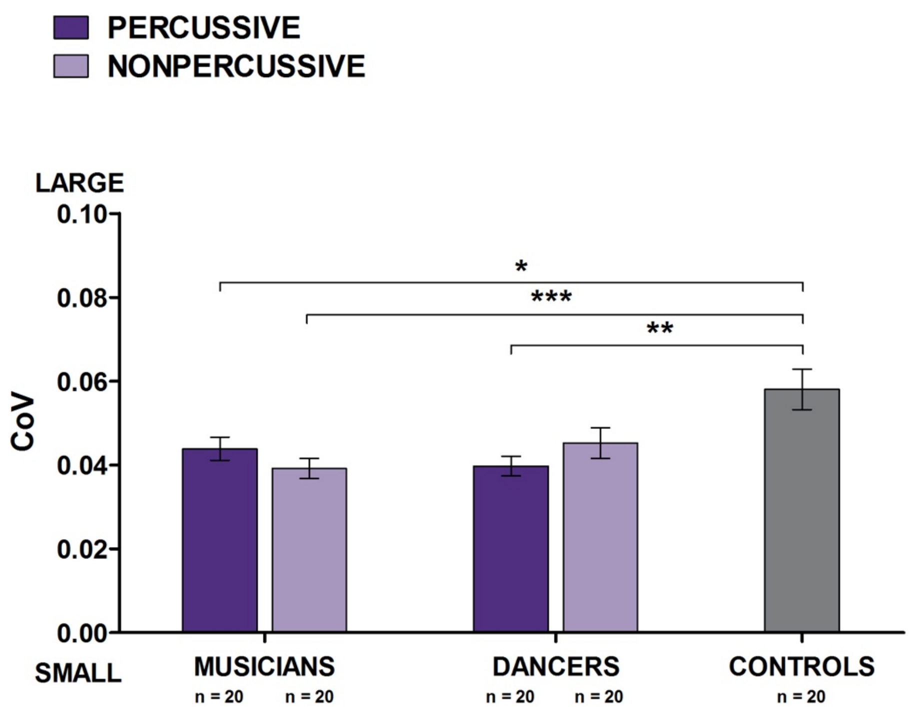

Figure 10: Performance on the bouncing beat production task measured using CoV. Bouncing variability did not significantly differ between musicians and dancers, or between percussionists and nonpercussionists. Percussive and nonpercussive musicians, as well as percussive dancers, bounced with significantly lower variability than controls. Error bars indicate standard error of the mean. * *p* < .05, ** *p* < .01, * *p* < .001.**

3.3.3.2 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, $F(1, 76) = .20$, $p = .66$, $\eta^2 = .003$. 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 significantly differ for training style, $F(1, 76) = .07$, $p = .79$, $\eta^2 = .001$. 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, $F(1, 76) = 2.66$, $p = 0.11$, $\eta^2 = 0.03$. However, the one-way between subjects ANOVA conducted to compare tempo matching accuracy in the five groups produced a significant effect of group, $F(4, 95) = 6.60$, $p < .001$, $\eta^2 = 0.22$. Percussive ($M = .045$, $SE = .005$) and nonpercussive musicians ($M = .038$, $SE = .004$) bounced to the tempo of the music with greater accuracy than controls ($M = .072$, $SE = .006$). Tempo matching accuracy was also significantly greater for percussive ($M = .039$, $SE = .003$) and nonpercussive dancers ($M = .049$, $SE = .008$) compared to controls (Figure 11).

3.3.3.3 Asynchrony

The two-way 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, $F(1, 76) = .41$, $p = .52$, $\eta^2 = .005$. Finally, the one-way between subjects ANOVA on bouncing accuracy also did not produce a significant effect of group, $F(4, 95) = 1.91$, $p = 0.12$, $\eta^2 = 0.07$. 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 ($M = .114$, $SE = .008$) (Figure 12).

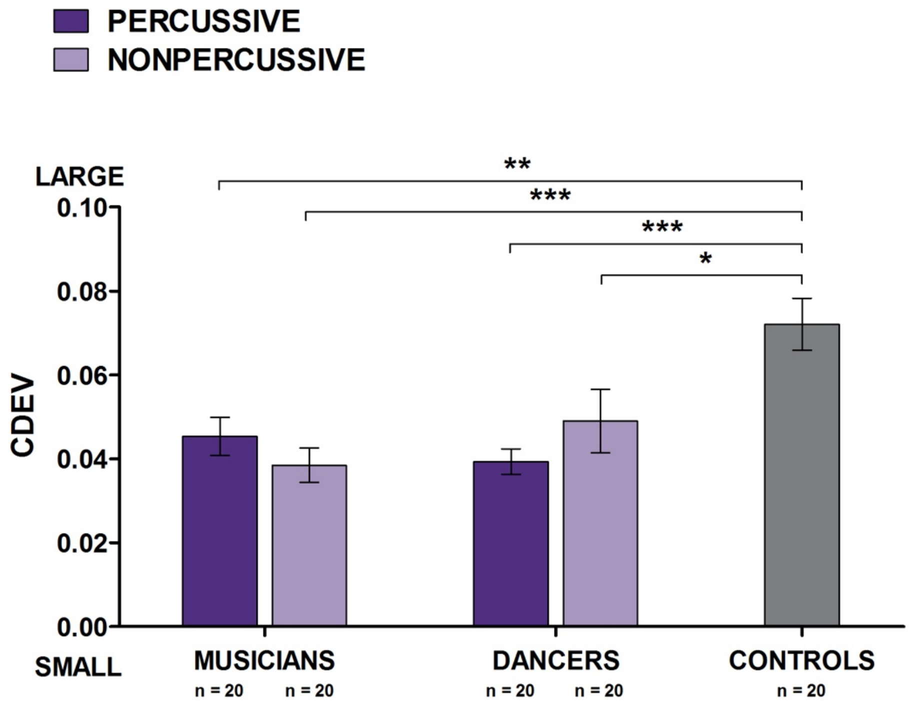

Figure 11: Performance on the bouncing beat production task measured using CDEV. Musicians and dancers bounced to the tempo of the music with similar accuracy. Tempo matching accuracy also did not differ between percussionists and nonpercussionists. Relative to controls, percussive and nonpercussive 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. * $p < .05$, ** $p < .01$, *** $p < .001$.

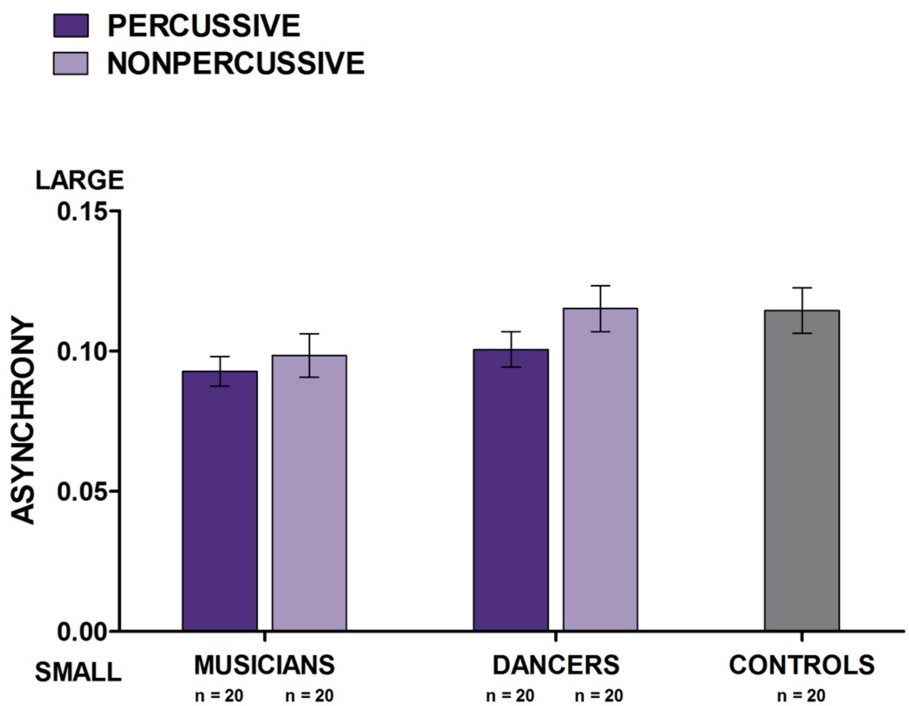

Figure 12: Performance on the bouncing beat production task measured using asynchrony. Musicians and dancers, as well as percussionists and nonpercussionists, bounced to the beat with similar mean asynchrony. Relative to controls, neither musicians or dancers significantly differed. Error bars indicate standard error of the mean.

3.4 Discussion

The current study examined how percussive and nonpercussive music and dance training influence beat perception and production, using an audiovisual variant of the BAT and a knee bending task recorded with motion capture to assess whole-body movements, respectively. It was predicted that if the musicians' superior performance in Chapter 2 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' superior performance in Chapter 2 was task specific, then the dancers should outperform the musicians, or perform comparably, in both the audiovisual beat perception and the bouncing beat production tasks. Furthermore, it was predicted that musicians and dancers would outperform their non-musician/non-dancer counterparts on both tasks (Karpati et al., 2016). The results indicated that musicians and dancers did not significantly differ on any measures of beat perception or production, but significantly outperformed their non-musician/non-dancer counterparts on the beat production task. On the beat perception task, performance was similar for musicians, dancers, and controls. On the beat production test, musicians and dancers bounced with lower variability, and bounced to the tempo of the music with greater accuracy compared to controls, but not compared to each other. The results suggest that dancers' beat production abilities are comparable to that of musicians' given that they are tested with movements that are more ecologically valid with respect to their training.

It was also predicted that percussionists would outperform nonpercussionists on both tasks (Cameron & Grahn, 2014b; Cicchini et al., 2012; Petrini et al., 2009). However, relative to nonpercussive training, percussive training did not significantly affect beat processing performance. A limitation of Chapter 2 that was addressed here was that the criteria used to classify percussionists and nonpercussionists were not restricted to musicians and dancers whose training were exclusively percussive or nonpercussive. In Chapter 2, as long as the participant's main instrument or dance style was percussive, they were considered a percussionist, and vice versa for participants whose main instrument or dance style was nonpercussive. Here, stricter criteria for training style were imposed to better distinguish the percussionist and nonpercussionist groups. As such, only musicians and dancers whose training are exclusively percussive or nonpercussive were recruited and tested. Any musicians or dancers with training in any instruments or dance styles that could not be classified exclusively as either percussive and nonpercussive were excluded. Nonetheless, training style did not affect beat processing performance. It is possible that both music and dance training focuses on the ability to perceive and produce the beat. Thus, musicians and dancers, regardless of style, show comparable beat processing performance.

Musicians and dancers may not have significantly differed on the tasks, but they did significantly outperform controls. Specifically, on the beat production test, musicians and dancers bounced with lower variability, and bounced to the tempo of the music with greater accuracy compared to controls. It seems likely that non-musician/non-dancer controls would have inferior performance compared to their trained counterpart because of their lack of specialized music or dance training. However, it is possible that musicians and dancers may have had more exposure to music than controls, and that mere exposure to music may affect their beat processing performance (Bläsing et al., 2012; Drake, 1998; Tillmann, 2008). To ensure that the differences in performance between musicians and controls, and dancers and controls, are not due to differences in music exposure, participants reported how many hours a week they listened to music, including practicing time. The results confirmed that there were no significant differences in music exposure between musicians, dancers, and controls. Therefore, the differences in performance between musicians and controls, and dancers and controls, are unlikely due to differences in music exposure.

Additional analyses of group demographics confirmed that the only difference between musicians, dancers, and controls was training, as great effort was made to recruit individuals that were comparable with regards to their respective training. Musicians had significantly more music training than dancers and controls (who did not significantly differ from each other). Likewise, dancers had significantly more dance training than musicians and controls (who did not significantly differ from each other). Musicians and dancers also 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. Another factor that was controlled for (or at least attempted) was the split between male and female in the five groups. Except for the nonpercussive dancers, which were predominately female (one male), the split between male and female were similar for the other four groups. However, there is no evidence in the literature to suggest that males and females significantly differ in their beat processing performance. Therefore, it is unlikely that sex is a significant factor influencing beat perception and production.

Performance on the audiovisual beat perception task did not significantly differ between the three groups. Although great effort was made to make the beat easy to perceive, the “off-beat” trials—particularly the “off-beat phase error” trials—may have still been too difficult as performance for those trials, irrespective of expertise, was below chance

(50%). Poor performance on the task may be due to how humans integrate audiovisual information. There is evidence to suggest that when auditory and visual information coincide within a temporal window of approximately 100 ms, integration occurs and the two stimuli are perceived as simultaneous (Andersen & Mamassian, 2008; Meredith, Nemitz, & Stein, 1987; Shams, Kamitani, & Shimojo, 2002). Here, 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. On average, the IBI for the clips was approximately 400 ms, which at 25% and 33% falls within the temporal window of audiovisual integration. Therefore, it is possible that the offset between the auditory and visual stimuli was not large enough, making it difficult for participants to perceive whether the bouncing stick figure (visual) is bouncing "on the beat" or "off the beat" (auditory). However, since music proceeds temporally, unfolding in time, any offsets that exceed 33% (for clips with a $\frac{4}{4}$ time signature) or 25% (for clips with a $\frac{3}{4}$ time signature) of the IBI would be too close to the proceeding beat, so performance would have likely been just as poor (or poorer) for all participants, irrespective of expertise.

An important feature of music training is the reliance on discrete effector-specific movements to produce music, whereas an important feature of dance training is the reliance on gross whole-body movements to follow choreography (Karpati et al., 2017). In Chapter 2, beat production was tested using a finger tapping (effector-specific movement) task, and musicians outperformed dancers. Although finger tapping is an ecologically valid movement for individuals with music training, it may not be for individuals with dance training. Therefore, in the current study, beat production was tested using a knee bending (whole-body movement) task (Miura et al., 2011; Miura, Kudo, & Nakazawa, 2013; Miura, Kudo, Ohtsuki, et al., 2013). It was predicted that if dance training did influence beat processing abilities than dancers would outperform musicians (and controls), or perform comparably to musicians, and outperform controls in a beat production task that requires whole-body movements. Such was the case, as musicians and dancers were significantly better than controls on the production task, but they did not significantly differ from each other. Thus, given that dancers are tested with movements that are more ecologically valid for their training, dance training does influence beat production.

However, relative to dancers, musicians may still have an advantage in terms of beat processing abilities. Although dancers did not outperform controls in the finger tapping task (see Chapter 2), musicians did outperform controls in the knee bending task. Therefore, it seems that music training may show some transfer to a beat production task that requires whole-body movements. It is likely that music training allows musicians to make better temporal predictions about the beat which facilitates their ability to make more synchronized movements, regardless of movement type (Karpati et al., 2016). Taken together, the results suggest that music and dance training does influence beat processing abilities, however, the effect of dance training on beat processing may only be specific to whole-body movements.

3.5 Conclusions

The current study demonstrated that dance training can be comparable to music training with regards to beat production performance, given that dancers are tested with movements that are ecologically valid with their respect to their training. However, the influence of dance training on beat production performance may only be specific to whole-body movements. On the audiovisual beat perception task, performance was similar for musicians, dancers, and controls possibly due to the difficult nature of the task. On the bouncing beat production test, musicians and dancers bounced with lower variability, and bounced to the tempo of the music with greater accuracy compared to controls, but not compared to each other. The current study also replicated the finding that percussive training compared to nonpercussive training did not have a significant effect on beat processing performance. On both the beat perception and production tasks, performance was similar for both percussionists and nonpercussionists. The current study is the first to examine how music or dance training and percussive or nonpercussive style interact to influence beat perception and production using whole-body movements.

Chapter 4

4 Effector-Specific Synchronization with Competing Auditory and Visual Rhythms in Musicians and Dancers

4.1 Introduction

Listening to auditory rhythms often gives rise to the perception of beat, which may compel people to automatically synchronize through overt or covert movements such as head bobbing, foot tapping, or hand clapping (Burger, Thompson, Luck, Saarikallio, & Toiviainen, 2013; Merker, Madison, & Eckerdal, 2009; Su & Pöppel, 2012). By contrast, however, viewing visual rhythms rarely compel people to move in the same way. In fact, there is considerable evidence that beat perception and sensorimotor synchronization performance is far superior for audition than for vision (Grahn et al., 2011; 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, when participants tap in synchrony with isochronous auditory (tones) and visual (flashes) sequences, asynchrony scores are much lower for auditory compared to visual sequences (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004).

According to the *modality appropriateness hypothesis* (Welch & Warren, 1980), perception gives precedence to the sensory modality best suited for the task at hand: audition for temporal processing and vision for spatial processing. When comparable auditory and visual stimuli are presented in the same task, performance in audition is often superior to performance in vision when it comes to beat perception (Grahn, 2012; Grahn et al., 2011; McAuley & Henry, 2010) and sensorimotor synchronization (Jäncke, Loose, Lutz, Specht, & Shah, 2000; Kato & Konishi, 2006; Repp, 2003). For example, the variability of tap times is typically lower when participants are asked to synchronize with auditory than with visual rhythms (Repp & Penel, 2002). Likewise, when isochronous auditory (tones) and visual (flashes) rhythms are presented simultaneously in a bimodal target-distractor synchronization task, the magnitude of the distractor effect is generally greater for auditory distractors than for visual distractors (Repp & Penel, 2004).

Thus, there is considerable evidence that temporal processing is better in the auditory modality than in the visual modality. However, there is growing evidence that challenges the notion of auditory superiority for rhythm processing and sensorimotor synchronization.

More recent research has suggested that visual beat perception and sensorimotor synchronization improves substantially if the visual stimuli are dynamic rather than static, such as a moving bar, a 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 variability of taps is lower when synchronizing with visual rhythms derived from apparent motion (i.e., a tapping finger) than with visual rhythms derived from static motion (i.e., a flashing light) (Hove & Keller, 2010). Moreover, tapping along to a bouncing ball (with a rectified sinusoidal velocity) yielded smaller asynchronies compared to tapping along to a flashing square (Iversen et al., 2012). In fact, synchronizing to a bouncing ball was no more variable than synchronizing to an auditory metronome, suggesting that dynamic stimuli enable better temporal prediction (Hove & Keller, 2010). However, many earlier studies often used spatially static visual stimuli that do not provide the rich spatiotemporal information that dynamic visual stimuli may, in order to optimize temporal processing (Grondin & McAuley, 2009; Guttman et al., 2005; McAuley & Henry, 2010; Repp & Penel, 2002; Repp & Penel, 2004).

Until recently, many studies using the bimodal target-distractor synchronization paradigm used stationary visual stimuli (flashes), and found that the magnitude of the distractor effect is generally greater for auditory distractors than for visual distractors (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004). However, the temporal precision for tapping to a bouncing ball led researchers to question whether a dynamic stimulus could be as competitive as an auditory metronome in a distractor task (Hove et al., 2013). Indeed, when the bouncing ball was pitted against an auditory metronome in a bimodal target-distractor synchronization task, the bouncing ball had a stronger effect than the metronome when used as the distractors for visual experts (video gamers and ball players). The auditory experts (musicians) showed the opposite effect; the metronome as the auditory distractor had a stronger effect than the bouncing ball as the visual distractor.

However, synchronization was still less variable with auditory than with visual rhythms for both groups (Hove et al., 2013). Regardless, it appears that visual stimuli with dynamic motion are better than visual stimuli with static motion for optimizing visual rhythm processing and synchronization.

Here, a bouncing stick figure (see Chapter 3) was pitted against an auditory metronome in a bimodal target-distractor synchronization task (Hove et al., 2013). Like the bouncing ball, the stick figure has a continuous motion, which consisted of a repetitive knee-bending motion generated from a dancer's bouncing trajectory. Thus, the movement was both continuous and biologically valid. While the current study is not the first to compare a dynamic visual stimulus with an auditory metronome, it is the first to examine how modality (auditory and visual rhythms) and expertise (in music and dance) interact to influence audiovisual integration and synchronization.

Many earlier sensorimotor synchronization studies have always tested musically trained individuals, thus further perpetuating the auditory superiority view for rhythm processing and sensorimotor synchronization (Chen et al., 2002; Repp, 2003; Repp, 2005; Repp & Penel, 2002; Repp & Penel, 2004). Musically trained individuals may be biased towards the auditory modality because music is defined by auditory rhythms (Repp & Penel, 2004). To date, only one study has directly compared auditory experts (musicians) and visual experts (video gamers and ball players) using the bimodal target-distractor synchronization paradigm. For the auditory experts, the auditory distractors (auditory metronome) were more distracting than the visual distractors (bouncing ball). For the visual experts, the visual distractors were more distracting than the auditory distractors. Nevertheless, synchronization was still less variable with auditory than with visual rhythms for both groups (Hove et al., 2013). But unlike musicians who have experience synchronizing to auditory rhythms, video gamers and ball players do not essentially have the same experience synchronizing to visual rhythms. Yet, a more comparable visual expert population to musicians may be dancers, as both music and dance training focus on synchronization with auditory and visual rhythms, but music perhaps focuses more on auditory while dance perhaps focuses more on visual.

To date, no work has examined how musicians and dancers synchronize to competing auditory and visual rhythms. More specifically, no other study has examined how musicians and dancers synchronize to an auditory metronome as the auditory stimulus, and a bouncing stick figure (see Chapter 3) as the visual stimulus. Furthermore, no other work has examined how expertise in music and dance and distractor modality interact to influence performance on the bimodal target-distractor synchronization task. Thus, it is unclear whether expertise in music and dance interacts with modality to affect audiovisual integration and synchronization.

4.1.1 The Current Study

The objective of the current study was to examine whether musicians and dancers rely on similar or different modalities (auditory and visual), and how that may affect their performance on an audiovisual integration (perception) task and an audiovisual synchronization (production) task. The audiovisual integration task was a variant of the "flash-beep" just-noticeable-difference task (de Boer-Schellekens, Eussen, & Vroomen, 2013; Fiedler, O'Sullivan, Schröter, Miller, & Ulrich, 2011; Innes-Brown et al., 2011): participants were presented with short audiovisual clips that paired the presentation of a single auditory tone with the bouncing stick figure (see Chapter 3), and then judged whether the audio and video were in synchrony. The audiovisual synchronization task was a variant of the bimodal target-distractor synchronization task (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004): participants tapped in synchrony with an isochronous auditory or visual (bouncing stick figure from Chapter 3) target sequence while a distractor sequence was presented in the other modality at one of nine temporal offsets. To fully understand the interaction between expertise and modality on audiovisual integration and synchronization, three groups of participants were tested: musicians, dancers, and non-musician/non-dancer controls. The non-musician/non-dancer control group was tested to compare audiovisual integration and synchronization between individuals with and without music and dance training.

It was predicted that musicians and dancers would not significantly differ in performance on the audiovisual integration task, but would outperform their non-musician/non-dancer counterparts, as both music and dance training often focus on the integration of auditory and visual information (Karpati et al., 2016). For example, both music and dance training commonly focus on combining auditory and visual information from one's own or another's output to produce a synchronized sound or a movement, respectively (Karpati et al., 2016). For the audiovisual synchronization task, it was predicted that musicians would be more influenced by the auditory modality because of their experience with auditory rhythms, whereas dancers would be more influenced by the visual modality, or at the least have a smaller auditory effect, because of their experience with visual rhythms. It was predicted that controls would be more influenced by the auditory modality given their lack of training and a bias towards the auditory modality on temporal tasks (Welch & Warren, 1980).

4.2 Methods

4.2.1 Participants

Three groups of participants were tested: musicians, dancers, and non-musician/non-dancer controls. There were 20 participants in each group, for a total of 60 participants. Participants ranged between the ages of 18 and 30 years (M = 22.02 years, SD = 3.11 years). Table 5 summarizes the demographic characteristics of the sample. 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. Non-musician/non-dancer 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 two research credits or $20.00 (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.

Table 5: Participant characteristics

	musicians	dancers	controls
n =	20	20	20
sex	14 females 6 males	19 females 1 male	14 females 6 males
age range (years)	19 to 26	19 to 30	18 to 29
mean age (years ± SD)	21.00±1.97	22.25±3.19	22.80±3.76
music training (years ± SD)	13.05±3.47	0.45±1.15	0.57±1.35
dance training (years ± SD)	0.20±0.70	12.95±4.26	0.40±0.91

4.2.2 Tasks

Audiovisual integration was tested using a task analogous to the "flash-beep" just-noticeable-difference paradigm (de Boer-Schellekens et al., 2013; Fiedler et al., 2011; Innes-Brown et al., 2011), while audiovisual synchronization was tested using a variant of the bimodal target-distractor synchronization task (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004). The tasks were administered on a MacBook Pro using MATLAB R2016a (The MathWorks Inc., Natick, MA, USA). All auditory stimuli for the tasks were delivered through Sennheiser HD 280 headphones at a comfortable volume. All participants completed the audiovisual integration task followed by the audiovisual synchronization task in one session. The entire session took approximately two hours. All participants were fully debriefed after the study.

4.2.2.1 "Bounce-Beep" Just-Noticeable-Difference Task

Participants watched a bouncing stick figure video (see Chapter 3), during which a single auditory tone was presented (500 Hz, 10 ms long, onset and offset ramps of 5 ms), to determine the threshold of their audiovisual integration. Participants made judgements of whether the audio and video were in synchrony. The level of synchrony was altered from trial to trial using an adaptive tracking procedure with four separate tracks. Trials for each track were randomly interleaved. Two tracks were audio-leading: the first started with the audio in synchrony with the video, with asynchrony increasing by 5% until a mistake was made [A0], then decreasing by 5% until an accurate response occurred, and so on, until 12 reversals were made. The second track started with the audio advanced by 50%, relative to the video [A50], with asynchrony decreasing on each trial until an error was made, then increasing, again until 12 reversals were made. The other two tracks were comparable, but the video was leading, with the first track starting in perfect synchrony [V0], and the second track starting with the video advanced by 50% [V50]. All responses were made on the laptop keyboard.

4.2.2.2 Bimodal Target-Distractor Synchronization Task

Participants tapped in synchrony with a target isochronous auditory sequence (500 Hz, 10 ms tones, with onset and offset ramps of 5 ms) or a target visual sequence (the bouncing stick figure from Chapter 3) while a distractor sequence was presented in the other modality at one of nine temporal offsets. Both target and distractor sequences consisted of 32 events with an IOI of 625 ms. The nine temporal phase displacements between the target and distractor sequences ranged from –50% and +50% of the IOI: 0%, $\pm$ 12.5%, $\pm$ 25%, $\pm$ 37.5%, $\pm$ 50%. The task consisted of 180 trials; each of the nine temporal offsets occurred with audition as the distractor sequence and with vision as the distractor sequence, and repeated ten times each. The order of the 180 trials was randomized for each participant, and broken into five blocks of 36 trials to prevent fatigue. Participants were instructed to tap in synchrony with the target sequence on the spacebar of a laptop keyboard, starting at the third event of each target sequence, and continued until the end of the trial, while ignoring the distractor events.

To ensure that participants did not deliberately close their eyes or look away in the auditory target-visual distractor (A-V) conditions, they were required to report whether the joints of the bouncing stick figure briefly changed colour (from black to red). Half of the A-V conditions contained a colour change (randomized to occur between event 13 and 21). Participants also performed a similar task for the visual target-auditory distractor (V-A) conditions; they reported whether an auditory tone changed in pitch (from 500 Hz to 700 Hz) (randomized between event 13 and 21). Half of the V-A conditions contained a pitch change. Responses regarding colour or pitch changes were made after each trial. Tap times and responses regarding colour/pitch changes were recorded on a laptop keyboard and saved for each participant.

4.2.3 Statistical Analyses

Performance on the "bounce-beep" just-noticeable-difference task was analyzed by averaging the percentage of asynchrony at the last four reversals for all four tracks. The audiovisual integration thresholds for the A0 and A50 tracks were averaged to get the audiovisual integration threshold value for the audio-leading tracks. Similarly, the audiovisual integration thresholds for the V0 and V50 tracks were averaged to get the audiovisual integration threshold value for the video-leading tracks. A 3 (*group*: musicians, dancers, and non-musician/non-dancer controls) x 2 (*track*: audio-leading and video-leading) mixed ANOVA with group as the between subjects variable and track as the within subjects variable was conducted to assess the interaction between group and track on audiovisual integration thresholds.

For the bimodal target-distractor synchronization task, the percentage of correct responses was calculated for the colour and pitch changes in the distractor sequences. Any participants with a score below 85% were excluded from the final analysis to ensure that participants were still attending to the distractor sequences while synchronizing to the target sequences. A 1 x 3 (*group*: musicians, dancers, and non-musician/non-dancer controls) ANOVA was conducted to assess group differences in response accuracy. The tap times from the bimodal target-distractor synchronization task were used to calculate distractor effects, which is the change in relative asynchrony between taps and target sequence as a function of target-distractor. To quantify the strength of the distractor effect, the range of values for the mean relative asynchrony scores (the maximum value of the nine mean relative asynchrony scores minus the minimum value of the nine mean relative asynchrony scores) in the distractor functions for each participant was calculated, and compared with a paired samples *t*-test (Hove et al., 2013). The range of values for the relative asynchrony were analyzed with a 3 (*group*: musicians, dancers, and non-musician/non-dancer controls) x 2 (*distractor modality*: audition and vision) mixed

ANOVA with group as the between subjects variable and distractor modality as the within subjects variable to assess the interaction between group and modality for the distractor effect. Finally, a 1 x 3 (*group*: musicians, dancers, and non-musician/non-dancer controls) ANOVA was conducted for all group demographics. 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.

4.2.3.1 Relative Asynchrony

Relative asynchrony measures the participant's ability to synchronize with the target sequence while ignoring the distractor sequence. To measure relative asynchrony, the mean difference between each response time and the nearest time in the target sequence was calculated and divided by the mean IOI (625 ms).

$$\text{RELATIVE ASYNCHRONY} = \frac{\text{MEAN}_{\text{RESPONSE}-\text{TARGET}}}{\text{MEAN}_{\text{IOI}}}$$

The relative asynchrony values were then averaged across 10 trials to obtain a single relative asynchrony score for each participant at each one of the nine temporal offsets. If the distractor effect was present, in conditions which the distractor preceded the target, the responses should occur earlier than the target, resulting in more negative asynchrony scores relative to trials in which the target and distractor were in synchrony. In conditions which the distractor followed the target, the responses should occur later than the target, resulting in more positive asynchrony scores relative to trials in which the target and distractor were in synchrony.

4.3 Results

4.3.1 Group Demographics

One-way ANOVAs conducted on years of music and dance training revealed expected significant differences for both music, $F(2, 57) = 215.48$, $p < .001$, $\eta^2 = .88$, and dance training, $F(2, 57) = 167.31$, $p < .001$, $\eta^2 = .85$, between the groups. Post hoc comparisons confirmed that musicians ($M = 13.05$ years, $SE = .78$ years) and controls ($M = .43$ years, *SE* = .26 years) significantly differed in years of music training, $t(38) = 15.39$, $p < .001$. Musicians and dancers (*M* = .45 years, *SE* = .26 years) also significantly differed, $t(38) = 15.42$, $p < .001$. However, there were no significant differences in years of music training between controls and dancers, $t(38) = .07$, $p = .95$. Similarly, for years of dance training, post hoc comparisons confirmed that dancers (*M* = 12.95 years, *SE* = .95 years) and controls (*M* = .30 years, *SE* = .18 years) significantly differed in years of dance training, $t(38) = 13.05$, $p < .001$. Dancers and musicians (*M* = .20 years, *SE* = .16 years) also significantly differed, $t(38) = 13.21$, $p < .001$, but there were no significant differences in years of dance training between controls and musicians, $t(38) = .42$, $p = .68$.

One-way ANOVAs were conducted on years of training, starting age of training, and hours of practice per week for each group's respective expertise with musicians and dancers as the between subject variables. Musicians (*M* = 13.05 years, *SE* = .78 years) and dancers (*M* = 12.95 years, *SE* = .95 years) did not significantly differ in the years of training in their respective expertise, $F(1, 38) = .01$, $p = .94$, $\eta^2 = .0002$. Musicians (*M* = 7.95 years old, *SE* = .67 years) and dancers (*M* = 8.35 years old, *SE* = .86 years) also did not significantly differ on the starting age of their respective training, $F(1, 38) = .14$, $p = .72$, $\eta^2 = .004$. Likewise, musicians (*M* = 2.60 hours/week, *SE* = .43 hours/week) and dancers (*M* = 4.15 hours/week, *SE* = .83 hours/week) did not significantly differ on the number of hours they practiced per week, $F(1, 38) = 2.74$, $p = .11$, $\eta^2 = .07$.

4.3.2 "Bounce-Beep" Just-Noticeable-Difference Task

Performance on the "bounce-beep" just-noticeable-difference task did not significantly differ between groups, $F(2, 57) = .81$, $p = .45$, $\eta^2 = .03$. Musicians (*M* = 24.59%, *SE* = 1.86%), dancers (*M* = 26.24%, *SE* = 1.57%), and controls (*M* = 27.68%, *SE* = 1.17%) all performed similarly on the task. However, performance did significantly differ for track type, $F(1, 57) = 8.34$, $p < .01$, $\eta^2 = .13$. For all groups, the window of perceived simultaneity was smaller when the audio led the video (*M* = 23.11%, *SE* = 1.55%) compared to when the video led the audio (*M* = 29.23%, *SE* = 1.32%), suggesting that there is more forgiveness in audiovisual integration when vision leads audition. The interaction between group and track type was not significant, $F(1, 57) = .33$, $p = .78$, $\eta^2 = .01$ (Figure 13).

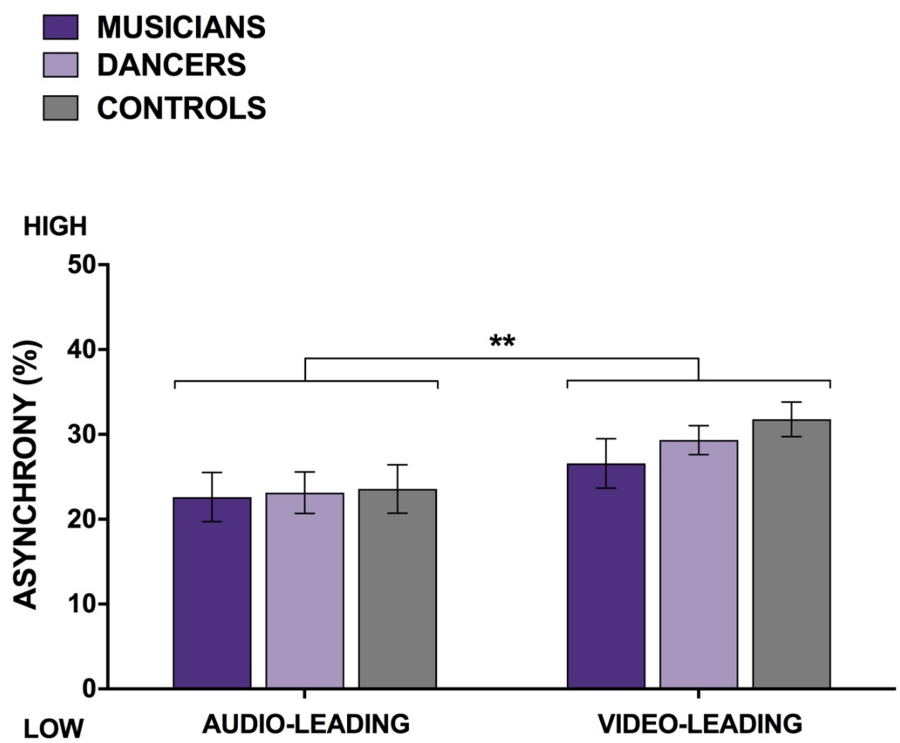

Figure 13: Interaction between group and track type for the "bounce-beep" just-noticeable-difference task. Musicians, dancers, and controls all performed similarly on the task. For all three groups, the window of perceived simultaneity was smaller for clips which audio led video compared to clips which video led audio. The interaction between group and track type was not significant. Error bars indicate standard error of the mean. ** $p < .01$.

4.3.3 Bimodal Target-Distractor Synchronization Task

4.3.3.1 Response Accuracy

To ensure that participants were still attending to the distractor sequences while they synchronized to the target sequences, participants were asked to detect a colour change in the A-V trials and a pitch change in the V-A trials. Any participants with a score below 85% were excluded from the final analysis. However, no participants were excluded as all had a response accuracy of 85% or above. Response accuracy did not significantly differ between groups, $F(2, 57) = 1.05$, $p = .36$, $\eta^2 = .04$. Musicians (M = 94.03%, SE = 9.72%), dancers (M = 95.89%, SE = 9.43%), and controls' (M = 94.86%, SE = 8.00%)

response accuracies were comparable to each other. Averaged across groups, response accuracy was 94.93%. Thus, participants were still attending to the distractor sequences while synchronizing to the target sequences.

4.3.3.2 Relative Asynchronies

4.3.3.2.1 Comparison between Groups

The 3 x 2 mixed ANOVA with group as the between subjects variable and distractor modality as the within subjects variable on the range of the mean relative asynchronies produced a significant main effect of expertise, $F(2, 57) = 4.38$, $p < .05$, $\eta^2 = .13$. Post hoc comparisons revealed that the magnitude of the distractor effects was significantly smaller for dancers ($M = .134$, $SE = .043$) than for musicians ($M = .195$, $SE = .019$), $t(19) = 2.83$, $p < .01$. However, the magnitude of the distractor effects did not significantly differ between controls ($M = .158$, $SE = .013$) and musicians, $t(38) = 1.57$, $p = .13$, or between controls and dancers, $t(38) = 1.45$, $p = .16$. There was no main effect of distractor modality, $F(1, 57) = .20$, $p = .66$, $\eta^2 = .003$, but the interaction was significant, $F(2, 57) = 5.38$, $p < .01$, $\eta^2 = .16$, confirming that the groups differed on the size of the auditory versus the visual distractor effects (detailed in the sections below). In general, musicians showed larger auditory distractor effects than visual distractor effects, whereas dancers showed larger visual distractor effects than auditory distractor effects. Controls showed equal distractibility for both modalities.

4.3.3.2.2 Musicians

For both the A-V and V-A conditions, musicians' mean relative asynchronies showed the expected sinusoidal shape (Hove et al., 2012; Repp & Penel, 2002; Repp & Penel, 2004). The sinusoidal function suggests that the distractor effect was similar when the targets and distractors were perfectly synchronized and when the targets and distractors were antiphase (Figure 14). For both the A-V and V-A conditions, relative to the zero lead/lag trials, the lagging distractors attracted the taps more strongly than the leading distractors. The comparison between the relative strength of the visual and auditory distractor effects, as determined by subtracting the minimum mean relative asynchrony value from the maximum mean relative asynchrony value for each distractor function, showed a significant difference, $t(19) = 2.12$, $p < .05$. The auditory distractor effect ($M = .237$, $SE = .036$) was significantly larger than the visual distractor effect ($M = .153$, $SE = .015$). Therefore, musicians were significantly more distracted by the auditory distractors than the visual distractors.

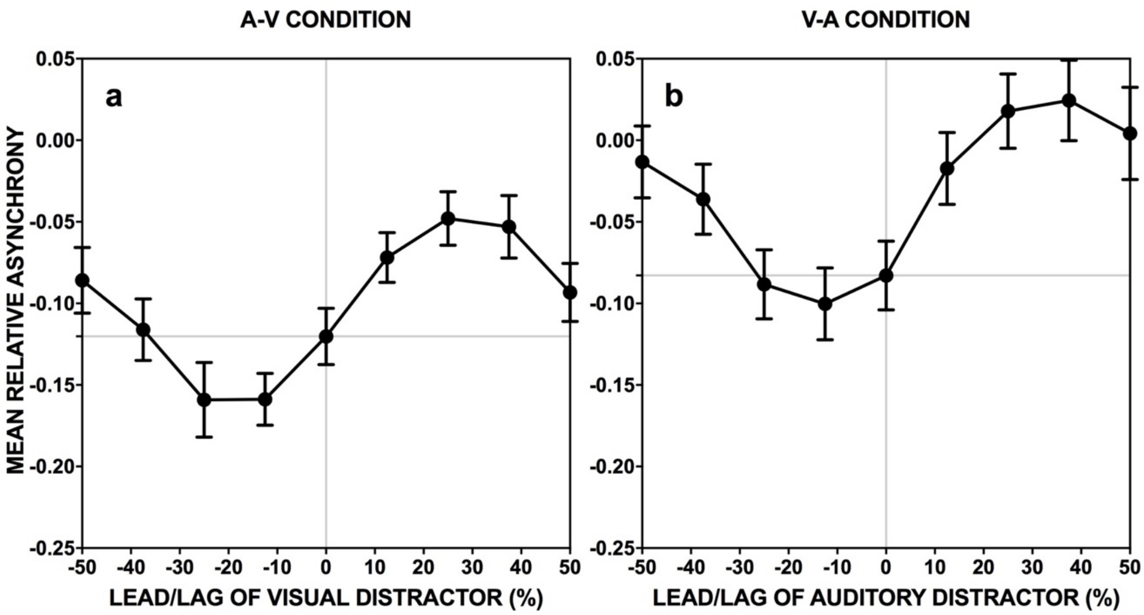

Figure 14: Mean relative asynchrony as a function of distractor lead/lag for musicians in the a) auditory target-visual distractor (A-V) condition, and b) visual target-auditory distractor (V-A) condition. The horizontal grey line is drawn through the mean relative asynchrony at zero lead/lag. Error bars indicate standard error of the mean.

4.3.3.2.3 Dancers

For both the A-V and V-A conditions, dancers' mean relative asynchronies also showed the expected sinusoidal shape. However, the sinusoidal shape was much shallower for the V-A condition than for the A-V condition (Figure 15). Relative to the zero lead/lag trials, for both the A-V and V-A condition, the distractor functions for dancers had the same asymmetrical effect as musicians, with the lagging distractors attracting the taps more strongly than the leading distractors. The comparison between the relative strength of the visual and auditory distractor effects indicated that for dancers, the visual distractor effect

(M = .156, SE = .006) was significantly larger than the auditory distractor effect (M = .112, SE = .019), $t(19) = 2.11$, $p < .05$. Thus, dancers were significantly more distracted by the visual distractors than the auditory distractors.

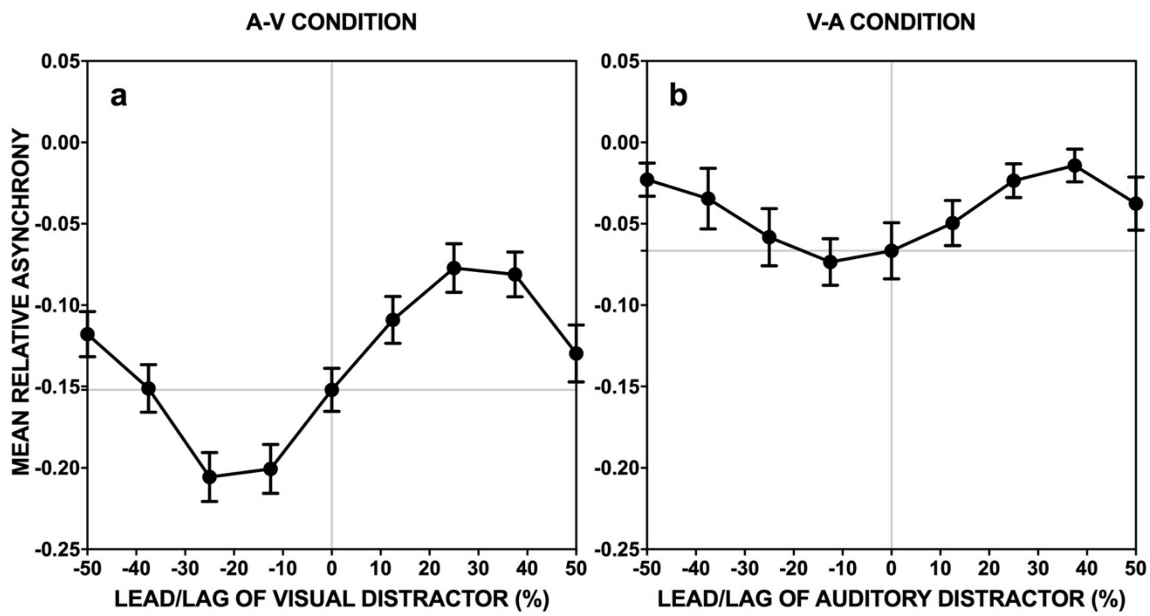

Figure 15: Mean relative asynchrony as a function of distractor lead/lag for dancers in the a) auditory target-visual distractor (A-V) condition, and b) visual target-auditory distractor (V-A) condition. The horizontal grey line is drawn through the mean relative asynchrony at zero lead/lag. Error bars indicate standard error of the mean.

4.3.3.2.4 Controls

Like musicians and dancers, controls' mean relative asynchronies showed the expected sinusoidal shape for both the A-V and V-A conditions (Figure 16). Relative to the zero lead/lag trials, the distractor function for controls had the same asymmetrical effect as musicians and dancers, with the lagging distractors attracting the taps more strongly than the leading distractors for both the A-V and V-A conditions. The comparison between the relative strength of the visual and auditory distractor effects showed no significant difference, $t(19) = .75$, $p = .46$. For controls, there was no difference in the magnitude of the visual distractor effect (M = .150, SE = .021) and the auditory distractor effect (M = .167, SE = .014). Therefore, controls showed equal distraction for both modalities.

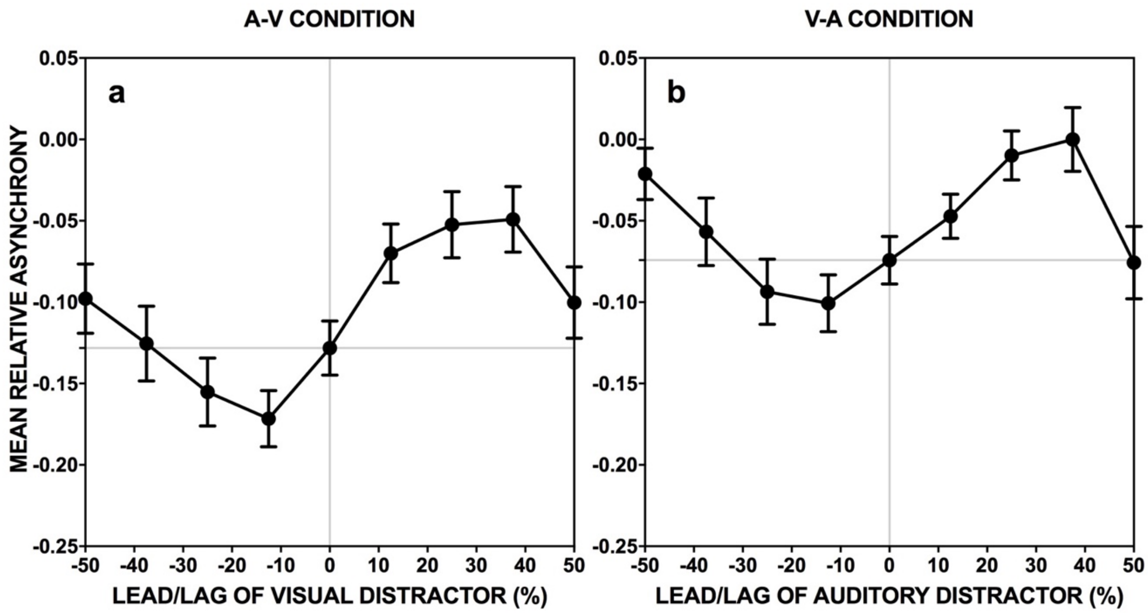

Figure 16: Mean relative asynchrony as a function of distractor lead/lag for non-musician/non-dancer controls in the a) auditory target-visual distractor (A-V) condition, and b) visual target-auditory distractor (V-A) condition. The horizontal grey line is drawn through the mean relative asynchrony at zero lead/lag. Error bars indicate standard error of the mean.

4.4 Discussion

The current study examined how expertise (in music and dance) and modality (auditory and visual) interact to influence audiovisual integration and synchronization on a "bounce-beep" just-noticeable-difference task and a bimodal target-distractor synchronization task, respectively. For the "bounce-beep" just-noticeable-difference task, participants made judgements of whether the auditory (tone) and visual (bouncing stick figure from Chapter 3) stimuli were in synchrony with each other. It was predicted that musicians and dancers would not significantly differ in performance on the task, but would outperform their non-musician/non-dancer counterparts (Karpati et al., 2016). For the bimodal target-distractor synchronization task, participants tapped in synchrony with an isochronous auditory (metronome) or visual (bouncing stick figure from Chapter 3) target sequence while a distractor sequence was presented in the other modality at one of nine temporal offsets. It was predicted that musicians would be more distracted by the auditory distractors than the visual distractors because of their experience with auditory rhythms, whereas dancers would be more distracted by the visual distractors than the auditory distractors, or at the least be less distracted by the auditory distractors compared to musicians, because of their experience with visual rhythms. It was also predicted that controls would be more distracted by the auditory distractors than the visual distractors given their lack of training and a bias towards the auditory modality on temporal tasks (Welch & Warren, 1980).

Performance on the “bounce-beep” just-noticeable-difference task did not significantly differ between musicians and dancers, perhaps because both music and dance training specialize in the integration of auditory and visual information (Karpati et al., 2016). Because of their training, it was predicted that musicians and dancers would outperform controls. Although the window of perceived simultaneity was larger for controls than for musicians and dancers, the difference was not significant. Previous literature seems to suggest that audiovisual integration may be an automatic process that is important for a range of human behaviours (Adams, 2016; Alais & Burr, 2004; Hartcher-O’Brien, Di Luca, & Ernst, 2014), particularly in the domain of speech (Alsius, Navarra, Campbell, & Soto-Faraco, 2005; Déry, Campbell, Lifshitz, & Raz, 2014; Gentilucci & Cattaneo, 2005). So, despite the lack of specialized training, the automatic process of audiovisual integration may have allowed controls to perform only slightly poorer, but not significantly different, than musicians and dancers on the “bounce-beep” just-noticeable-difference task.

It should be noted that the window of perceived simultaneity for the “bounce-beep” just-noticeable-difference task for all three groups was larger for the visual-leading stimuli rather than the auditory-leading stimuli. That is, the audio and video were more likely to be perceived as occurring simultaneously if vision led audition. Previous studies have also shown that audiovisual asynchrony scores are smaller if audio precedes the video rather than if the video precedes the audio (Dixon & Spitz, 1980; Kayser, Petkov, &

Logothetis, 2008; Keetels & Vroomen, 2012; Vatakis & Spence, 2006; Zampini, Guest, Shore, Spence, 2005). It is unclear why an overall visual-leading asymmetry was observed, but one speculation is that audition is processed faster than vision (Keetels & Vroomen, 2012). Therefore, when vision leads audition the two stimuli are more likely to be perceived as occurring at the same time. The other possibility is that the continuous motion of the bouncing stick figure provides more visual information than the sudden onset of the auditory tone, allowing the slower visual stimulus to be processed before than the auditory stimulus (Neumann & Niepel, 2004), which results in a preference for vision to lead audition to be perceived as simultaneous.

Differences in performance on the bimodal target-distractor synchronization task was driven by the interaction effect between expertise and modality: participants with music experience were more distracted by the auditory distractors than the visual distractors, whereas participants with dance experience were more distracted by the visual distractors than the auditory distractors. It seems likely that musicians were more affected by the auditory distractors because of their experience with auditory rhythms. In contrast, it seems likely that dancers were more affected by the visual distractors because of their experience with visual rhythms. It was also predicted that controls would be more distracted by the auditory distractors than the visual distractors given the dominance of the auditory modality for temporal tasks (Welch & Warren, 1980). However, participants without any music or dance experience were equally distracted by the distractors in both modalities. Thus, the results showed a nice dissociation between individuals with and without music and dance training.

To ensure that performance on the bimodal target-distractor synchronization task was not affected by allowing the participants to close their eyes or look away to completely ignore the distractors, participants were instructed to detect a colour change in half of the A-V trials and a pitch change in half of the V-A trials. Although it is easier to close to one's eyes to ignore a visual distractor than to close one's ears to ignore an auditory distractor, participants were asked to perform a comparable task for the V-A trials for uniformity. Furthermore, to prevent any expectations, the occurrence of the colour or pitch change was randomized throughout the sequence. On average, the response accuracy was 94.93% and did not significantly differ between groups, confirming that participants were still attending to the distractor sequences while synchronizing to the target sequences. Thus, it seems unlikely that this strategy was adopted to ignore the distractors.

The results also indicated that the bouncing stick figure was as effective as an auditory metronome at engaging participants' movements. It appears that visual stimuli with dynamic motion are important for optimizing visual rhythm processing and synchronization (Hove & Keller, 2010; Hove et al., 2010; Su, 2014). The visual stimuli of past studies may have been less effective at engaging movements because they lacked the dynamic motion that may have provided rich spatiotemporal information (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004). Like the bouncing ball (Hove et al., 2013), the bouncing stick figure had a continuous motion which consisted of a repetitive knee-bending motion generated from a dancer's bouncing trajectory. The choice to use a bouncing stick figure as the visual stimulus, rather than a bouncing ball, was that the bouncing movement of the stick figure was both ecologically valid and pertinent for dancers. Indeed, while synchronizing to the auditory metronome, dancers were more distracted by the bouncing stick figure than they were by the auditory distractor, while synchronizing to the bouncing stick figure.

The sinusoidal pattern of changes in mean relative asynchrony scores for musicians, dancers, and control were consistent with the pattern seen in previous literature. However, the overall mean relative asynchrony scores for both distractor functions were larger for all three groups than for previous studies (Hove et al., 2012; Repp & Penel, 2002; Repp & Penel, 2004). It should be noted, though, that the participants in the previous studies were often musicians who had partaken in many auditory sensorimotor synchronization studies, and their laboratory experience may have contributed to their superior performance (Repp, 2010). In the current study, the participants had very little to no experience with the bimodal target-distractor synchronization task or any sensorimotor synchronization task. Therefore, any differences in performance between groups are most likely due to differences in training (or lack thereof).

To ensure that any differences in performance between groups were due to training, analyses of group demographics were conducted. The results confirmed that the only difference between musicians, dancers, and controls was training, as great effort was made to recruit individuals that were comparable with regards to their respective training. Musicians had significantly more music training than dancers and controls (who did not significantly differ from each other). Likewise, dancers had significantly more dance training than musicians and controls (who did not significantly differ from each other). Importantly, with regards to their respective training, musicians and dancers did not significantly differ in the number of years of training, starting age of their training, and the number of hours they practiced per week. Thus, it is unlikely that differences in performance on the bimodal target-distractor synchronization task were due to factors other than the participants' expertise.

4.5 Conclusions

The current study demonstrated how expertise (in music and dance) interacted with modality (auditory and visual) to affect performance on an audiovisual just-noticeable-difference task and a bimodal target-distractor synchronization task. Performance on the "bounce-beep" just-noticeable-difference task did not significantly differ between groups. However, for the bimodal target-distractor synchronization task, musicians were more distracted by the auditory than the visual distractors. In contrast, dancers were more distracted by the visual than the auditory distractors. Individuals with no music or dance training were equally distracted by the distractors in both modalities. While the current study is not the first to examine how expertise and modality interact to affect sensorimotor synchronization, it is the first to examine how music and dance training influence rhythm processing and sensorimotor synchronization.

Chapter 5

5 Whole-Body Synchronization with Competing Auditory and Visual Rhythms in Musicians and Dancers

5.1 Introduction

Sensorimotor synchronization is an important skill possessed by both musicians and dancers, but the movements that musicians and dancers use to optimally synchronize with an external rhythm or beat may differ considerably (see Chapter 3). For example, 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 show advantages in hand and finger movements compared to non-musicians (Fernandes & de Barros, 2012; Inui & Ichihara, 2001; Verheul & Geuze, 2004), whereas dancers show advantages in upper and lower limb movements compared to non-dancers (Buchanan et al., 2007; Sofianidis et al., 2012; Thullier & Moufti, 2004). Moreover, on tasks that involve effector-specific movements, musicians tend to outperform dancers, but on tasks that involve whole-body movements, dancers tend to outperform musicians (Karpati et al., 2016). Therefore, it is possible that musicians' sensorimotor synchronization is more accurate with effector-specific movements, but dancers' sensorimotor synchronization is more accurate with whole-body movements.

Previous studies using the bimodal target-distractor synchronization paradigm have exclusively assessed sensorimotor synchronization with finger tapping, and often finding a bias towards the auditory modality (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004). To date, no other study using the bimodal target-distractor synchronization paradigm has examined whole-body sensorimotor synchronization. Yet, assessing whole-body synchronization is warranted because when beat production was tested with finger tapping, musicians showed better beat processing performance than dancers and controls (see Chapter 2). However, when beat production was tested with knee bending, musicians and dancers showed better beat processing performance than controls, but did not significantly differ from each other (see Chapter 3). Taken together, the results suggest that music and dance training can be comparable with regards to sensorimotor synchronization performance given that dancers are tested with movements that are ecologically valid with their respect to their training.

In Chapter 4, performance on the bimodal target-distractor synchronization task showed that musicians may have a bias towards the auditory modality, whereas dancers may have a bias towards the visual modality. Meaning that, musicians were more distracted by the auditory than the visual distractors, whereas dancers were more distracted by the visual than the auditory distractors. The results suggested that expertise and modality interacted to affect sensorimotor synchronization. However, in Chapter 4, sensorimotor synchronization was tested with finger tapping. Therefore, it is unclear whether the results reported in Chapter 4 would replicate if the movement tested was whole-body rather than effector-specific.

5.1.1 The Current Study

The objective of the current study was to examine whether experts (musicians and dancers) rely on different modalities (auditory and visual) to different degrees, measured by performance in an audiovisual integration task and an audiovisual synchronization task assessed with whole-body movements. The audiovisual integration task was identical to the task described in Chapter 4: participants were presented with short audiovisual clips that paired the presentation of a single auditory tone with the bouncing stick figure, and then judged whether the audio and video were in synchrony. The audiovisual synchronization task was also similar to the task described in Chapter 4, except modified to be appropriate for whole-body movements (i.e., knee bending): participants bounced in synchrony with an isochronous auditory or visual (bouncing stick figure) target sequence while a distractor sequence was presented in the other modality at one of nine temporal offsets. To fully understand the interaction between expertise and modality on audiovisual integration and synchronization, three groups of participants were tested: musicians, dancers, and non-musician/non-dancer controls. The non-musician/non-dancer control group was tested to compare audiovisual integration and synchronization between individuals with and without music and dance training.

Based on previous findings, it was predicted that all three groups would not significantly differ in performance on the audiovisual integration task (see Chapter 4). For the audiovisual synchronization task, it was predicted that musicians would be more influenced by the auditory modality because of their experience with auditory rhythms. Dancers, however, would be more influenced by the visual modality, and would show a larger visual effect here than in Chapter 4, because of their experience with visual rhythms and the use of whole-body movements (see Chapter 3). Finally, based on previous findings, it was predicted that controls would not show a bias towards one modality over the other (see Chapter 4).

5.2 Methods

5.2.1 Participants

Three groups of participants were tested: musicians, dancers, and non-musician/non-dancer controls. There were 20 participants in each group, for a total of 60 participants. Participants ranged between the ages of 18 and 47 years (M = 22.55 years, SD = 4.48 years). Table 6 summarizes the demographic characteristics of the sample. The participant criteria for the current study is identical to participant criteria for the study in Chapter 4. All participants reported normal hearing and normal or corrected-to-normal vision. Participants received either two and a half research credits or $25.00 (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.

Table 6: Participant characteristics

	musicians	dancers	controls
n =	20	20	20
sex	11 females 9 males	19 females 1 male	12 females 8 males
age range (years)	19 to 34	18 to 25	18 to 47
mean age (years ± SD)	22.90±3.86	21.30±2.11	23.45±6.35
music training (years ± SD)	11.25±3.45	0.55±1.23	0.33±0.56
dance training (years ± SD)	0.23±0.57	11.45±5.20	0.05±0.26

5.2.2 Tasks

Audiovisual integration was tested using the same "bounce-beep" just-noticeable-difference task used in Chapter 4, while audiovisual synchronization was tested using a variant of the bimodal target-distractor synchronization task (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004) assessed with whole-body movements recorded by a motion capture system. All participants completed the audiovisual integration task followed by the audiovisual synchronization task in one session. The entire session took approximately two and a half hours. All participants were fully debriefed after the study.

5.2.2.1 "Bounce-Beep" Just-Noticeable-Difference Task

Participants watched a bouncing stick figure video (see Chapter 3), during which a single auditory tone was presented (500 Hz, 10 ms long, onset and offset ramps of 5 ms), to determine the threshold of their audiovisual integration. Participants made judgements of whether the audio and video were in synchrony. The level of synchrony was altered from trial to trial using an adaptive tracking procedure with four separate tracks. Trials for each track were randomly interleaved. Two tracks were audio-leading: the first started with the audio in synchrony with the video, with asynchrony increasing by 5% until a mistake was made [A0], then decreasing by 5% until an accurate response occurred, and so on, until

12 reversals were made. The second track started with the audio advanced by 50%, relative to the video [A50], with asynchrony decreasing on each trial until an error was made, then increasing, again until 12 reversals were made. The other two tracks were comparable, but the video was leading, with the first track starting in perfect synchrony [V0], and the second track starting with the video advanced by 50% [V50]. The task was administered on a MacBook Pro using MATLAB R2016a (The MathWorks Inc., Natick, MA, USA). All auditory stimuli were delivered through Sennheiser HD 280 headphones at a comfortable volume. All responses were made on the laptop keyboard.

5.2.2.2 Bimodal Target-Distractor Synchronization Task

Participants bounced in synchrony with a target isochronous auditory sequence (500 Hz, 10 ms tones, with onset and offset ramps of 5 ms) or a target visual sequence (the bouncing stick figure from Chapter 3) while a distractor sequence was presented in the other modality at one of nine temporal offsets. Both target and distractor sequences consisted of 32 events with an IOI of 925 ms. The nine temporal phase displacements between the target and distractor sequences ranged from –50% and +50% of the IOI: 0%, $\pm$ 12.5%, $\pm$ 25%, $\pm$ 37.5%, $\pm$ 50%. The task consisted of 108 trials; each of the nine temporal offsets occurred with audition as the distractor sequence and with vision as the distractor sequence, and repeated six times each. The order of the 108 trials was randomized for each participant, and broken into 12 blocks of nine trials to prevent fatigue. The auditory sequences were played over Dell A215 speakers at a comfortable volume, while the visual sequences were rear projected from a NEC LT260 projector onto a 3 by 4 feet screen (Figure 17). The projected image was approximately 35 x 25 inches. Participants were instructed to face the projection screen while standing approximately 55 inches away as they bounced in synchrony with the target sequence by bending their knees, ensuring that the bottom of their bounces synchronized with the target sequence, starting at the third event of each target sequence, and continued until the end of the trial, while ignoring the distractor events.

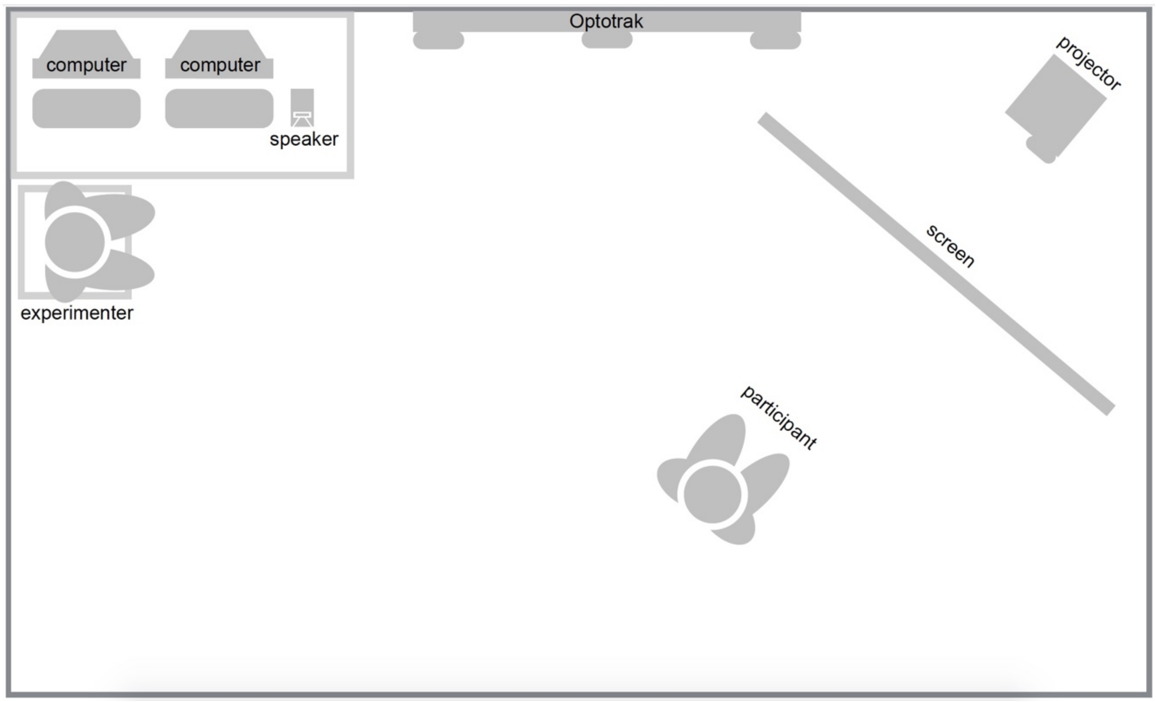

Figure 17: Schematic diagram of the experimental setup.

Participants' movements were recorded by a three-camera optoelectronic recording system (Optotrak, Northern Digital Inc., Waterloo, Canada). The system captured the 3-D positions of 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 3-D 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 30 s.

To ensure that participants did not deliberately close their eyes or look away in the A-V conditions, they were required to report whether the joints of the bouncing stick figure briefly changed colour (from black to red). Half of the A-V conditions contained a colour change (randomized to occur between event 13 and 21). Participants also performed a similar task for the V-A conditions; they reported whether an auditory tone changed in pitch (from 500 Hz to 700 Hz) (randomized between event 13 and 21). Half of the V-A conditions contained a pitch change. Responses regarding colour or pitch changes were made out loud by the participant and inputted by the experimenter on a PC desktop that runs the OTCollect program after each trial.

5.2.3 Statistical Analyses

Performance on the "bounce-beep" just-noticeable-difference task was analyzed by averaging the percentage of asynchrony at the last four reversals for all four tracks. The audiovisual integration thresholds for the A0 and A50 tracks were averaged to get the audiovisual integration threshold value for the audio-leading tracks. Similarly, the audiovisual integration thresholds for the V0 and V50 tracks were averaged to get the audiovisual integration threshold value for the video-leading tracks. A 3 (*group*: musicians, dancers, and non-musician/non-dancer controls) x 2 (*track*: audio-leading and video-leading) mixed ANOVA with group as the between subjects variable and track as the within subjects variable was conducted to assess the interaction between group and track on audiovisual integration thresholds.

For the bimodal target-distractor synchronization task, the percentage of correct responses was calculated for the colour and pitch changes in the distractor sequences. Any participants with a score below 85% were excluded from the final analysis to ensure that participants were still attending to the distractor sequences while synchronizing to the target sequences. A 1 x 3 (*group*: musicians, dancers, and non-musician/non-dancer controls) ANOVA was conducted to assess group differences in response accuracy. Custom in-house software (OTDisplay, programmed by Haitao Yang) was used to calculate the IRIs, which is 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 trial were used to calculate distractor effects, which is the change in relative asynchrony between bounces and target sequence as a function of target-distractor (see Chapter 4). To quantify the strength of the distractor effect, the range of values for the mean relative asynchrony scores (the maximum value of the nine mean relative asynchrony scores minus the minimum value of the nine mean relative asynchrony scores) in the distractor functions for each participant was calculated, and compared with a paired samples *t*-test (Hove et al., 2013). The range of values for the relative asynchrony were analyzed with a 3 (*group*:

musicians, dancers, and non-musician/non-dancer controls) x 2 (*distractor modality*: audition and vision) mixed ANOVA with group as the between subjects variable and distractor modality as the within subjects variable to assess the interaction between group and modality for the distractor effect. Finally, a 1 x 3 (*group*: musicians, dancers, and non-musician/non-dancer controls) ANOVA was conducted for all group demographics. 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.

5.3 Results

5.3.1 Group Demographics

One-way ANOVAs conducted on years of music and dance training revealed significant group differences for both music, $F(2, 57) = 169.08$, $p < .001$, $\eta^2 = .86$, and dance training, $F(2, 57) = 93.51$, $p < .001$, $\eta^2 = .77$. Post hoc comparisons confirmed that musicians ($M = 11.25$ years, $SE = .77$ years) and controls ($M = .33$ years, $SE = .15$ years) significantly differed in years of music training, $t(38) = 13.93$, $p < .001$. Musicians and dancers ($M = .55$ years, $SE = .28$ years) also significantly differed, $t(38) = 13.07$, $p < .001$, but there were no significant differences in years of music training between controls and dancers, $t(38) = .72$, $p = .48$. Likewise, for years of dance training, post hoc comparisons confirmed that dancers ($M = 11.45$ years, $SE = 1.16$ years) and controls ($M = .05$ years, $SE = .05$ years) significantly differed in years of dance training, $t(38) = 9.80$, $p < .001$. Dancers and musicians ($M = .23$ years, $SE = .13$ years) also significantly differed, $t(38) = 9.60$, $p < .001$. However, there were no significant differences in years of dance training between controls and musicians, $t(38) = 1.27$, $p = .21$.

One-way ANOVAs were conducted on years of training, starting age of training, and hours of practice per week for each group's respective expertise with musicians and dancers as the between subject variables. Musicians ($M = 11.25$ years, $SE = .77$ years) and dancers ($M = 11.45$ years, $SE = 1.16$ years) did not significantly differ in the years of training in their respective expertise, $F(1, 38) = .02$, $p = .89$, $\eta^2 = .001$. Musicians ($M = 8.50$ years old, $SE = .82$ years) and dancers ($M = 9.85$ years old, $SE = 1.23$ years) also did not significantly differ on the starting age of their respective training, $F(1, 38) = .84$, $p = .37$, $\eta^2 = .02$. Similarly, musicians (M = 2.60 hours/week, SE = .63 hours/week) and dancers (M = 4.80 hours/week, SE = 1.31 hours/week) did not significantly differ on the number of hours they practiced per week, $F(1, 38) = 2.29$, $p = .14$, $\eta^2 = .06$.

5.3.2 "Bounce-Beep" Just-Noticeable-Difference Task

Performance on the "bounce-beep" just noticeable difference task did not significantly differ between groups, $F(2, 57) = 2.05$, $p = .14$, $\eta^2 = .07$. Musicians (M = 23.09%, SE = 1.83%), dancers (M = 26.27%, SE = 1.29%), and controls (M = 28.25%, SE = 2.22%) all performed similarly on the task. However, performance did significantly differ for track type, $F(1, 57) = 7.27$, $p < .01$, $\eta^2 = .12$. For all groups, the window of perceived simultaneity was smaller when the audio led the video (M = 22.86%, SE = 1.78%) compared to when the video led the audio (M = 28.88%, SE = 1.28%), suggesting that there is more forgiveness in audiovisual integration when vision leads audition. The interaction between group and track type was not significant, $F(1, 57) = 1.02$, $p = .37$, $\eta^2 = .03$ (Figure 18).

5.3.3 Bimodal Target-Distractor Synchronization Task

5.3.3.1 Response Accuracy

Participants were asked to detect a colour change in the A-V trials and a pitch change in the V-A trials to ensure that they were still attending to the distractor sequences while they synchronized to the target sequences. Any participants with a score below 85% were excluded from the final analysis. However, no participants were excluded as all had a response accuracy of 85% or above. Response accuracy did not significantly differ between groups, $F(2, 57) = 1.38$, $p = .26$, $\eta^2 = .05$. Musicians (M = 96.30%, SE = 9.26%), dancers (M = 97.96%, SE = 7.41%), and controls' (M = 96.06%, SE = 9.64%) response accuracies were comparable to each other. On average, response accuracy was 96.77%, thus ensuring that participants were still attending to the distractor sequences while synchronizing to the target sequences.

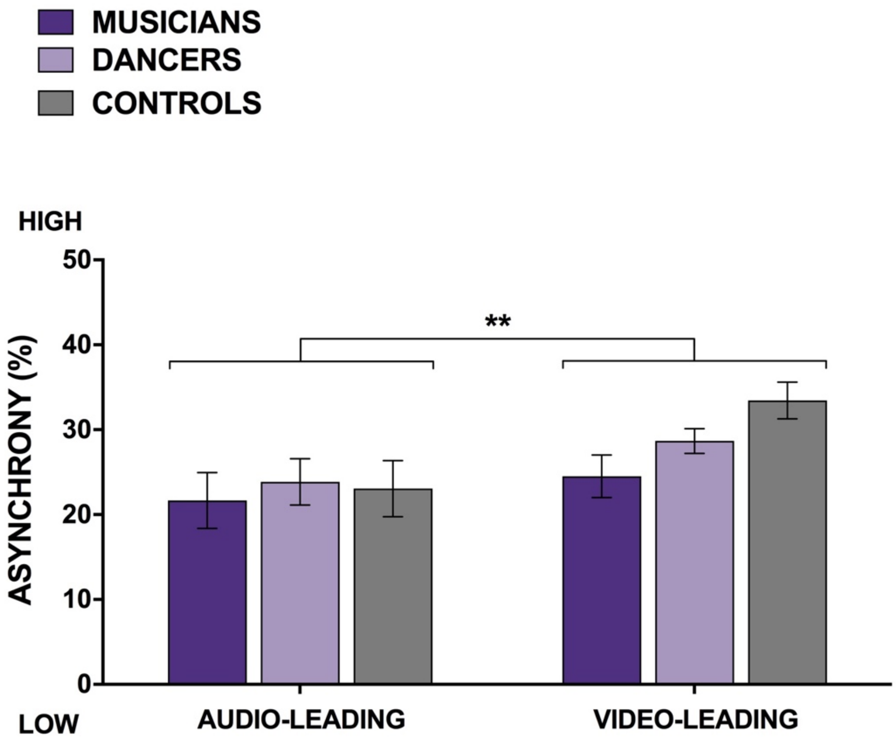

Figure 18: Interaction between group and track type for the "bounce-beep" just-noticeable-difference task. Musicians, dancers, and controls all performed similarly on the task. For all three groups, the window of perceived simultaneity was smaller for clips which audio led video compared to clips which video led audio. The interaction between group and track type was not significant. Error bars indicate standard error of the mean. ** *p* < .01.

5.3.3.2 Relative Asynchronies

5.3.3.2.1 Comparison between Groups

The 3 x 2 mixed ANOVA with group as the between subjects variable and distractor modality as the within subjects variable on the range of the mean relative asynchronies did not produce a significant main effect of expertise, $F(2, 57) = .92$, $p = .41$, $\eta^2 = .03$. Thus, the magnitude of the distractor effect was similar for musicians ($M = .171$, $SE = .013$), dancers ($M = .176$, $SE = 0.13$), and controls ($M = .195$, $SE = .015$). However, there was a main effect of distractor modality, $F(1, 57) = 178.59$, $p < .001$, $\eta^2 = .76$. For musicians, the visual distractor effect ($M = .261$, $SE = .020$) was significantly larger than the auditory distractor effect (*M* = .081, *SE* = .011), $t(19) = 9.97$, $p < .001$. For dancers, the auditory distractor effect (*M* = .267, *SE* = .018) was also significantly smaller than the visual distractor effect (*M* = .081, *SE* = .011), $t(19) = 11.66$, $p < .001$. Likewise, for controls, the visual distractor effect (*M* = .276, *SE* = .024) was significantly larger than the auditory distractor effect (*M* = .115, *SE* = .018), $t(19) = 5.18$, $p < .001$. For all three groups, visual distractors (*M* = .268, *SE* = .001) were significantly more distracting than auditory distractors (*M* = .093, *SE* = .008). For the A-V conditions, all three groups' mean relative asynchronies showed the expected sinusoidal shape consistent with previous literature (Hove et al., 2012; Repp & Penel, 2002; Repp & Penel, 2004). Relative to the zero lead/lag trials, the visual distractors had an asymmetrical effect, with leading visual distractors attracting the bounces more strongly than lagging visual distractors (Figures 19a, 20a, and 21a). However, for the V-A conditions, all three groups' mean relative asynchronies showed remnants of the sinusoidal shape, however, the shape was shallower, and closer to a flat line (Figures 19b, 20b, and 21b). Finally, the interaction between expertise and distractor modality was not significant, $F(2, 57) = .28$, $p = .75$, $\eta^2 = .01$.

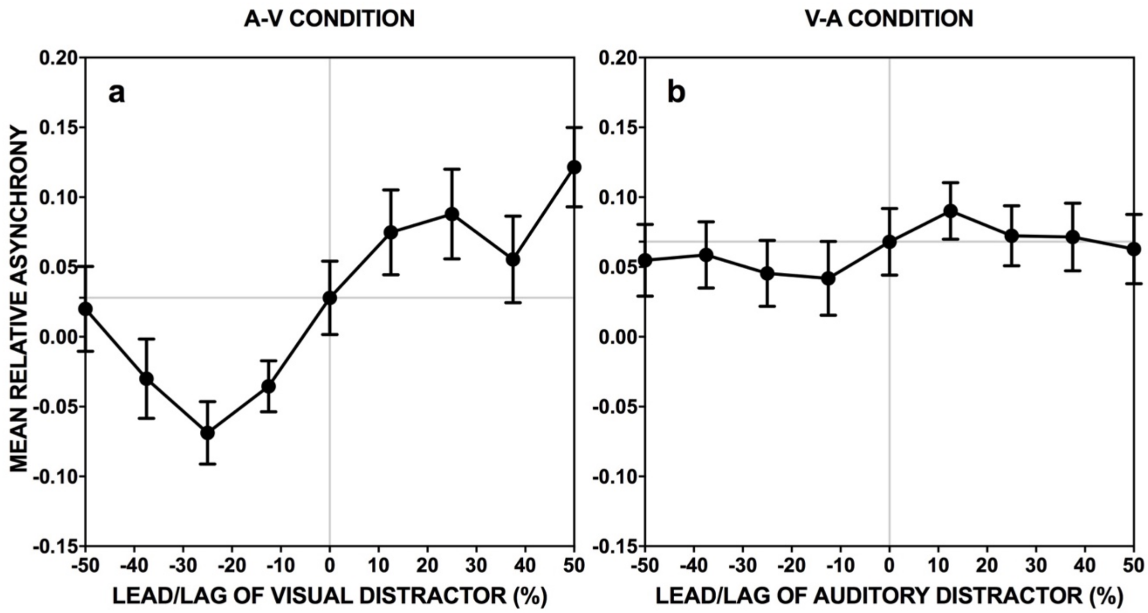

Figure 19: Mean relative asynchrony as a function of distractor lead/lag for musicians in the a) auditory target-visual distractor (A-V) condition, and b) visual target-auditory distractor (V-A) condition. The horizontal grey line is drawn through the mean relative asynchrony at zero lead/lag. Error bars indicate standard error of the mean.

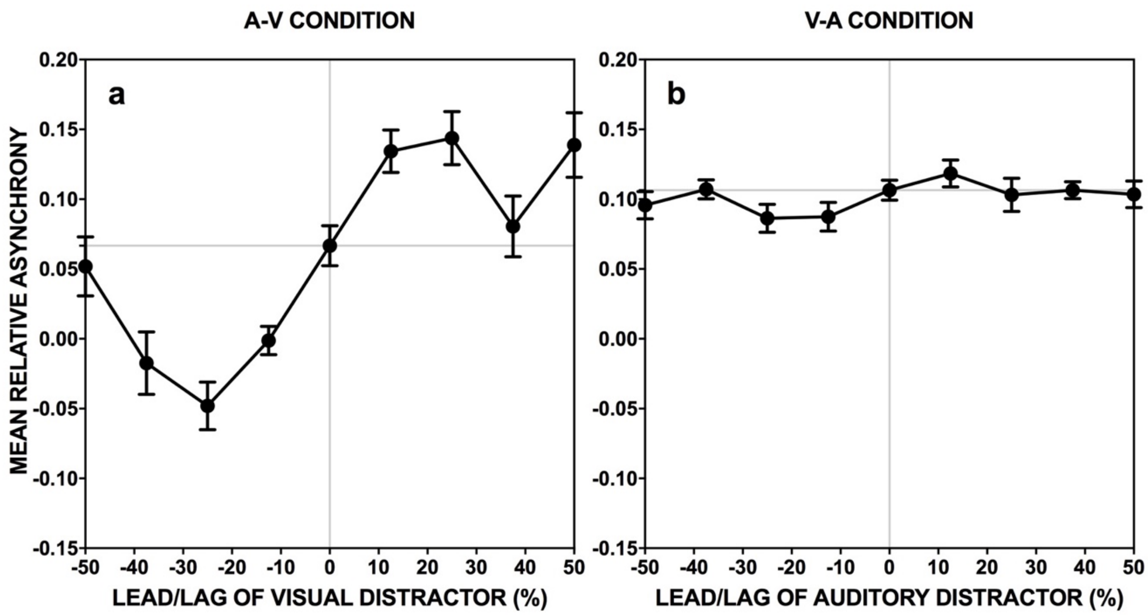

Figure 20: Mean relative asynchrony as a function of distractor lead/lag for dancers in the a) auditory target-visual distractor (A-V) condition, and b) visual target-auditory distractor (V-A) condition. The horizontal grey line is drawn through the mean relative asynchrony at zero lead/lag. Error bars indicate standard error of the mean.

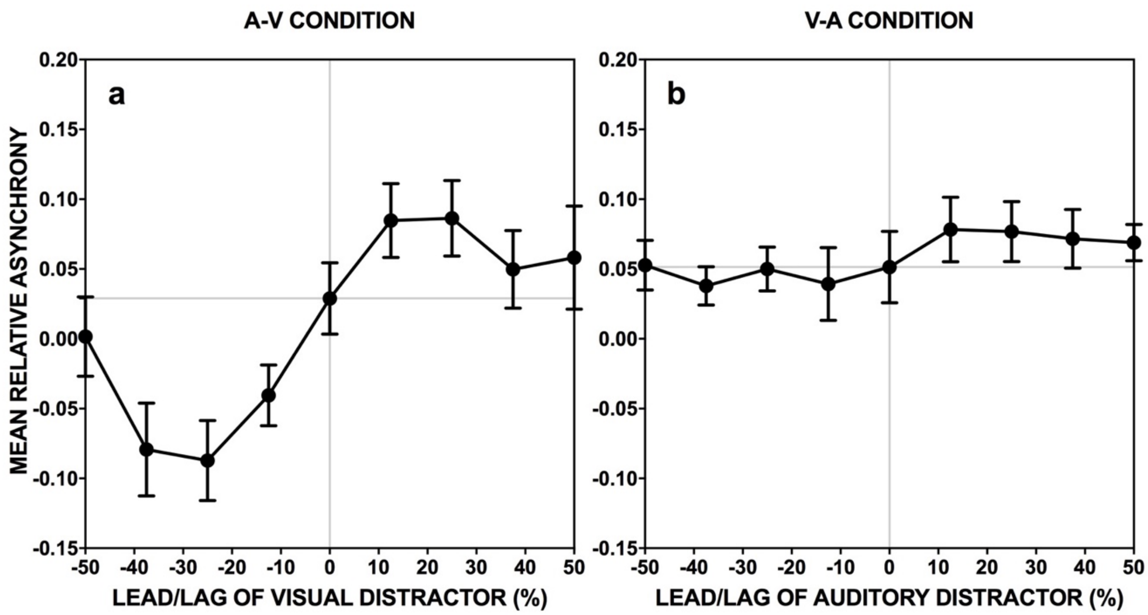

Figure 21: Mean relative asynchrony as a function of distractor lead/lag for non-musician/non-dancer controls in the a) auditory target-visual distractor (A-V) condition, and b) visual target-auditory distractor (V-A) condition. The horizontal grey line is drawn through the mean relative asynchrony at zero lead/lag. Error bars indicate standard error of the mean.

5.4 Discussion

The current study examined how expertise (in music and dance) and modality (auditory and visual) interact to influence audiovisual integration and synchronization using a "bounce-beep" just-noticeable-difference task and a bimodal target-distractor synchronization task assessed with whole-body movements, respectively. For the "bounce-beep" just-noticeable-difference task, participants made judgements of whether the auditory (tone) and visual (bouncing stick figure from Chapter 3) stimuli were in synchrony with each other. Based on the previous findings, it was predicted that musicians, dancers, and controls would not significantly differ in their performance on the task (see Chapter 4). For the bimodal target-distractor synchronization task, participants bounced in synchrony with an isochronous auditory (metronome) or visual (bouncing stick figure from Chapter 3) target sequence while a distractor sequence was presented in the other modality at one of nine temporal offsets. It was predicted that musicians would be more distracted by the auditory distractors than the visual distractors because of their experience with auditory rhythms, whereas dancers would be more distracted by the visual distractors than the auditory distractors, and would show a larger visual effect here than in Chapter 4, because of their experience with visual rhythms and the use of whole-body movements (see Chapter 3). Finally, based on previous findings, it was predicted that controls would not show a bias towards one modality over the other (see Chapter 4).

Results for the “bounce-beep” just-noticeable-difference task replicated the findings reported in Chapter 4. Performance did not significantly differ between musicians, dancers, and controls. Although it was originally predicted that the specialized training that musicians and dancers possess may give them an advantage over controls (see Chapter 4) on the task, the results suggest that audiovisual integration, as an automatic process of human behaviour (Adams, 2016; Alais & Burr, 2004; Hartcher-O’Brien et al., 2014), is not enhanced by music or dance training. Consistent with the findings reported in Chapter 4, the window of perceived simultaneity for the “bounce-beep” just-noticeable-difference task was larger for the visual-leading stimuli rather than the auditory-leading stimuli, irrespective of expertise. The auditory and visual stimuli were more likely to be perceived as occurring simultaneously if vision led audition, indicated by the larger window of perceived simultaneity observed for the video-leading clips than the audio-leading clips. Why a visual-leading asymmetry was observed remains unclear, but one possibility is that audition is processed faster than vision (Keetels & Vroomen, 2012), thus when vision leads audition it is more likely to be perceived as simultaneous (Kayser et al., 2008; Vatakis & Spence, 2006; Zampini et al., 2005). It is also possible that the continuous motion of the bouncing stick figure provides more visual information than the sudden onset of the auditory tone, allowing the slower visual stimulus to be processed before than the auditory stimulus (Neumann & Niepel, 2004). Therefore, when vision leads audition the two stimuli are more likely to be perceived as occurring at the same time.

Results for the bimodal target-distractor synchronization task showed that the magnitude of the distractor effect was similar for musicians, dancers, and controls. For all three groups, the visual distractors were significantly more distracting than the auditory distractors. Specifically, the changes in mean relative asynchrony scores for the A-V conditions (expected sinusoidal pattern) were more prominent than the changes in mean relative asynchrony scores for the V-A conditions (flatter line pattern). A visual dominance observed by all three groups is a departure from previous literature and the results reported in Chapter 4. Previous studies using the bimodal target-distractor synchronization paradigm have often reported an auditory dominance (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004). Even in the one study that directly compared auditory and visual experts, the researchers found that for the auditory experts, the auditory distractors were more distracting than the visual distractors, whereas for the visual experts, the visual distractors were more distracting than the auditory distractors (Hove et al., 2013). Thus, it was predicted that musicians would at least be more distracted by the auditory distractors than the visual distractors. However, in the aforementioned studies sensorimotor synchronization was tested using finger tapping. Here, sensorimotor synchronization was tested using whole-body movements, which does not allow for direct comparisons with similar studies in the literature because the current study is the first to use whole-body movements to test performance on the bimodal target-distractor synchronization task.

Results for the bimodal target-distractor synchronization task also indicated that synchronization with the visual sequences was also more accurate than synchronization with the auditory sequences. Better synchronization with visual sequences than with auditory sequences is also a finding that is inconsistent with the literature. It is commonly observed that asynchrony scores are typically lower when participants synchronize with auditory than with visual rhythms (Kato & Konishi, 2006; Lorås et al., 2012; Patel et al., 2005; Repp & Penel, 2002; Repp & Penel, 2004). So why an overall visual dominance was observed when sensorimotor synchronization was assessed with knee bending rather than finger tapping is unclear. However, one possibility is that participants were biased to imitate the movement they were observing when they were performing a movement that was more similar to the one they were observing (Bonda, Petrides, Ostry, & Evans, 1996; Downing, Jiang, Shuman, & Kanwisher, 2001; Downing, Peelen, Wiggett, & Tew, 2006; Grossman et al., 2000; Vaina, Solomon, Chowdhury, Sinha, & Belliveau, 2001).

Therefore, watching the stick figure bounce may make it difficult to separate observation from execution, particularly when synchronizing via knee bending, which is more comparable to the stick figure's movement than synchronizing via finger tapping.

The results suggested that visual rhythms can be as effective as auditory rhythms at engaging participants' movements, particularly if the observed movements of the visual stimulus are familiar to the participants (Gardner, Goulden, & Cross, 2015; Shimada, 2010; Vogt et al., 2007). For example, in musicians, there are overlaps in activation for neural systems involved in action observation and execution when musicians are observing musically familiar actions (Bangert et al., 2006; Pau, Jahn, Sakreida, Domin, & Lotze, 2013; Proverbio, Calbi, Manfredi, & Zani, 2014). Likewise, in dancers, similar overlaps in activation are observed for the neural systems involved in action observation and execution when dancers are observing dance movements within their motor repertoire (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Cross, Hamilton, & Grafton, 2006; Pilgramm, Lorey, Munzert, Vaitl, & Zentgraf, 2010). Although the choice to use a bouncing stick figure was because the knee bending motion produced by the stick figure was familiar for dancers, knee bending is a biological movement that should be a familiar to musicians and controls as well. Therefore, it is possible that the observation of familiar, whole-body movement, led to better synchronization with the visual sequences for all three groups.

To ensure that the only difference between groups was training (or lack thereof), analyses of group demographics were conducted. Indeed, musicians had significantly more music training than dancers and controls (who did not significantly differ from each other). Likewise, dancers had significantly more dance training than musicians and controls (who did not significantly differ from each other). With regards to their respective training, musicians and dancers did not significantly differ in the number of years of training, starting age of their training, and the number of hours they practiced per week, as great effort was made to recruit individuals that were comparable with regards to their respective training.

5.5 Conclusions

The current study demonstrated how expertise (in music and dance) interacted with modality (auditory and visual) to affect performance on an audiovisual just-noticeable-difference task and a bimodal target-distractor synchronization task assessed with whole-body movements. Performance on both tasks also did not significantly differ between groups. More specifically, on the bimodal target-distractor synchronization task, all three groups were biased toward the visual modality: the visual distractors were significantly more distracting than the auditory distractors. The current study is the first to examine how music and dance training influence rhythm processing and sensorimotor synchronization on the bimodal target-distractor synchronization task using whole-body movements.

Chapter 6

6 General Discussion

The research presented in this dissertation was conducted to examine four factors that may influence beat processing and sensorimotor synchronization 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 and sensorimotor synchronization performance differ among musicians, dancers, and their non-musician/non-dancer counterparts, 2) training style did not significantly influence beat perception and production, as performance did not significantly differ between percussionists and nonpercussionists, 3) musicians were biased toward the auditory modality, whereas dancers were biased toward the visual modality when synchronizing to bimodal sequences, and 4) musicians performed better with finger movements, while dancers performed better with whole-body movements. This dissertation addressed an existing gap in the literature, with focus on how music and dance training interact with training style, stimulus modality, and movement types to influence beat processing and sensorimotor synchronization abilities.

6.1 Discussion of the Experimental Chapters

In Chapter 2, percussive and nonpercussive musicians and dancers, as well as non-musician/non-dancer controls, completed two tasks used to measure beat perception and production. Expertise (i.e.; in music and dance) and training style (i.e.; percussive and nonpercussive) were examined together so that the interaction, as well as the main effects of each factors, could be assessed. On both tasks, percussionists performed numerically better than the nonpercussionists, but the difference was not significant. The lack of an effect for percussive versus nonpercussive music training is a departure from the existing literature, as percussive musicians have shown enhanced temporal precision in both perception and production tasks compared to nonpercussive musicians (Cameron & Grahn, 2014b; 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. The results show that dancers with percussive training do not have a significant advantage over dancers with nonpercussive training, possibly because the foundations of their training are similar (Rosenfeld, 2011).

In Chapter 2, it was predicted that musicians and dancers would outperform their non-musician/non-dancer counterparts (Karpati et al., 2016). The results showed that musicians performed significantly better on both beat processing tasks than dancers and controls, suggesting that music training is related to better beat processing performance (although no causal connection can be made from these data). Dancers also performed better than controls, but not significantly so, indicating that there is no evidence that dance training has a reliable effect on beat processing. However, in Chapter 2, beat perception was measured using auditory stimuli and beat production was measured using a finger tapping task, both of which are arguably music-related. Thus, musicians' superior performance may have been biased by their focused training with auditory stimuli and the use of finger tapping (Fernandes & de Barros, 2012; Repp, 2010; Verheul & Geuze, 2004).

To assess whether the musicians' superior performance in Chapter 2 was specific to the tasks used, in Chapter 3, percussive and nonpercussive musicians and dancers, as well as non-musician/non-dancer controls, completed an audiovisual variant of the original (audio only) beat perception task and a whole-body movement beat production task. A limitation of Chapter 2 was that percussionists and nonpercussionists were made up of musicians and dancers whose main instrument or dance style were classified as percussive or nonpercussive, respectively. As long as the participant's main instrument or dance style was percussive, they were considered a percussionist, and vice versa for participants whose main instrument or dance style was nonpercussive. Therefore, the lack of significant differences may have been because the distinction between the two groups was not strong enough. To better distinguish the percussionist and nonpercussionist groups, and to address a limitation of Chapter 2, in Chapter 3, only musicians and dancers whose training was exclusively percussive or nonpercussive were recruited, excluding any participants with both percussive and nonpercussive training. However, even with more distinct groups, there were no differences in performance between the percussionists and nonpercussionists on the beat processing tasks. Therefore, across two experiments (in Chapters 2 and 3), training style did not significantly affect beat perception and production, despite efforts to make the two groups as distinct as possible.

In Chapter 3, 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 on the audiovisual beat perception task 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 below or close to chance (50%). 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, 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., 2009). Results of the "bounce-beep" just-noticeable-difference audiovisual integration task in Chapters 4 and 5 seem to also suggest that the window of perceived simultaneity is between 25% and 30% of the IBI (the same temporal window as the offsets used for the audiovisual beat perception task). 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). Therefore, the results of the audiovisual beat perception task are difficult to interpret.

Beat production was measured with knee bending rather than finger tapping to examine whether expertise (in music or dance) that favours effector-specific or whole-body movement affects beat production. It was predicted that if the musicians' superior performance in Chapter 2 was not task specific, then the musicians should outperform the dancers in the bouncing beat production tasks in Chapter 3. However, performance on the task did not significantly differ between musicians and dancers, although musicians and dancers did significantly outperform controls. Thus, the results suggest that the musicians' superior production performance in Chapter 2 was task specific.

Given the similar performance when dancers were tested with the movement type compatible to their training, musicians and dancers may have comparable beat production abilities. While no statistical analyses were conducted to compare beat production performance with effector-specific and whole-body movements, the results indicated that participants were capable of synchronizing to the beat using both types of movements. Indeed, the CoV, CDEV, and asynchrony scores for musicians and controls were comparable for both types of movements. Dancers, however, produced lower variability and bounced to the tempo of the music with greater accuracy when tested with knee bending than with finger tapping, possibly due to the fact that dance training involves performing whole-body movements in synchrony with auditory stimuli (Karpati et al., 2016). The results suggest that music and dance training does influence beat production abilities, however, the effect of dance training on beat production may be specific to whole-body movements. Music training may still have a greater influence on beat processing abilities than dance training because when asked to tap (effector-specific movement) to the beat in Chapter 2, dancers were not significantly better than controls. However, when asked to bounce (whole-body movement) to the beat in Chapter 3, musicians were significantly better than controls. Music training may show some transfer that allows musicians to make better temporal predictions about the beat which facilitates their ability to make more synchronized movements, regardless of movement type (Karpati et al., 2016).

In Chapters 4 and 5, musicians and dancers, as well as non-musician/non-dancer controls, completed two tasks used to measure audiovisual integration (perception) and synchronization (production) with finger tapping and knee bending, respectively. As the experiments in Chapters 2 and 3 found no effect of percussive versus nonpercussive training style, the experiments in Chapters 4 and 5 did not include training style as a factor. Audiovisual integration was tested using a task that is analogous to the "flash-beep" just-noticeable-difference paradigm (de Boer-Schellekens et al., 2013; Fiedler et al., 2011; Innes-Brown et al., 2011). It was predicted that musicians and dancers would not significantly differ in performance on the audiovisual integration task, but would outperform their non-musician/non-dancer counterparts (Karpati et al., 2016). Inconsistent with predictions, performance for the audiovisual integration task in Chapter 4 did not significantly differ between musicians, dancers, and controls. Although the window of perceived simultaneity was larger for controls than for both musicians and dancers, the difference was not significant. The window of audiovisual integration appeared to be around 25% and 30% of the IBI for all three groups. When the same audiovisual integration task was used in Chapter 5 on a different set of participants, the results replicated the results reported in Chapter 4. Both sets of findings seem to suggest audiovisual integration may be an automatic process of human behaviour (Adams, 2016; Alais & Burr, 2004; Hartcher-O'Brien et al., 2014). Therefore, despite specialized training, musicians and dancers do not have a significant advantage on the audiovisual integration task over controls.

A variant of the bimodal target-distractor synchronization paradigm was used for the audiovisual synchronization task in Chapters 4 and 5 (Chen et al., 2002; Repp & Penel, 2002; Repp & Penel, 2004), pitting a visual bouncing stick figure against an auditory metronome. Expertise (i.e.; in music and dance) and stimulus modality (i.e.; auditory and visual) were both examined so that the interaction could be assessed. It was predicted that musicians would have a strong bias for the auditory modality, whereas dancers would have a strong bias for the visual modality. In Chapter 4, the results indicated that musicians were more distracted by auditory distractors when tapping to visual targets than visual distractors when tapping to auditory targets, whereas dancers were more distracted by visual distractors when tapping to auditory targets than to the auditory distractors when tapping to visual targets. Non-musician/non-dancer controls showed no preference for one modality over the other. Although no other studies have directly compared musicians and dancers on the bimodal target-distractor synchronization paradigm, the results are broadly consistent with another study that compared auditory experts (musicians) and visual experts (video gamers and ball players) on a similar task (Hove et al., 2013). The researchers found that for the auditory experts, the auditory distractors were more distracting than the visual distractors, whereas the opposite was observed for the visual experts (Hove et al., 2013). It appears that musicians have a bias for the auditory modality, whereas dancers have a bias for the visual modality.

In Chapter 5, participants were instructed to bounce rather than tap to the target sequence while ignoring the distractor sequence. Again, it was predicted that musicians would have a strong bias for the auditory modality, whereas dancers would have a strong bias for the visual modality, but the magnitude of the visual distractor effect for dancers would be larger than observed in Chapter 4 because of the use of whole-body movements. The results describe for the first time the effect of whole-body movements used in a bimodal target-distraction synchronization task. In contrast to Chapter 4, in Chapter 5, all three groups appeared to have a bias for the visual modality. Musicians, dancers, and controls were all more distracted by the visual distractors when tapping to the auditory targets than to the auditory distractors when tapping to the visual targets. In fact, the magnitude of the visual distractor was large. The changes in mean relative asynchrony scores for the A-V conditions produced a prominent sinusoidal pattern, consistent with previous literature, while the changes in mean relative asynchrony scores for the V-A conditions produced a flatter pattern, suggesting that there was little to no effect of the auditory distractors (Hove et al., 2012; Repp & Penel, 2002; Repp & Penel, 2004).

It is unclear why an overall visual dominance was observed when sensorimotor synchronization was assessed with knee bending instead than finger tapping. However, one possibility is that participants were biased to imitate the movement they were observing when they were performing a movement that was more similar to the one they were observing (Bonda et al., 1996; Downing et al., 2001; Downing et al., 2006; Grossman et al., 2000; Vaina et al., 2001). In Chapter 4, the stick figure was displayed on a laptop screen. In Chapter 5, however, the stick figure was a life-size projection of a figure who bounced in front of the participants. Therefore, watching the stick figure bounce may make it difficult to separate observation from execution, particularly when synchronizing via knee bending, which is more comparable to the stick figure's movement than synchronizing via finger tapping.

Taken together, the research in this dissertation described for the first time how music and dance training interact with training style, stimulus modality, and movement type to influence beat processing and sensorimotor synchronization. Beat processing and sensorimotor synchronization performance differ among musicians, dancers, and their non-musician/non-dancer counterparts. Training style did not significantly influence beat perception and production, as performance did not significantly differ between percussionists and nonpercussionists. In terms of sensorimotor synchronization tasks, musicians show a strong bias for the auditory modality, whereas dancers show a strong bias for the visual modality. Finally, musicians performed better with finger movements, while dancers performed better with whole-body movements.

6.2 Limitations

The experiments in this dissertation have the limitation of being quasi-experimental. Participants had pre-existing music and dance training so they were not subject to random assignment. Thus, it cannot be said that differences in training *caused* the observed 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 respective training (or lack thereof). All participants were similar in age, post-secondary educated, and were recruited within the university community. Furthermore, to ensure that any differences in performance between groups were not due to differences such as music exposure, which might influence beat processing and sensorimotor synchronization performance (Bläsing et al., 2012; Drake, 1998; Tillmann, 2008), participants reported how many hours a week they listened to music, including practicing time. The results confirmed that there were no significant differences in music exposure between musicians, dancers, and controls.

Great effort was also made to recruit musicians and dancers that were similar with regards to their respective disciplines. Therefore, only individuals with at least five or more years of music or dance training (but not both) were recruited and tested. Five years of training is perhaps an arbitrary cut-off criterion, but it is consistent with the criteria used by other studies in the existing literature (Crawley, Acker-Mills, Pastore, & Weil, 2002; Grahn & Rowe, 2009; Grahn & Schuit, 2012; Kumar, Sanju, & Nikhil, 2016;

Nikjeh, Lister, & Frisch, 2008). Musicians and dancers in all four experiments had on average more than 10 years of experience in their respective discipline. Group demographics confirmed that musicians and dancers did not significantly differ in the number of years of training, starting age of their training, and the number of hours they practiced per week. Therefore, all measured differences between the groups were only in their respective disciplines. Moreover, the interaction of expertise with stimulus modality in Chapter 4 allows for the interpretation of otherwise confounding group differences, as these confounding factors are less likely to affect performance in a modality-specific way. Thus, the interaction between expertise and stimulus modality suggests that musicians and dancers may have responded differently to different modalities as a consequence of their respective training.

Other possible confounding factors in this dissertation are sex differences. A major challenge of recruiting and testing musicians and dancers was trying to maintain an even ratio of male to female for each of the groups, especially for the dancer groups. While male and female dancers were recruited equally, more female dancers met the inclusion criteria, so for all four experiments in this dissertation, there were predominately more female dancers than male dancers (only one male in each of the groups of dancers). It is possible that sex differences may have accounted for the group differences, but it seems unlikely as there is no evidence to suggest that males and females differ in their abilities to process temporal information. Moreover, not all comparisons between musicians and dancers were significant, particularly in Chapter 3 and the audiovisual integration tasks in Chapters 4 and 5, yet the ratio of male to female were the same across all four experiments. Therefore, it seems unlikely that sex differences are significant factors influencing beat processing and sensorimotor synchronization abilities. Nevertheless, it is wise to be cognizant of the possibility that such differences might exist.

Beat processing performance in this dissertation were measured using the BAT taken from the Gold-MSI. A limitation of the Gold-MSI BAT is that it is only a brief measure of beat processing abilities, and does not provide as much information as more extensive beat processing measures such as the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA) (Benoit et al., 2014) or the Harvard BAT

(Fujii & Schlaug, 2013). However, the Gold-MSI BAT is easy to implement, uses ecologically valid music, and is capable of quantifying the normal range of beat processing abilities in the general population. Since the intention of this research was to compare beat processing performance of musicians, dancers, and non-musician/non-dancer controls, the Gold-MSI BAT proved to be easily comprehensible by all participants, independent of music experience. Therefore, despite its limitations, the Gold-MSI has significant strengths as a measure of beat processing abilities.

Sensorimotor synchronization in this dissertation was assessed using two different types of movements: effector-specific and whole-body. In the existing literature, the basic mechanisms of sensorimotor synchronization are often studied with finger tapping paradigms (Repp & Su, 2013), and synchronization is generally better with discrete movements than with continuous movements (Torre & Balasubramaniam, 2009). However, the results observed in this dissertation seems to suggest that participants can effectively synchronize to the beat with both types of movements. Indeed, beat production scores (CoV, CDEV, and asynchrony) in Chapters 2 and 3 and the mean relative asynchrony scores in Chapters 4 and 5 were within the same magnitude for both types of movements. However, no statistical analyses were conducted to directly compare sensorimotor synchronization performance using effector-specific and whole-body movements, since the intention of this dissertation was to explore the potential interaction of expertise and movement types, rather than the main effect of movement types. As such, the significance of the findings above are speculative because no direct comparison between the two types of movements were made. Given the importance of sensorimotor synchronization in music and dance, future studies could build upon this work to investigate how the mechanisms of sensorimotor synchronization differs between effector-specific and whole-body movement in the same group of participants.

6.3 Implications and Practical Applications

The research presented in this dissertation contributes to a greater understanding of how music and dance training may be related to beat processing and sensorimotor synchronization. While it is not the first body of work to demonstrate that music and dance training are different from each other, it is the first to demonstrate how music and dance training interact with training style (percussive and nonpercussive), stimulus modality (auditory and visual), and movement types (effector-specific and whole-body) to influence beat processing and sensorimotor synchronization performance. More specifically, it is the first to directly examine percussive and nonpercussive dancers on the same tasks, as little is known about the differences between percussionists and nonpercussionists with respect to dance in the existing literature. It is also the first to compare how musicians and dancers perform on a bimodal target-distractor synchronization task using effector-specific and whole-body movements, with the two types of movements providing distinct results. The research presented in this dissertation contributed to a body of research that does not exist in the literature.

It is important to consider the training related differences between musicians and dancers, and how those differences may affect different cognitive processes. An implication of understanding how music and dance training are different is to selectively use those differences to enhance or compensate an area of weakness. For example, dancers show poorer beat processing performance compared to musicians when tested with finger tapping, but comparable performance when tested with knee bending. Moreover, musicians seemed to have a bias for the auditory modality, whereas dancers seemed to have a bias for the visual modality when synchronizing to bimodal rhythms. The research presented in this dissertation only begins to touch on the individual differences that might exist in the beat processing domain, but understanding the contrasts between musicians and dancers allow for future research to better accommodate for their individual differences.

Moreover, the results of current research have direct practical implications because it can contribute to the development of music- and dance-based therapies for special populations, particularly for individuals affected by Parkinson's disease (PD). PD is most relevant to the current research because it adversely affects temporal processing abilities, likely due to dopaminergic dysfunction in the basal ganglia known to be involved in temporal processing (Harrington, Haaland, & Hermanowicz, 1998; O'Boyle, Freeman, & Cody, 1996; Wiener, Loho, Coslett, 2011). However, research shows that using music with rhythmic properties that emphasizes a regular beat can help regulate timing (Pastor, Artieda, Jahanshahi, & Obeso, 1992; Skodda, Flasskamp, & Schlegel, 2010; Thaut, McIntosh, McIntosh, & Hoemberg, 2001), and facilitate synchrony of movement (Hallett, 2008). Far less is known about the benefits of dance-based therapies for individuals with PD, but there is evidence to indicate that dance may also be an effective form of therapy for individuals with PD (Earhart, 2009). As the literature on the benefits of dance-based therapies for those with PD is relatively scant, the neural mechanisms that explains why dance may have beneficial effects on individuals affected by PD are speculative. One speculation is that dance facilitate activation of areas that normally show reduced activation in individuals with PD when synchronizing to a predictable beat, particularly the putamen, a structure of the basal ganglia (Brown, Martinez, & Parsons, 2006). Therefore, not only does the research presented in this dissertation motivate several areas of future research, it also serves as a foundation for future developments of music- and dance-based therapies.

6.4 Conclusion

The research presented in this dissertation contributes to a better understanding of how music and dance training interact with other factors such as training style (percussive and nonpercussive), stimulus modality (auditory and visual), and movement types (effector-specific and whole-body) to influence beat processing and sensorimotor synchronization abilities, notwithstanding the limitations describe above. As this research is the first to demonstrate how music and dance training affect beat processing and sensorimotor synchronization, it may serve as a foundation for future research, particularly in the area of music and dance. The results suggest that tailoring methods, techniques, and materials to accommodate individual differences is important for highlighting those differences in temporal processing research. Together, the research presented in this dissertation inform how music and dance—similar, yet different types of training—may affect beat processing and sensorimotor synchronization abilities.

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Appendices

Appendix A: Ethics approval for the experiment in Chapter 2.

Western Research

Research Ethics

Use of Human Participants - Initial Ethics Approval Notice

Principal Investigator: Dr. Jessica Grahn
File Number:104521
Review Level: Delegated
Protocol Title: Examining Differences in Beat Perception in Musicians and Dancers
Department & Institution: Social Science\Psychology,Western University
Sponsor:
Ethics Approval Date: November 04, 2013 **Expiry Date:** October 01, 2015

Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Letter of Information & Consent	Consent Form	2013/10/01
Other	Debriefing Form	2013/10/01
Western University Protocol		2013/10/10
Advertisement	SIGN UP POSTER (ADVERTISEMENT) FOR NON WESTERN PSYCHOLOGY RESEARCH POOL PARTICIPANTS	2013/10/23
Advertisement	SIGN UP POSTER (ADVERTISEMENT) FOR WESTERN PSYCHOLOGY RESEARCH POOL PARTICIPANTS	2013/10/01
Revised Letter of Information & Consent	REVISED LOI ACCORDING TO BOARD RECOMMENDATIONS	2013/10/23
Instruments		2013/10/23

This is to notify you that The University of Western Ontario Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the applicable laws and regulations of Ontario has granted approval to the above named research study on the approval date noted above.

This approval shall remain valid until the expiry date noted above assuming timely and acceptable responses to the NMREB's periodic requests for surveillance and monitoring information.

Members of the NMREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussions related to, nor vote on, such studies when they are presented to the NMREB.

The Chair of the NMREB is Dr. Riley Hinson. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Signature

Ethics Officer to Contact for Further Information

Grace Kelly (grace.kelly@uwo.ca)	___Vikki Tran (vikki.tran@uwo.ca)	___ Erika Basile (ebasile@uwo.ca)

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Appendix B: Ethics approval for the experiment in Chapter 3.

Western Research

Research Ethics

Western University Health Science Research Ethics Board
NMREB Delegated Initial Approval Notice

Principal Investigator: Dr. Jessica Grahn
Department & Institution: Social Science\Psychology,Western University

NMREB File Number: 106087
Study Title: Audiovisual Beat Perception and Production in Musicians and Dancers
Sponsor:

NMREB Initial Approval Date: January 23, 2015
NMREB Expiry Date: January 23, 2016

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Data Collection Form/Case Report Form	Questionnaire Clean Version	2014/12/23
Advertisement	Sign Up Poster Clean Version	2014/12/23
Other	Debriefing Form Clean Version	2014/12/23
Western University Protocol	Ethics Protocol #106087 Clean Version	2014/12/23
Letter of Information & Consent	Letter of Information & Consent Form for SONA participants Clean Version	2014/12/23
Letter of Information & Consent	Letter of Information & Consent Form for Musicians/Dancers Clean Version	2014/12/23
Advertisement	Sign Up Poster (Advertisment) for Western Psychology Research Pool Participants	2014/11/15
Advertisement	Sign Up Poster (Advertisement) for Non Western Psychology Research Pool Participants	2014/11/15

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the above named study, as of the NMREB Initial Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Ethics Officer, on behalf of ~~Riley~~ Hinson, NMREB Chair or delegated board member

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Appendix C: Ethics approval for the experiments in Chapters 4 and 5.

Western Research

Research Ethics

Western University Health Science Research Ethics Board
NMREB Delegated Initial Approval Notice

Principal Investigator: Dr. Jessica Grahn
Department & Institution: Social Science\Psychology,Western University

NMREB File Number: 106385
Study Title: Behavioral studies of rhythm and music perception
Sponsor: Natural Sciences and Engineering Research Council

NMREB Initial Approval Date: March 30, 2015
NMREB Expiry Date: March 30, 2016

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Advertisement	Poster for SONA Participants	2015/02/11
Advertisement	Script for email recruitment	2015/02/11
Advertisement	Poster for Paid Participants	2015/02/11
Other	debriefing form	2015/02/11
Letter of Information & Consent	LOI and Consent form	2015/02/11
Revised Western University Protocol	clean version	2015/03/18

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the above named study, as of the NMREB Initial Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Ethics Officer, on behalf of Riley Hinson, NMREB Chair or delegated board member

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Curriculum Vitae

Name:	Tram Nguyen
Post-secondary Education and Degrees:	The University of Western Ontario London, Ontario, Canada 2006-2011 B.Sc. (Psychology Honors Specialization)
	The University of Western Ontario London, Ontario, Canada 2011-2013 M.Sc. (Psychology)
	The University of Western Ontario London, Ontario, Canada 2013-2017 Ph.D. (Psychology)
Honours and Awards:	Western Graduate Research Scholarship 2011-2017
	Reva Gerstein Fellowship for Masters Study in Psychology 2011-2012
	Ralph S. Devereux Award in Psychology 2011-2012
	Ontario Graduate Scholarship 2015-2016
	Richard A. Harshman Scholarship 2015-2016
Related Work Experience:	Research Assistant The University of Western Ontario 2010-2011
	Teaching Assistant The University of Western Ontario 2011-2017
	Thesis Advisor The University of Western Ontario 2013-2016

Related Work Experience: Trials Co-ordinator
Cambridge Brain Sciences Incorporated
Toronto, Ontario, Canada
2015-present

Publications:

Nguyen, T., & Grahn, J. A. (2017). Mind your mind: the effects of music-induced mood and arousal across different memory tasks. *Psychomusicology: Music, Mind, and Brain*, *27*(2), 81-94.

Nguyen, T., Gibbings, A., & Grahn, J. A. (in press). *Rhythm and beat perception*. In Springer Handbook for Systematic Musicology. Springer Publishing.

Presentations:

Nguyen, T., Everling, J. C., Henry, M. J., & Grahn, J. A. (2017). Synchronization with competing visual and auditory rhythms in musicians and dancers. Poster presented at the biennial meeting of the Society for Music Perception and Cognition (SMPC), San Diego, CA, USA, August 2017.

Nguyen, T., & Grahn, J. A. (2016). Let's dance: examining the differences in beat perception and production between musicians and dancers using motion capture. Poster presented at the 14th biannual meeting of the International Conference on Music Perception and Cognition (ICMPC), San Francisco, CA, USA, July 2016.

Nguyen, T., Tam, S., Wickett, M. C., & Grahn, J. A. (2015). Differences in beat perception and production between musicians and dancers. Talk presented at the biennial meeting of the Society for Music Perception and Cognition (SMPC), Nashville, TN, USA, August 2015.

Nguyen, T., Tam, S., Wickett, M. C., & Grahn, J. A. (2014). Examining differences in beat perception and production between musicians and dancers. Poster presented at the 43rd annual meeting of the Lake Ontario Visionary Establishment (L.O.V.E.), Niagara Falls, ON, Canada, February 2014.