The Effects of Parkinson's Disease, Music Training and Dance Training on Beat Perception and Production Abilities

Prisca Hsu

Thesis Advisors. Dr. Emily Ready & Dr. Jessica Grahn

The Department of Neuroscience, Schulich School of Medicine & Dentistry,

Brain and Mind Institute, The University of Western Ontario, London, ON, Canada

Abstract

Humans naturally perceive and move to a musical beat, entraining body parts to the complex auditory stimuli through clapping, tapping and dancing. Yet, the accuracy of this seemingly effortless behavior varies widely across individuals. Beat perception and production abilities can be positively impacted by past experiences, like music and dance training, and are now better understood to be negatively impacted by progressive neurological changes in Parkinson's Disease (PD). In this study, we assessed the combined effects of past music or dance training and early-stage PD to determine whether the positive effects of rhythm-based training in healthy adults on beat processing abilities are altered in PD. We predicted that music and dance training would positively impact beat perception and production skills, while the neurological deficits associated with PD would negatively impact these skills. We further predicted that some positive impacts of music and dance training would be preserved despite disease state and therefore expected effects of music training within PD patients. We used the Beat Alignment Test (BAT) to assess beat perception and production abilities among 458 participants, comprised of 278 healthy younger adults, 139 healthy older adults, and 41 people with early-stage PD, across varying levels of music and dance training. In general, participants with over three years of music training reflected more accurate beat perception abilities compared to those with minimal training ($p<.001$). Interestingly, PD patients with over three years of music training demonstrated beat production abilities comparable to healthy adults ($p>.05$) while PD patients with minimal music training performed significantly worse ($p<.01$). These results broadly inform the role of music training in preserving certain motor timing functions related to beat processing in early-stage PD. No dance training effects were found.

Keywords: Beat Alignment Test, beat perception, beat production, sensorimotor entrainment, Parkinson's Disease, music training, dance training

Acknowledgements

I am incredibly grateful to have uplifting mentors and labmates, without which, this thesis would not be possible. I would like to thank my supervisors, Drs. Emily Ready and Jessica Grahn for their support and guidance throughout this project. To Emily Ready, thank you for being patient with me especially during the statistical analysis stage of this study. You are not only a mentor to my research but also someone I could come to for career advice. To Jessica Grahn, thank you for providing me with the opportunity to work with you, and for always pointing me in the right direction. Thank you both for being incredible mentors who ignited my interest in scientific research. To Chantal Rochon, thank you for your support with all things administrative. To the rest of the Music and Neuroscience lab, thank you for all the helpful advice given during lab meetings and an unforgettable lab experience. I also thank Western University, the Brain and Mind Institute and NSERC for funding this project. Finally, I would like to thank my family and friends for their endless support in every step of my undergraduate journey.

The Effects of Parkinson's Disease, Music Training and Dance Training on Beat Perception and Production Abilities

The vast majority of humans effortlessly process timing interval durations required to perceive a musical beat; a process known as beat perception. Humans also naturally entrain or synchronize, their body movements with the complex musical stimuli through tapping or clapping; a process called beat production. Early studies have shown that external auditory stimuli can promote and guide motor timing (Aschersleben & Prinz, 1995; Thaut et al., 1996). These findings were further explored in behavioral tests which demonstrated that humans effortlessly entrained their finger tapping to metronome ticks even when its tempo was subtly adjusted faster or slower (Thaut et al., 1998). Emerging imaging techniques demonstrated that EEG signal amplitudes highly correlate to the beat pattern of the given auditory stimuli (Nozaradan et al., 2011). In addition, both behavioral movements and brain waves were found to entrain with external rhythmic auditory stimuli (Will & Berg, 2007). White matter tracts and fibers extended from the auditory cortex to the motor cortex, providing structural evidence for auditory-motor connectivity (Dhillon et al., 2005). These studies provide behavioral and neural evidence that a degree of auditory-motor entrainment is innate.

The process of entraining human motor output to complex sensory input engages the basal ganglia and the cerebellum. The basal ganglia plays a key role in beat perception (Grahn & Brett, 2007) and the cerebellum contributes to motor coordination processes (Teki et al., 2011). Early lesion studies found that cerebellar and basal ganglia lesion patients exhibited movement timing errors and increased variability on various finger tapping tasks (Diener et al., 1993). In addition, basal ganglia lesion patients demonstrated perception impairments on timing-rigorous tasks such as visual motion processing and timing perception (Ivry, 1996). Stroke and

Parkinson's Disease patients whose basal ganglia are affected also displayed compromised ability on rhythm perception and motor entrainment tasks (Patterson et al., 2018; Puyjarinet et al., 2019). These findings provide evidence that auditory-motor entrainment processes are implicated in motor areas.

Despite these closely linked auditory-motor systems, people show a striking range in how accurately they both perceive and move with a beat. This phenomenon led to research speculating that rhythm entrainment can be affected by the environment. Beat perception and production abilities are impacted by past experiences, like music and dance training (Tranchant et al., 2016; Zatorre et al., 2007), and is now better understood to also be impacted by progressive neurological changes (Grahn & Brett, 2009; Patterson et al., 2018).

Rhythm Disturbance in Parkinson's Disease

Parkinson's Disease (PD) is a neurodegenerative disease characterized by progressive cell death of dopaminergic neurons in the substantia nigra resulting in loss of excitatory stimulation on the putamen. Neural timing networks overlap with many motor control areas and are based in both the cortical and subcortical structures (Schubotz et al., 2000; Thaut et al., 2008). These cortical structures include the premotor cortex and supplementary motor area (SMA), and the subcortical structures include the basal ganglia and the cerebellum (Schubotz et al., 2000). The disruption of dopamine projection within these networks may consequently result in beat processing deficits (Grahn & Brett, 2009). PD patients are especially of interest in investigating the disrupted dynamics of normal beat perception and production. Previous works have found that PD patients were impaired on simple timing tasks and more complex beat-based rhythm discrimination tasks (Grahn & Brett, 2009; Harrington et al., 1998). Cameron and colleagues (2016) predicted that these deficits were likely due to low dopamine levels in the basal ganglia. They manipulated dopamine levels in the basal ganglia and found that PD patients improved on rhythm discrimination tasks after taking dopaminergic medication. Conversely, healthy adults were impaired on a temporal discrimination task after taking a dopamine receptor antagonist that reduced dopamine neurotransmission (Rammsayer, 1999). These studies confirmed the crucial role of dopamine in maintaining normal basal ganglia activity to elicit precise timing and rhythm processing mechanisms.

Though beat perception and production processes are thought to be intertwined and are thus often tested together (Diener et al., 1993; Will & Berg, 2007), the Beat Alignment Test (BAT) is a behavioral assessment that measures beat perception and production skills independently to better understand the two processes (Müllensiefen et al., 2014). The BAT has been successful in identifying people with impaired beat perception abilities but intact beat production abilities, and vice versa (Bégel et al., 2017; Palmer et al., 2014). As mentioned, beat perception relies primarily on the basal ganglia, while beat production relies more heavily on the integration between the basal ganglia and other motor areas such as the premotor cortex, SMA, and the cerebellum (Grahn & Brett, 2007; Zatorre et al., 2007). The BAT is especially useful in testing clinical populations, such as PD patients, because both rhythm perception and motor control are affected by disease-related neurological changes. Recent research used the BAT to assess sensorimotor integration abilities through beat perception and production in PD patients (Cameron et al., 2016; Dauvergne et al., 2018).

Music Training

The human brain controls the movements required to produce music in a coordinated and rhythmic manner. Both accurate temporal perception and motor control are required for music-making (Matthews et al., 2016). Musicians are often studied to understand the neuronal functions that allow humans to perceive and produce such intricate processes (Wan & Schlaug, 2010). Musicians have enhanced brain structures that are believed to relate to their training. For example, musicians have a larger Heschel's gyrus (Schneider et al., 2002), greater white matter connections between the hemispheres (Steele et al., 2013) and greater functional connectivity between the auditory and motor cortices (Palomar-García et al., 2017). In addition, musicians have extensive brain plasticity in areas directly engaged during their training (Haueisen & Knösche, 2001). Imaging studies have demonstrated automatic coupling between auditory-motor systems by showing that musicians activate both their auditory and motor systems even when passively listening to music. By contrast, non-musicians only activate their auditory areas when passively listening to music (Haueisen & Knösche, 2001).

The auditory and motor systems interact both ways during music-making. The auditory system relays information to the motor system in a predictive manner and the motor system sends information back to the auditory system for error correction and fine-tuning sound outputs (Zatorre et al., 2007a). A process requiring information flow from motor to auditory areas would be entraining finger tapping to music; the listener is required to extract a beat from the music and entrain their motor output with the incoming beat. This mechanism is impaired in neurological disorders such as PD (McIntosh et al., 1997). The impairment in timing-related functions, such as gait, could be remediated by engaging this auditory-motor network by using rhythmic auditory stimulation, an external stimulus that works to improve the coupling between the two systems (Thaut et al., 2015; Leow et al., 2018; Ready et al., 2019). Information is also relayed back from the motor system to the auditory areas. Musicians rely heavily on this neural circuitry in which their motor inputs determine the quality of the output sound and the accuracy of the rhythmic timing. Musicians extensively engage the auditory-motor networks in both directions. The increased use of the auditory-motor neural circuitry allows researchers to investigate the effects of training on motor timing mechanisms such as beat perception and production (Zatorre et al., 2007).

Dance Training

Music and dance often occur in similar contexts. Humans naturally move to the beat of the music, a phenomenon thought to be closely associated with beat perception (Grahn, 2012). Similar to musicians, dancers have enhanced gray and white matter networks in temporal and motor brain areas (Karpati et al., 2015). However, unlike musicians, dancers are especially skilled at entraining their movements to visual events. Dancers must synchronize their movements to the music and with the movements of other dancers, resulting in elevated motor entrainment abilities with both auditory and visual stimuli (Washburn et al., 2014). Dancers are accustomed to learning choreography by watching others perform and later fine-tuning their movements by observing their actions (Jola et al., 2012). Dancers engage both visual and motor networks during their training and are found to be better at extracting a beat from visual stimuli compared to musicians (Su & Salazar-López, 2016). In addition, viewing dance movements has been found to enhance auditory meter perception in dancers suggesting visual-auditory entrainment abilities (Lee et al., 2015). Dancers are experts in tasks involving whole-body coordination in the presence of auditory cues. A study comparing dancer and non-dancer muscle contractions at the onset of salient metronome beats found that dancers had more accurate movements compared to non-dancers (Miura et al., 2013). Overall, dancers have exceptional whole-body sensorimotor entrainment and motor coordination, both dynamic properties that are thought to contribute to their superior visual-motor and auditory-motor entrainment abilities (Miura et al., 2011).

Study Rationale

Beat perception and production accuracy are positively impacted by music and dance training but negatively impacted by neurological changes in PD. Previous studies have used the BAT to assess rhythmic abilities in healthy and clinical groups (Cameron et al., 2016). We expect training to impact rhythmic abilities in healthy adults, but whether this advantage is altered in PD is unknown. In this study, the BAT will be used to measure beat perception and production abilities in the three participant groups: healthy younger adults, healthy older adults and people with early-stage PD across varying levels of music and dance training. We aim to assess how music and dance training influence rhythmic abilities across the lifespan and in the early-PD population. We hypothesize that music and dance training experience would correlate with more accurate beat perception and production abilities, while PD would negatively impact these abilities because of the neurological changes to the basal ganglia (Grahn & Brett, 2009). Based on previous research, we expect musicians and dancers to perform better on the BAT than non-musicians and non-dancers, respectively. Due to increased use of auditory-motor networks and the neuroplastic changes associated with musicians and dancers, we predict that PD patients with prior music or dance training would perform better on the BAT compared to patients without previous training. Results from the study will be crucial in understanding the combined impact of previous life experiences (e.g., music and dance training) and neurological changes (e.g., PD) on beat perception and production abilities.

Methods

Participants

278 healthy young adults (M = 20.41, SD = 3.01), 139 healthy older adults (M = 64.63, SD = 9.27) and 41 people with early-stage PD (M = 68.28, SD = 7.73) were recruited from a

variety of music and walking studies conducted in the Music & Neuroscience Lab. People with early-stage Parkinson's Disease (Hoehn & Yahr stages 2-3) were recruited from the community of Southwestern Ontario through community outreach and flyers. Because participants were recruited for a walking experiment, only participants who could walk independently (i.e., without a gait aid/support from another person), who do not experience regular freezing of gait, and who have been on a consistent medication for over four weeks were included. Given the exploratory nature of the study, PD patients were not excluded based on medication regiment, years since diagnosis, or having received deep brain stimulation. 6 participants who did not complete both beat perception and production tasks of the BAT and 11 participants who did not indicate the years of previous music and dance training experience were excluded from the analyses in this thesis. Participants of each group varied in level of music and dance training (Table 1). Years of music training were classified into two categories: 0-2 years and 3+ years and years of dance training were also classified into two categories: 0-5 years and 6+ years. These groupings were made to mitigate the varying sample sizes across participants with different degrees of music and dance training and to ensure each group had two decently sized samples. Only one PD patient indicated having dance training experience at all. Informed consent was obtained from all participants.

Table 1 Participant Demographics.

		Age	Music Training (years)		Dance Training (years)	
	N = 458	Years (SD)	0-2	3+	0-5	6+
Younger Adults	278	20.41 (3.01)	111	167	241	37
Older Adults	139	64.63 (9.27)	71	68	120	19
People with early-stage PD	41	68.28 (7.73)	25	16	40	1

Stimuli

Musical stimuli were taken from the Beat Alignment Test of the Goldsmiths Musical Sophistication Index v1.0 (Müllensiefen et al., 2014). Musical excerpts were selected from a variety of music genres and averaged 15.9s in duration (Appendix A). In the beat perception task, beeps were superimposed on the music excerpts 5 seconds into the music. The BAT was administered on a PC laptop using E-Prime (2.0) software (Psychology Software Tools, 2002). Auditory stimuli were delivered through Sennheiser HD 280 headphones. All participants completed both beat perception and production tasks in one session.

Beat Perception Task

Participants listened to a series of musical excerpts (3 practice trials, 17 test trials) with superimposed metronome beeps either on or off the musical beat. Off-beat excerpts could either result from beeps coming in too early or too late relative to the actual beat (phase error), or from beeps too fast or too slow relative to the tempo of the actual beats (period error). Participants listened to the excerpts passively and were tasked to identify whether the superimposed beeps were "on the beat" or not, without using body movement to assist the judgement. The trial order was randomized, and participants were asked to rate how confident they were of their judgment after each clip on a 7-point Likert scale.

Beat Production Task

Participants were presented with the same musical excerpts as the beat perception task with the superimposed beats removed. Each participant was instructed to synchronize their finger tapping as soon as they perceive the beat of the music. Each excerpt was presented twice consecutively. The extent to which participants matched their tapping to the actual beats was measured based on phase and tempo accuracy. The order of the musical excerpts was randomized, and participants were asked to rate their familiarity with each musical excerpt on a 7-point Likert scale.

Phase matching accuracy was represented by the asynchrony score (Equation 1), which measured the absolute difference between tap time and nearest beat position. The asynchrony score was obtained by taking the mean of the absolute difference between each tap and its nearest beat divided by the mean inter-beat interval (IBI). IBI was calculated by subtracting consecutive beat onsets. High asynchrony scores reflect high tapping phase error, indicating that participants tapped too early or too late relative to the actual beat. In contrast, low asynchrony scores reflected less variable and more consistent tap times. Asynchrony scores were averaged across the 17 trials to obtain an average asynchrony score for each participant.

$$asynchrony = \frac{mean_{|response-beat|}}{mean_{IBI}}$$

Equation 1.

Tempo matching accuracy was represented by the coefficient of deviation (CDEV) score (Equation 2), which measured the absolute deviation between inter-response interval (IRI) and inter-beat interval (IBI). The Inter-response interval was determined by subtracting tap onsets. In other words, the coefficient of deviation reflects the extent to which participant tapping tempo matched the actual beat tempo. CDEV scores were averaged across the 17 trials to obtain an average CDEV score for each participant.

$$CDEV = \frac{mean_{|IRI-IRB|}}{mean_{IBI}}$$

Equation 2.

Demographic Questionnaire

After the beat production and perception tasks, participants filled out a demographics questionnaire to describe their age and years of music and dance training experience (Appendix B). Due to using a convenient sample of participants that partook in different music and walking studies, healthy young and older adults were given section two of the Demographics Questionnaire (Appendix C) while PD patients were given the Goldsmith Musical Sophistication Index Questionnaire (Müllensiefen et al., 2014) (Appendix D).

Statistical Analyses

Beat perception was measured based on the percent of correct responses. Beat production was measured based on asynchrony and coefficient of deviation scores reflecting phase matching and tempo matching accuracy, respectively. 3 (healthy young adults, healthy older adults, PD patients) x 2 (0-2 years, 3+ years of music training) ANOVAs were conducted to investigate the effects of music training on beat perception and production abilities. Only one PD patient reported music training at all. For this reason, a separate 2 (healthy young adults, healthy older adults) x 2 (0-5 years, 6+ years of dance training) x 2 (0-2 years, 3+ years of music training) ANOVA was conducted to investigate the effects of dance training on beat perception and production in the healthy adult groups, excluding the PD group. Follow-up ANCOVAs using age, music training and participant groups as covariates were conducted to investigate the dance training effects. Main effects and interactions were confirmed by follow-up post-hoc pairwise comparisons using Tukey correction. Data were analyzed and visualized using JASP and R software.

Results

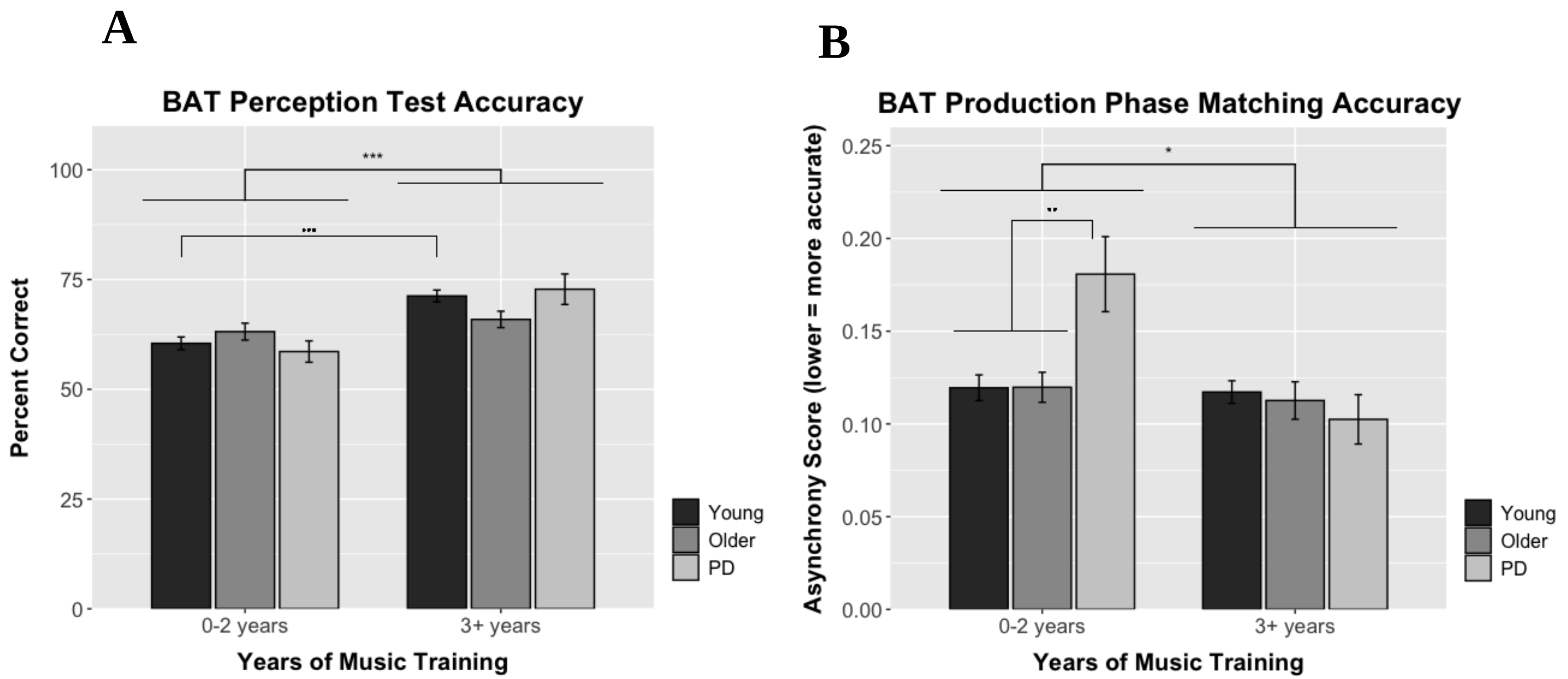
Beat Alignment Test Perception Scores

Participants with 0-2 years and 3+ years of music training averaged 61% (SD = 0.16) and 70% (SD = 0.17) correct responses, respectively. The 3 (group) x 2 (music training) ANOVA revealed a main effect of music training [$F(1, 457) = 20.42$, $p<.001$, $\eta p^2 = 0.043$], see Appendix E. Follow-up t-tests indicated that participants with 3+ years of music training, regardless of participant group, demonstrated more accurate beat perception compared to those with minimal (0-2 years) music training [$t(457) = -4.52$, $p < .001$]. Also, a music training x group interaction [$F(1, 457) = 3.49$, $p = <.05$, $\eta p^2 = 0.015$] was qualified by younger adults with 0-2 years of music training that differed significantly from younger adults with 3+ years of music training [$t(278) = -5.48$, $p<.001$], while 0-2 years and 3+ years of music training did not differ among older adults and PD patients (see Figure 1A). These significant results and large effect sizes suggest that increased music training experience is strongly associated with better beat perception abilities. However, this may only be the case for healthy young adults as they demonstrated greater accuracy with increased music training, but older adults and PD patients did not. Figure 1A may suggest a difference between PD patients with 3+ years of music training compared to PD patients with minimal music training. However, it is important to note that the smaller PD sample size (N=41) may contribute to more variability as reflected by the larger error bars. No main effect for dance training was noted ($p>.05$).

Beat Alignment Test Production Scores

Phase Matching. The 3 (group) x 2 (music training) ANOVA revealed a significant main effect of music training [$F(1, 457) = 8.86$, $p < .01$, $\eta p^2 = 0.019$] and a music training x group interaction effect [$F(1, 457) = 4.19$, $p<.05$, $\eta p^2 = 0.018$]. Follow-up t-tests indicated that PD patients with 0-2 years of music training have lower phase matching accuracy compared to PD patients with 3+ years of training [t(41) = 3.17, p<.05]. PD patients with 0-2 years of training also had lower phase matching accuracy compared to younger adults and older adults in both music training groups (see Appendix H for t-test statistics). Interestingly, PD patients with 3+ years of music training performed comparable to healthy adults, while PD patients with minimal training reflected significantly worse phase matching accuracy. These results indicate that music training positively impacted phase matching abilities in PD patients. The 2 (healthy adult groups) x 2 (music training) x 2 (dance training) ANOVA revealed no significant dance training effects among healthy young and older adults (Appendix F).

Tempo Matching. There were no significant effects in the 3 (group) x 2 (music training) ANOVA. The 2 (healthy adult groups) x 2 (music training) x 2 (dance training) ANOVA indicated a main effect of music training among healthy young and older adults [F(2, 409) = 4.19, p<.05, $\eta p^2 = 0.010$], see Appendix G. While this effect appeared in the 2 x 2 x 2 ANOVA, it was not consistent across analyses that included all participants, suggesting that it is perhaps a weaker effect that was not detectable in an analysis with more variability from PD patients. Figure 1C includes PD patients solely for visualization purposes, as the difference between healthy adults with 0-2 years and 3+ years of music training were from the 2 x 2 x 2 ANOVA which excluded them to examine dance training effects. Though figure 1C may suggest a difference between PD patients with 0-2 years compared to PD patients with 3+ years of music training, it is important to note that this difference did not reach statistical significance (p = .728) possibly due to the variability in the PD group as seen in the large error bars. No significant dance effects were observed (p>.05).


A
BAT Perception Test Accuracy
***
***
Percent Correct
100
75
50
25
0
0-2 years
3+ years
Years of Music Training
Young
Older
PD
B
BAT Production Phase Matching Accuracy
*
**
Asynchrony Score (lower = more accurate)
0.25
0.20
0.15
0.10
0.05
0.00
0-2 years
3+ years
Years of Music Training
Young
Older
PD

C

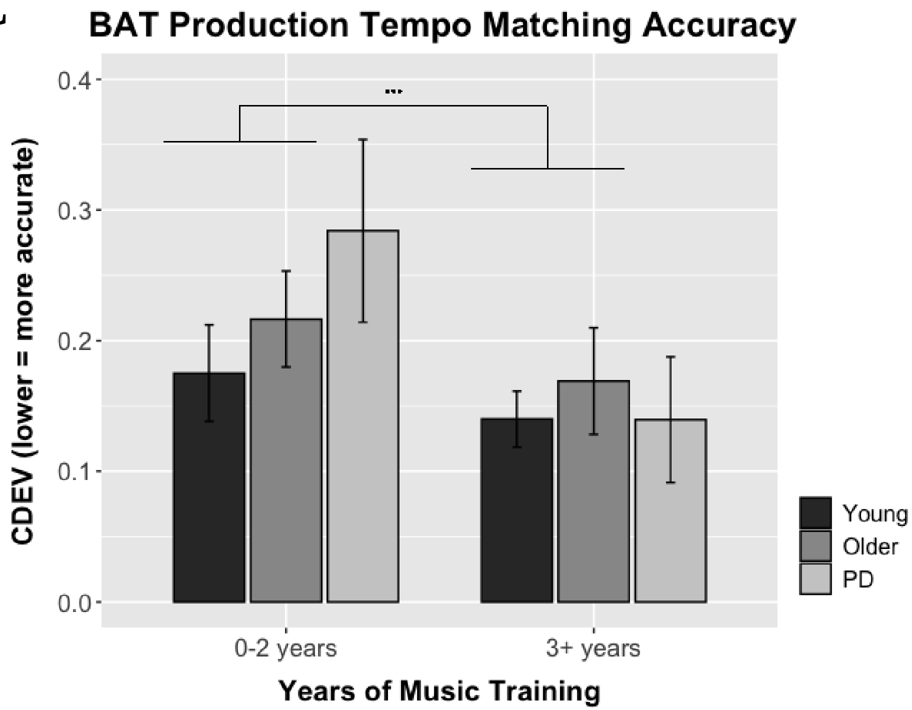


Figure 1 Music training effects based on years of training. Analyses of variance indicated a significant difference between 0-2 and 3+ years of music training for beat perception driven by young adults (A), beat production phase matching accuracy driven by PD patients with 0-2 years of music training (B) and beat production tempo matching accuracy across healthy young and older adults (C). Note: Figure C includes PD patients for visualization purposes only, results are from the 2x2x2 ANOVA which omitted them. CDEV = coefficient of deviation score. Error bars indicate the standard error of the mean. * = p <.05, ** = p<.01, ***= p<.001.

Discussion

This study examined the effects of music and dance training on beat perception and production abilities across the life span and in the context of PD. We predicted that music and dance training would positively impact beat perception and production skills, while the neurological deficits associated with PD would negatively impact these skills. We further predicted that some positive impacts of music and dance training would be preserved despite disease state and therefore expected effects of music training within PD patients. This study demonstrated that music training positively impacted beat perception abilities, but that this may be the case only among younger adults but not older adults (regardless of whether they have PD). This is evidenced by the interaction between music and group in which younger adults demonstrated greater accuracy with increased music training, but older adults and PD patients did not. This study also indicated that music training positively impacted beat production abilities. This is evidenced by more accurate phase and tempo matching abilities among participants (including those with PD) with 3+ years of music training compared to those with only minimal training experience. Furthermore, the interaction between music and group on phase matching accuracy demonstrated an interesting phenomenon that PD patients with 3+ years of music training performed comparable to healthy adults, while PD patients with minimal training reflected significantly worse phase matching accuracy. Tempo matching accuracy was greater among healthy adults with 3+ years of music training. However, with a smaller effect size, the significant effect was only detectable when healthy adults were analyzed independently (without PD patients). Interestingly, no dance training effects were found across the dependent variables.

Beat Perception

Contrary to our hypothesis, PD patients were not significantly impaired on the beat perception task. These results were consistent with Cameron et al.'s (2016) findings that beat perception using the BAT did not differ across PD and healthy control groups. However, Cameron et al. found that the rhythm discrimination task using metric simple and metric complex rhythms was more sensitive to timing perception deficits in PD. While both tasks measured beat perception abilities, beat perception in the discrimination task relied solely on temporal information, without the pitch and musical cues available in the BAT. The rhythm discrimination task also involved working memory to compare two similar rhythmic sequences presented consecutively. In contrast, the BAT relied on a comparison between simultaneous temporal sequences (musical stimuli and overlayed tones) and could be performed without attending to the stimuli for its entire duration. Furthermore, the BAT provided musical context (e.g., harmony, timber, pitches) that could make the underlying beat more apparent while the rhythm discrimination task relied solely on temporal perception without additional context cues. For these reasons, the different neural mechanisms required to perform the beat perception task in the BAT could be intact in PD but impaired on other beat perception tasks.

Young adults with 3+ years of music training demonstrated significantly better beat perception abilities compared to their counterparts with minimal music training; however, older adults and PD patients showed no differences based on music training. Though there is strong evidence that musicians have elevated beat processing abilities (Besson & Faïta, 1995; Repp, 2010; Repp & Doggett, 2007), this study revealed an intriguing effect of music training on only young adults that was not noted in previous literature. This effect of training on younger, but not older adult groups (regardless of PD diagnosis), may be driven by time-related effects as formal music training most often occurs during childhood and adolescent years. Perhaps, the effects of music training change as it becomes more distant.

We predicted that dance training would improve beat perception ability. Although dancers generally performed better on the beat perception test compared to non-dancers, these results did not reach significance. Similar results were found in a study examining beat perception and production abilities in musicians and dancers (Nguyen, 2017). We predicted that rhythm-intensive training such as through dance or music would improve beat perception skills. Surprisingly, only music training elicited positive effects on beat perception. We believe there may be other factors that imposed these differences between music and dance training. For example, the expertise of training was quantified by years of training in this study. Yet, the rigor of certain music or dance training programs could impose differences in quality of training and should be more carefully assessed in future studies.

Beat Production

We found that PD patients indeed performed worse on the beat production task compared to healthy adults, however, this appeared to be influenced by music training. PD patients with minimal music training exhibited lower phase matching accuracy as reflected by their increased asynchrony scores compared to healthy adults. Compromised motor performance associated with PD was expected. Therefore, decreased accuracy on the motor tasks overall may reflect nothing more than the characteristics of PD. These results were consistent with previous findings that PD patients, especially those without levodopa medication, demonstrated more variable self-paced tapping compared to healthy controls (O'Boyle et al., 1996). These results support that consistent motor timing behavior relies on the integrity of dopaminergic transmission in the basal ganglia, an area that is disrupted in PD (Grahn & Brett, 2007; Harrington et al., 1998). Interestingly, phase matching accuracy in PD patients with music training approximated that of healthy adults, but the performance of PD patients without training did not. This suggests that music training may, in some way, influence motor control during music tapping tasks. Though the literature on music training effects in the PD population is limited, these results were consistent with the trends seen in healthy adult populations (Cameron & Grahn, 2014; Repp & Doggett, 2007).

Contrary to previous findings that PD patients tapped either faster or slower on both synchronization and self-paced timing tasks (Jones & Jahanshahi, 2014), PD patients in this study did not demonstrate significantly different tapping tempos compared to healthy adults. Significant music training effects on tempo matching accuracy were observed in healthy adults. These results were consistent with the literature that musicians were able to detect tempo changes in rhythmic stimuli and maintain steady tapping tempo compared to non-musicians (Repp, 2010).

People with 0-5 years of dance training did not differ from those with 6+ years on beat production. These results contrast previous findings on rhythm entrainment through knee-bending (Miura et al., 2011). However, it is important to note that the beat production task was more geared towards musicians. For example, dancers are more accustomed to entraining temporal and visual events by fine-tuning their movements by observing other dancers (Jola et al., 2012). Furthermore, dancers use whole-body coordination to synchronize with music instead of effector-specific movements seen in musicians (Miura et al., 2013; Repp, 2010). For these reasons, the beat production task is more similar to music training compared to dance training. Future studies could investigate both auditory-motor and visual-motor entrainment to better understand the effects of dance training on motor entrainment skills.

Implications

PD-related motor symptoms are most commonly treated using pharmaceutical therapies, such as levodopa, MAO-B inhibitors and dopamine agonists (Müller, 2012). Yet, the PD population exhibits variable combinations and severity of symptoms, and each case of PD progresses uniquely (Sveinbjornsdottir, 2016). Medications help manage some motor symptoms but are not necessarily successful in improving symptoms related to gait, such as shuffling and freezing (Bloem et al., 2004). In addition, pharmaceutical interventions may not be sufficient in later disease stages as symptoms become increasingly severe (Xia & Mao, 2012). As a result, rehabilitative therapies such as rhythmic auditory stimulation (RAS) are often paired with pharmaceutical therapies to achieve more individualized and targeted treatments (Erra et al., 2019). These complementary therapies are non-invasive, cost-effective and easily individualized depending on motor abilities and goals. Studies have correlated increased rhythm processing abilities with better RAS outcomes in both healthy and PD populations (Cochen De Cock et al., 2018; Ready et al., 2019). The finding that music training may promote more accurate rhythm-based motor timing abilities informs the possibility that PD patients with these life experiences may be better candidates for music- and rhythm-based therapies. The BAT being sensitive to music training effects on beat perception and production could thus create an effective avenue in screening PD patients who would benefit from rhythm-based interventions by identifying those with more intact beat processing abilities.

Limitations

The current study employed a convenience sample of 458 participants across multiple studies conducted in the Music & Neuroscience Lab. This inevitably resulted in pre-existing music and dance training groupings. PD patients completed the Goldsmith Music Index

Sophistication questionnaire that grouped music training into categories, (e.g., 0, 1, 2, 3, 4-5, 6-9 years) whereas healthy adults completed a general music training survey that simply asked for the number of years in which they engaged in regular music practice. In consequence, music training in healthy adults was grouped similarly to that of PD patients to analyze the entire dataset. To account for unequal sample sizes in years of training during statistical analysis, music training categories were grouped once more to create two decently sized groups (e.g., 0-2 vs. 3+ years of music training). Not many participants reported dance training experience, so two sizable groups (0-5 vs. 6+ years) were created for statistical analysis purposes. Only one PD patient reported dance training at all, and thus, dance training effects could not be examined in PD patients. Null results found across the three participant groups on the beat perception task must be interpreted carefully and replicated in other sensorimotor entrainment tasks. In addition, most PD patients in the study were receiving dopaminergic medication. Previous work supports that beat perception and production abilities in PD improve after taking dopaminergic medication (Cameron et al., 2016; Jones & Jahanshahi, 2014). Therefore, it is possible that more significant group differences would be found in an off-medication paradigm and that these findings cannot be generalized to an off-medication state or to those who do not take dopaminergic medication. Finally, this study did not include a control task to ensure that group differences are attributed to sensorimotor entrainment abilities instead of general perceptual and other cognitive demands. Though most timing tasks cannot be matched with control tasks, this study carefully screened PD patients for cognitive impairments and psychiatric comorbidities (e.g., depression and anxiety) that could potentially impact task performance.

Future Directions

The current study sheds light on the possible benefits of music training in preserving sensorimotor entrainment abilities in PD. Future studies could combine imaging techniques with appropriate behavioral tests to better understand beat perception and production processes among PD patients with varying degrees of music and dance training. Findings in this study indicated that increased music training was associated with more accurate motor timing abilities through finger tapping. Whether music training promotes more accurate motor timing behaviors in other motor modalities is not yet studied. Future studies could examine whether the positive effects of music training on beat production extend to other motor modalities (e.g., gait) to develop more effective rhythm-based therapies for movement disorders. Lastly, the current study examined beat perception and production abilities in early-stage PD patients. Whether the positive effects of music training persist into later stages of PD is unknown. Future studies could examine later-stage PD patients with previous music and dance training to better understand the sensorimotor networks that may be preserved or more easily recruited during rhythm-based tasks.

Conclusion

The study used the BAT to examine beat perception and production abilities in Parkinson's Disease patients, healthy young and healthy older adults, across varying levels of music and dance training. Our findings indicate significantly better beat perception and production skills among musicians with 3+ years of training. PD patients demonstrated less accurate motor timing abilities on the beat production subtest overall. However, PD patients with 3+ years of music training exhibited more preserved beat perception and production skills compared to PD patients with minimal training. These results contribute to the growing knowledge of the long-term effects of music training, as well as the new-found knowledge that life experiences such as music training may preserve certain motor timing functions related to beat processing in early-stage PD.

References

Aschersleben, G., & Prinz, W. (1995). Synchronizing actions with events: The role ofsensory information. *Perception & Psychophysics*, *57*(3), 305–317.

Bégel, V., Benoit, C. E., Correa, A., Cutanda, D., Kotz, S. A., & Dalla Bella, S. (2017). "Lost in time" but still moving to the beat. *Neuropsychologia*, *94*(November 2016), 129–138. https://doi.org/10.1016/j.neuropsychologia.2016.11.022

Besson, M., & Faïta, F. (1995). An Event-Related Potential (ERP) Study of Musical Expectancy: Comparison of Musicians With Nonmusicians. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(6), 1278–1296. https://doi.org/10.1037/0096-1523.21.6.1278

Bloem, B. R., Hausdorff, J. M., Visser, J. E., & Giladi, N. (2004). Falls and freezing of Gait in Parkinson's disease: A review of two interconnected, episodic phenomena. *Movement Disorders*, *19*(8), 871–884. https://doi.org/10.1002/mds.20115

Cameron, D. J., & Grahn, J. A. (2014). Enhanced timing abilities in percussionists generalize to rhythms without a musical beat. *Frontiers in Human Neuroscience*, *8*(DEC), 1–10. https://doi.org/10.3389/fnhum.2014.01003

Cameron, D. J., Pickett, K. A., Earhart, G. M., & Grahn, J. A. (2016). The effect of dopaminergic medication on beat-based auditory timing in Parkinson's disease. *Frontiers in Neurology*, *7*(FEB), 1–8. https://doi.org/10.3389/fneur.2016.00019

Cochen De Cock, V., Dotov, D. G., Ihalainen, P., Bégel, V., Galtier, F., Lebrun, C., … Dalla Bella, S. (2018). Rhythmic abilities and musical training in Parkinson's disease: do they help? *Npj Parkinson's Disease*, *4*(1), 1–8. https://doi.org/10.1038/s41531-018-0043-7

Dalla Bella, S., & Sowiński, J. (2015). Uncovering beat deafness: Detecting rhythm disorders with synchronized finger tapping and perceptual timing tasks. *Journal of Visualized Experiments*, *2015*(97), 1–11. https://doi.org/10.3791/51761

Dauvergne, C., Bégel, V., Gény, C., Puyjarinet, F., Laffont, I., & Dalla Bella, S. (2018). Home-based training of rhythmic skills with a serious game in Parkinson's disease: Usability and acceptability. *Annals of Physical and Rehabilitation Medicine*, *61*(6), 380–385. https://doi.org/10.1016/j.rehab.2018.08.002

Dhillon, G. S., Krüger, T. B., Sandhu, J. S., & Horch, K. W. (2005). Effects of short-term training on sensory and motor function in severed nerves of long-term human amputees. *Journal of Neurophysiology*, *93*(5), 2625–2633. https://doi.org/10.1152/jn.00937.2004

Diener, H. C., Hore, J., Ivry, R., & Dichgans, J. (1993). Cerebellar Dysfunction of Movement and Perception. *Canadian Journal of Neurological Sciences / Journal Canadien Des Sciences Neurologiques*, *20*(S3), S62–S69. https://doi.org/10.1017/s031716710004854x

Erra, C., Mileti, I., Germanotta, M., Petracca, M., Imbimbo, I., De Biase, A., … Padua, L. (2019). Immediate effects of rhythmic auditory stimulation on gait kinematics in Parkinson's disease ON/OFF medication. *Clinical Neurophysiology*, *130*(10), 1789–1797. https://doi.org/10.1016/j.clinph.2019.07.013

Grahn, J. A. (2012). Neural Mechanisms of Rhythm Perception: Current Findings and Future Perspectives. *Topics in Cognitive Science*, *4*(4), 585–606. https://doi.org/10.1111/j.1756-8765.2012.01213.x

Grahn, J. A., & Brett, M. (2007). Rythm in Motor Areas of the Brain. *Journal of Cognitive Neuroscience*, *19*(5), 893–906.

Grahn, J. A., & Brett, M. (2009). Impairment of beat-based rhythm discrimination in Parkinson's disease. *Cortex*, *45*(1), 54–61. https://doi.org/10.1016/j.cortex.2008.01.005

Harrington, D. L., Haaland, K. Y., & Hermanowicz, N. (1998). Temporal processing in the basal ganglia. *Neuropsychology*, *12*(1), 3–12. https://doi.org/10.1037/0894-4105.12.1.3

Haueisen, J., & Knösche, T. R. (2001). Involuntary motor activity in pianists evoked by music perception. *Journal of Cognitive Neuroscience*, *13*(6), 786–792. https://doi.org/10.1162/08989290152541449

Ivry, R. B. (1996). The representation of temporal information in perception and motor control. *Current Opinion in Neurobiology*, *6*(6), 851–857. https://doi.org/10.1016/S0959-4388(96)80037-7

Jola, C., Abedian-Amiri, A., Kuppuswamy, A., Pollick, F. E., & Grosbras, M. H. (2012). Motor simulation without motor expertise: Enhanced corticospinal excitability in visually experienced dance spectators. *PLoS ONE*, *7*(3). https://doi.org/10.1371/journal.pone.0033343

Jones, C. R. G., & Jahanshahi, M. (2014). Motor and Perceptual Timing in Parkinson's Disease. In *Advances in Experimental Medicine and Biology* (Vol. 829, pp. 265–290). https://doi.org/10.1007/978-1-4939-1782-2_14

Karpati, F. J., Giacosa, C., Foster, N. E. V., Penhune, V. B., & Hyde, K. L. (2015). Dance and the brain: A review. *Annals of the New York Academy of Sciences*, *1337*(1), 140–146. https://doi.org/10.1111/nyas.12632

Lee, K. M., Barrett, K. C., Kim, Y., Lim, Y., & Lee, K. (2015). Dance and music in "gangnam style": How dance observation affects meter perception. *PLoS ONE*, *10*(8), 1–19. https://doi.org/10.1371/journal.pone.0134725

Leow, L. A., Waclawik, K., & Grahn, J. A. (2018). The role of attention and intention in synchronization to music: effects on gait. *Experimental Brain Research*, *236*(1), 99–115.

https://doi.org/10.1007/s00221-017-5110-5

Matthews, T. E., Thibodeau, J. N. L., Gunther, B. P., & Penhune, V. B. (2016). The Impact of Instrument-Specific Musical Training on Rhythm Perception and Production. *Frontiers in Psychology*, *7*(February), 1–16. https://doi.org/10.3389/fpsyg.2016.00069

McIntosh, G. C., Brown, S. H., Rice, R. R., & Thaut, M. H. (1997). Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, *62*(1), 22–26. https://doi.org/10.1136/jnnp.62.1.22

Miura, A., Kudo, K., Ohtsuki, T., & Kanehisa, H. (2011). Coordination modes in sensorimotor synchronization of whole-body movement: A study of street dancers and non-dancers. *Human Movement Science*, *30*(6), 1260–1271. https://doi.org/10.1016/j.humov.2010.08.006

Miura, A., Kudo, K., Ohtsuki, T., Kanehisa, H., & Nakazawa, K. (2013). Relationship between muscle cocontraction and proficiency in whole-body sensorimotor synchronization: A comparison study of street dancers and nondancers. *Motor Control*, *17*(1), 18–33. https://doi.org/10.1123/mcj.17.1.18

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The Musicality of Non-Musicians: An Index for Assessing Musical Sophistication in the General Population. *PLoS ONE*, *9*(2), e89642. https://doi.org/10.1371/journal.pone.0089642

Müller, T. (2012). Drug therapy in patients with Parkinson's disease. *Translational Neurodegeneration*, *1*(1), 10. https://doi.org/10.1186/2047-9158-1-10

Nozaradan, S., Peretz, I., Missal, M., & Mouraux, A. (2011). Tagging the neuronal entrainment to beat and meter. *Journal of Neuroscience*, *31*(28), 10234–10240. https://doi.org/10.1523/JNEUROSCI.0411-11.2011

O'Boyle, D. J., Freeman, J. S., & Cody, F. W. J. (1996). The accuracy and precision of timing of self-paced, repetitive movements in subjects with Parkinson's disease. *Brain*, *119*(1), 51–70. https://doi.org/10.1093/brain/119.1.51

Palmer, C., Lidji, P., & Peretz, I. (2014). Losing the beat: deficits in temporal coordination. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1658), 20130405. https://doi.org/10.1098/rstb.2013.0405

Palomar-García, M. Á., Zatorre, R. J., Ventura-Campos, N., Bueichekú, E., & Ávila, C. (2017). Modulation of Functional Connectivity in Auditory-Motor Networks in Musicians Compared with Nonmusicians. *Cerebral Cortex*, *27*(5), 2768–2778. https://doi.org/10.1093/cercor/bhw120

Patterson, K. K., Wong, J. S., Knorr, S., & Grahn, J. A. (2018). Rhythm Perception and Production Abilities and Their Relationship to Gait After Stroke. *Archives of Physical Medicine and Rehabilitation*. https://doi.org/10.1016/j.apmr.2018.01.009

Puyjarinet, F., Bégel, V., Gény, C., Driss, V., Cuartero, M. C., Kotz, S. A., … Dalla Bella, S. (2019). Heightened orofacial, manual, and gait variability in Parkinson's disease results from a general rhythmic impairment. *Npj Parkinson's Disease*, *5*(1), 1–7. https://doi.org/10.1038/s41531-019-0092-6

Rammsayer, T. H. (1999). Neuropharmacological evidence for different timing mechanisms in humans. *The Quarterly Journal of Experimental Psychology. B, Comparative and Physiological Psychology*, *52*(3), 273–286. https://doi.org/10.1080/713932708

Ready, E. A., McGarry, L. M., Rinchon, C., Holmes, J. D., & Grahn, J. A. (2019). Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait and Posture*, *68*(June 2018), 555–561. https://doi.org/10.1016/j.gaitpost.2018.12.038

Repp, B. H. (2010). Sensorimotor synchronization and perception of timing: Effects of music training and task experience. *Human Movement Science*, *29*(2), 200–213. https://doi.org/10.1016/j.humov.2009.08.002

Repp, B. H., & Doggett, R. (2007). Tapping to a Very Slow Beat: A Comparison of Musicians and Nonmusicians. *Music Perception*, *24*(4), 367–376. https://doi.org/10.1525/mp.2007.24.4.367

Schneider, P., Scherg, M., Dosch, H. G., Specht, H. J., Gutschalk, A., & Rupp, A. (2002). Morphology of Heschl's gyrus reflects enhanced activation in the auditory cortex of musicians. *Nature Neuroscience*, *5*(7), 688–694. https://doi.org/10.1038/nn871

Schubotz, R. I., Friederici, A. D., & Yves Von Cramon, D. (2000). Time perception and motor timing: A common cortical and subcortical basis revealed by fMRI. *NeuroImage*, *11*(1), 1–12. https://doi.org/10.1006/nimg.1999.0514

Steele, C. J., Bailey, J. A., Zatorre, R. J., & Penhune, V. B. (2013). Early musical training and white-matter plasticity in the corpus callosum: Evidence for a sensitive period. *Journal of Neuroscience*, *33*(3), 1282–1290. https://doi.org/10.1523/JNEUROSCI.3578-12.2013

Su, Y. H., & Salazar-López, E. (2016). Visual Timing of Structured Dance Movements Resembles Auditory Rhythm Perception. *Neural Plasticity*, *2016*. https://doi.org/10.1155/2016/1678390

Sveinbjornsdottir, S. (2016). The clinical symptoms of Parkinson's disease. *Journal of Neurochemistry*, *139*, 318–324. https://doi.org/10.1111/jnc.13691

Teki, S., Grube, M., Kumar, S., & Griffiths, T. D. (2011). Distinct neural substrates of duration-based and beat-based auditory timing. *Journal of Neuroscience*, *31*(10), 3805–3812. https://doi.org/10.1523/JNEUROSCI.5561-10.2011

Thaut, M. H., McIntosh, G. C., Rice, R. R., Miller, R. A., Rathbun, J., & Brault, J. M. (1996). Rhythmic auditory stimulation in gait training for Parkinson's disease patients. *Movement Disorders*, *11*(2), 193–200. https://doi.org/10.1002/mds.870110213

Thaut, Michael H., Demartin, M., & Sanes, J. N. (2008). Brain networks for integrative rhythm formation. *PLoS ONE*, *3*(5), 1–10. https://doi.org/10.1371/journal.pone.0002312

Thaut, Michael H., McIntosh, G. C., & Hoemberg, V. (2015). Neurobiological foundations of neurologic music therapy: rhythmic entrainment and the motor system. *Frontiers in Psychology*, *5*(February), 1–6. https://doi.org/10.3389/fpsyg.2014.01185

Thaut, Michael H., Miller, R. A., & Schauer, L. M. (1998). Multiple synchronization strategies in rhythmic sensorimotor tasks: Phase vs period correction. *Biological Cybernetics*, *79*(3), 241–250. https://doi.org/10.1007/s004220050474

Tranchant, P., Vuvan, D. T., & Peretz, I. (2016). Keeping the beat: A large sample study of bouncing and clapping to music. *PLoS ONE*, *11*(7), 1–19. https://doi.org/10.1371/journal.pone.0160178

Wan, C. Y., & Schlaug, G. (2010). Making music as a tool for brain plasticity. *Neuroscientist*, *16*(5), 566–577. https://doi.org/10.1177/1073858410377805.Music

Washburn, A., DeMarco, M., de Vries, S., Ariyabuddhiphongs, K., Schmidt, R. C., Richardson, M. J., & Riley, M. A. (2014). Dancers entrain more effectively than non-dancers to another actorâ€™s movements. *Frontiers in Human Neuroscience*, *8*(OCT), 800. https://doi.org/10.3389/fnhum.2014.00800

Will, U., & Berg, E. (2007). Brain wave synchronization and entrainment to periodic acoustic stimuli. *Neuroscience Letters*, *424*(1), 55–60. https://doi.org/10.1016/j.neulet.2007.07.036

Xia, R., & Mao, Z. H. (2012). Progression of motor symptoms in Parkinson's disease.

Neuroscience Bulletin, *28*(1), 39–48. https://doi.org/10.1007/s12264-012-1050-z

Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007a). When the brain plays music: Auditory-motor interactions in music perception and production. *Nature Reviews Neuroscience*, *8*(7), 547–558. https://doi.org/10.1038/nrn2152

Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007b, July). When the brain plays music: Auditory-motor interactions in music perception and production. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn2152

Appendix A: BAT Stimuli

	Style		Artist	Link to original song file
1	Jazz	Crazy	Tim Garland	https://www.audionetwork.com/browse/m/track/crazy_5197
2	Pop, Orchestral	Freedom of the City	Ray Davies	https://www.audionetwork.com/browse/m/track/freedom-of-the-city_35540
3	Jazz	Four Handed Hedgehog	Chris Egan	https://www.audionetwork.com/browse/m/track/four-handed-hedgehog_33902
4	Pop, Orchestral	For King and Country	Terry Devine-King	https://www.audionetwork.com/browse/m/track/for-king-and-country_29632
5	Pop, Orchestral	Lord Arbinger Waltz	Debbie Wiseman	https://www.audionetwork.com/browse/m/track/lord-abinger-waltz_19351
6	Rock	Prime Rib	Adam Drake/Neil Williams	https://www.audionetwork.com/browse/m/track/prime-rib_15643
7	Rock	Psychedelic Space	Igor Dvorkin/ Duncan Pittock	https://www.audionetwork.com/browse/m/track/psychedelic-space_9831
8	Jazz	Sassy Stomp	Terry Devine-King	https://www.audionetwork.com/browse/m/track/sassy-stomp_26241
9	Rock	Switchblade	Barrie Gledden	https://www.audionetwork.com/browse/m/track/switchblade-2_14006
10	Pop, Orchestral	One Jump Ahead	Ray Davies	https://www.audionetwork.com/browse/m/track/one-jump-ahead_35559
11	Jazz	Roaring Twenties	Terry Devine-King	https://www.audionetwork.com/browse/m/track/roaring-twenties_26259
12	Rock	Never Going Back Again	Chris Norton	https://www.audionetwork.com/browse/m/track/never-going-back-again_17255

Appendix B: Demographic Questionnaire (Section one of the demographic questionnaire provided to all participants)

Start of Block: Default Question Block

Q1 FOR THE EXPERIMENTER: Enter the study participant number (e.g., FREE-001).

____

Q2 What is your gender?

- ○ Male (1)
- ○ Female (2)
- ○ Other (3)

Q3 What is your age?

____

Q4 Do you take any psychotropic drugs, either recreationally or medicinally?

Psychotropic drugs: ones that can alter chemical levels in the brain which impact mood and behavior (e.g., marijuana, anti-depressants, muscle relaxants)

○ Yes (1)

○ No (2)

Q5 If yes, please describe:

____

Q6 Do you have any psychiatric or neurological conditions?

○ Yes (1)

○ No (2)

Q7 If yes, please describe:

____

Q8 How many years of education do you have (starting at Grade 1 and including any higher education)?

____

Q9 What is your dominant hand?

○ Right (1)

○ Left (2)

○ Ambidextrous (3)

Q10 Do you have normal hearing?

○ Yes (1)

○ No (2)

Q11 If you indicated that you do not have normal hearing, please elaborate:

____

Q12 Have you experienced any difficulties walking in the past year?

○ Yes (1)

○ No (2)

Q13 If you indicated yes to the question above, please elaborate:

____

Page Break

Q14 You have completed the first part of the survey. Please DO NOT continue to the next part of the survey OR close this window.

You may inform the experimenter that you're ready to continue with the rest of the study.

Appendix C: Demographic Questionnaire (section two of the demographic questionnaire regarding music and dance training experience, completed by healthy young and older adults)

Q15 Do you have any formal music training (for either voice or an instrument)?

○ Yes (1)

○ No (2)

Q15 Do you have any formal music training (for either voice or an instrument)?

○ Yes (1)

○ No (2)

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q16 Which instrument(s)?

____

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q19 What type of training did you received?

- ☐ School/Band/Choir (1)
- ☐ Private Lessons (2)
- ☐ Church (3)
- ☐ Friends/Family (4)
- ☐ Self Taught (5)
- ☐ Other (6)

Display This Question:

If What type of training did you received? = Other

Q20 You indicated "Other" - Please describe your training

____

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q21 When was the last time you played?

____

Q25 Please list the age at which you started each style and the age you stopped (if you no longer dance).

____

Display This Question:

If Do you have any formal dance training? = Yes

Q26 Please list the number of years of training you have for each style.

____

Display This Question:

If Do you have any formal dance training? = Yes

Q17 Please list the age you starting playing each instrument (or singing) and the age you stopped playing (if you no longer play)

____

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q18 Please list the number of years of training you have for each instrument you listed.

____

____

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q22 Do you identify as a musician?

○ Yes (1)

○ No (2)

Page Break

Q23 Do you have any formal dance training?

○ Yes (1)

○ No (2)

Display This Question:

If Do you have any formal dance training? = Yes

Q24 What style(s) of dance?

____

Q27 What type of training did you receive?

▢ School (1)

▢ Private/Group lessons (2)

▢ Friends/Family (3)

▢ Self-Taught (4)

▢ Other (5)

Display This Question:

If What type of training did you receive? = Other

Q28 You indicated "other" - please describe your training.

____

Display This Question:

If Do you have any formal dance training? = Yes

Q29 When was the last time you danced?

____

Appendix D: Goldsmith Music Sophistication Index music training subscale (completed by PD patients)

Please circle the most appropriate category:

Please circle the most appropriate category:	1 Completely Disagree	2 Strongly Disagree	3 Disagree	4 Neither Agree nor Disagree	5 Agree	6 Strongly Agree	7 Completely Agree
1. I have never been complimented for my talents as a musical performer.	1	2	3	4	5	6	7
2. I would not consider myself a musician.	1	2	3	4	5	6	7

3. I engaged in regular, daily practice of a musical instrument (including voice) for 0 / 1 / 2 / 3 / 4-5 / 6-9 / 10 or more years.
4. At the peak of my interest, I practiced 0 / 0.5 / 1 / 1.5 / 2 / 3-4 / 5 or more hours per day on my primary instrument.
5. I have had formal training in music theory for 0 / 0.5 / 1 / 2 / 3 / 4-6 / 7 or more years.
6. I have had 0 / 0.5 / 1 / 2 / 3-5 / 6-9 / 10 or more years of formal training on a musical instrument (including voice) during my lifetime.
7. I can play 0 / 1 / 2 / 3 / 4 / 5 / 6 or more musical instruments.

Appendix E: 3 x 2 ANOVA results

Results from original 3x2 ANOVAs with group (healthy young adults, healthy older adults, PD patients) and music training (0-2, 3+ years).

	Perception Test Percent Correct				Asynchrony				Coefficient of Deviation (CDEV)			
Effect	F-value	p-value	ηp^2	p<.05	F-value	p-value	ηp^2	p<.05	F-value	p-value	ηp^2	p<.05
music	20.422	< .001	0.043	***	8.86	0.003	0.019	**	3.384	0.067	0.007	
group	0.322	0.725	0.001		1.762	0.173	0.007		0.848	0.429	0.004	
music*group	3.486	0.031	0.015	*	4.187	0.016	0.018	*	0.489	0.613	0.002	

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

Appendix F: 2 x 2 x 2 ANOVA results

Results from 2x2x2 ANOVA with group (healthy young adults, healthy older adults), music training (0-2, 3+ years), and dance training (0-5, 6+ years).

	Perception Test Percent Correct				Asynchrony				Coefficient of Deviation (CDEV)			
Effect	F-value	p-value	ηp^2	p<.05	F-value	p-value	ηp^2	p<.05	F-value	p-value	ηp^2	p<.05
music	7.161	0.008	0.017	**	0.552	0.458	0.001		4.188	0.041	0.010	*
dance	1.447	0.230	0.003		0.002	0.968	0.000		0.195	0.659	0.000	
group	0.029	0.865	0.000		0.379	0.538	0.000		0.390	0.533	0.000	
music*dance	0.000	0.981	0.000		0.205	0.651	0.000		2.520	0.113	0.006	
music*group	2.949	0.087	0.007		0.758	0.384	0.002		0.587	0.444	0.001	
dance*group	0.249	0.618	0.000		0.320	0.572	0.000		3.048	0.082	0.007	
music*dance*group	0.063	0.802	0.000		0.827	0.364	0.002		1.418	0.234	0.003	

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

Appendix G: 3 x 2 ANOVA Post-Hoc Comparisons for BAT Perception Test

Years of music training, group	Years of music training, group	Mean Difference	SE	t	p_{Tukey}	p<.05
0-2 years, Older	3+ years, Older	-0.028	0.027	-1.021	0.911	
	0-2 years, PD	0.045	0.037	1.215	0.829	
	3+ years, PD	-0.097	0.044	-2.172	0.253	
	0-2 years, Young	0.027	0.024	1.091	0.885	
	3+ years, Young	-0.081	0.023	-3.568	0.005	**
3+ years, Older	0-2 years, PD	0.073	0.038	1.949	0.374	
	3+ years, PD	-0.069	0.045	-1.54	0.639	
	0-2 years, Young	0.055	0.025	2.202	0.239	
	3+ years, Young	-0.053	0.023	-2.31	0.192	
0-2 years, PD	3+ years, PD	-0.142	0.051	-2.761	0.066	
	0-2 years, Young	-0.019	0.036	-0.528	0.995	
	3+ years, Young	-0.127	0.034	-3.675	0.004	**
3+ years, PD	0-2 years, Young	0.123	0.043	2.868	0.049	*
	3+ years, Young	0.015	0.042	0.365	0.999	
0-2 years, Young	3+ years, Young	-0.108	0.02	-5.482	< .001	***

Note. P-value adjusted for comparing a family of 6
* p < .05, ** p < .01, *** p < .001

Appendix H: 3 x 2 ANOVA Post-Hoc Comparisons for BAT Production Phase Matching Accuracy

Years of music training, group	Years of music training, group	Mean Difference	SE	t	p_{Tukey}	p<.05
0-2 years, Older	3+ years, Older	0.007	0.013	0.546	0.994	
	0-2 years, PD	-0.061	0.018	-3.403	0.009	**
	3+ years, PD	0.017	0.021	0.812	0.965	
	0-2 years, Young	0	0.012	0.023	1	
	3+ years, Young	0.003	0.011	0.235	1	
3+ years, Older	0-2 years, PD	-0.068	0.018	-3.78	0.002	**
	3+ years, PD	0.01	0.021	0.475	0.997	
	0-2 years, Young	-0.007	0.012	-0.579	0.992	
	3+ years, Young	-0.005	0.011	-0.413	0.998	
0-2 years, PD	3+ years, PD	0.078	0.025	3.173	0.02	*
	0-2 years, Young	0.061	0.017	3.591	0.005	**
	3+ years, Young	0.064	0.017	3.846	0.002	**
3+ years, PD	0-2 years, Young	-0.017	0.021	-0.827	0.963	
	3+ years, Young	-0.015	0.02	-0.731	0.978	
0-2 years, Young	3+ years, Young	0.002	0.009	0.243	1	

Note. P-value adjusted for comparing a family of 6
* $p < .05$, ** $p < .01$, *** $p < .001$