Dance experience predicts improvement from movement therapy in Parkinson's disease

by

Anna Allene Krotinger
Class of 2019

A thesis submitted to the faculty of Wesleyan University in partial fulfillment of the requirements for the Degree of Bachelor of Arts with Departmental Honors in the Neuroscience and Behavior Program

Middletown, Connecticut April, 2019
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ABSTRACT

Parkinson’s disease (PD) is associated with a loss of internal cueing systems, affecting rhythmic motor tasks such as walking. To address this deficit, researchers have pursued methods of supplementing rhythmic cueing in patients with PD. Rhythmic auditory stimulation has been shown to improve motor deficits in some individuals; these findings have inspired the development of dance programs for PD. In further investigating the effects of music and auditory stimulation on movement, it has been shown that musical groove is related to ease of sensorimotor coupling in a simple tapping task. We were curious to see how PD individuals attending weekly dance classes respond to differing levels of musical groove. Additionally, while PD symptoms have been shown to improve from dance therapy, it is unknown whether these effects are modulated by groove and sensorimotor experience, and if previous experience with music and dance affect these relationships.

We assessed tapping to high- and low-groove songs, music and dance experience, and disease severity using the Unified Parkinson’s Disease Rating Scale (UPDRS) in PD individuals before and after four months of weekly dance classes. We tested the hypothesis that groove and sensorimotor experience, as quantified by music and dance experience, affect the therapeutic outcome of dance classes for PD. We found associations between dance experience, sensorimotor coupling ability, and improvement in disease severity from baseline to four months. The presence of dance experience (>1 year of training) resulted in enhanced sensorimotor coupling ability during tapping to both high [F(1,118)=18.6, p<0.001***] and low [F(1,118)=5.98, p=0.016*] groove songs. Variability in tapping performance was negatively
correlated with improvement in UPDRS scores from baseline to 4 months for high 
(r=-0.465, p< 0.001***) and low (r=-0.585, p<0.001***) groove songs, indicating 
that more accurate sensorimotor coupling was associated with greater UPDRS 
improvements. Furthermore, participants with dance experience also exhibited greater 
improvements in UPDRS scores [F(1,94)=73.4, p<0.001**]. These data suggest that 
dance experience predicts rhythmic movement consistency and may contribute to 
motor improvement following a dance intervention. Together, our findings suggest 
that dance and sensorimotor experience act as predictors of the therapeutic outcome 
of four months of dance classes for PD.
1. INTRODUCTION

1.1 Overview of Clinical Question

Arts therapy is becoming an increasingly popular practice in the medical and nursing fields. While pharmaceutical interventions often reliably treat physical disease symptoms, they may not address other important aspects of health such as quality of life and mood. The use of the arts in a therapeutic setting has been most commonly implemented in the treatment of psychological illnesses such as post-traumatic stress disorder (Baker et al., 2018) and depression (Dunphy et al., 2018). These creative arts therapy programs have been shown to benefit mood, cognition, confidence, and sleep (Wilson et al., 2016). Healthcare providers have also reported both physical and social benefits such as increases in strength and socialization in patients (Dunphy et al., 2018).

The use of the arts as therapy has now extended beyond the realm of psychological disorders and has been tested for diseases such as cerebral palsy (Lopez-Ortiz et al., 2018), Alzheimer’s disease (Fang et al., 2017), dementia (Karkou and Meekums, 2017), and Parkinson’s disease (Sharp and Hewitt, 2014; Hashimoto et al., 2015; Ghai et al., 2018).

Movement therapy has become a particular point of interest in the management of Parkinson’s disease (PD), as motor impairment is central to PD symptomology. PD is also associated with a loss of internal cueing systems which affects rhythmic motor tasks such as walking and the processing of musical rhythm (Grahn, 2009). To address this deficit, researchers have pursued methods of supplementing rhythmic cueing in patients with PD. Rhythmic auditory stimulation
(RAS) has been shown to improve motor symptoms in some patients (Bella et al., 2017). These results have inspired the development of dance programs (Hackney and Earhart, 2009; Rehfeld et al., 2018) in hopes that the combination of musical auditory cues and choreographic visual cues may help PD individuals regain some motor control.

One such program is Dance for PD®. Founded in 2010 in Brooklyn, New York by members of the Mark Morris Dance Group, Dance for PD® now holds classes in over 250 locations around the world. These classes aim to provide a social and creative outlet for PD individuals to explore movement in a supportive environment. Promisingly, dance has been shown to benefit the symptoms of PD primarily by improving gait and balance (Sharp and Hewitt, 2014; de Natale et al., 2017; Hulbert et al., 2017).

The underlying biological mechanisms supporting these benefits are likely related to the effects of music on movement. Research shows that musical groove (discussed in 1.3.4) is related to ease of sensorimotor coupling in a simple tapping task (Janata et al., 2012). These results were observed in a non-PD population, so questions remain about the effects of musical groove on movement in PD individuals. Additionally, while PD symptoms have been shown to improve from dance classes, it is unknown whether these effects are modulated by groove and sensorimotor experience, and if previous experience with music and dance affect these relationships. The current study aims to investigate the relationship between the effects of attending weekly Dance for PD® classes and groove, sensorimotor experience, and experience with music and dance.
In this introduction, I will discuss the symptoms, pathology, and available treatments for Parkinson’s disease. I will then review research on rhythm perception, production, and musical groove, followed by a discussion of existing literature on the neurological effects of dance and the impact of dance on PD. I will close the introduction by returning to the aims of the current study.

1.2 Parkinson’s Disease Overview

1.2.1 Disease Summary

Parkinson’s disease is the most common movement disorder and the second-most common neurodegenerative disease following Alzheimer’s (Oertel and Schulz, 2016). PD typically affects people over the age of 65, though there are early-onset and familial forms of the disease that present before then. Most cases of PD are sporadic; only about 5-10% of cases are heritable (Poewe et al., 2017). The incidence of Parkinson’s disease ranges from 5 to around 30 new cases per 100,000 people per year (Poewe et al., 2017), and the disease has been found to be about twice as common in men than in women (Baldereschi et al., 2000).

PD primarily affects the dopaminergic neurons of the substantia nigra (SN), a midbrain structure implicated in motor, motivation, and reward circuits. This results in a decrease of available dopamine and causes both motor and non-motor symptoms. The second pathological hallmark of the disease is the accumulation of the intracellular protein α-synuclein (Poewe et al., 2017).

The characteristic symptoms of PD are tremor, bradykinesia, and akinesia or rigidity (Oertel and Schulz, 2016; Poewe et al., 2017). Variability in symptom
presentation is great, as each patient may experience slightly different symptomology. Other motor symptoms associated with PD include festination, shuffling, flat affect, and compromised speech capacity (Poewe et al., 2017). These motor symptoms can be extremely disabling and can result in progressive losses in independence as disease severity increases.

The non-motor symptoms of PD also contribute to disease burden. These symptoms include cognitive impairment, hallucinations, numbness or tingling in extremities, autonomic dysfunction, sleep disturbances, and depression (Poewe et al., 2017). The majority of existing treatments for PD target the motor symptoms of the disease, leaving the non-motor symptoms largely unaddressed. These, as well as potential avenues of treatment for non-motor symptoms, will be discussed later in the disease overview.

1.2.2 Pathology

As mentioned previously, the main pathological markers of PD are the loss of dopaminergic (DA) neurons in the substantia nigra and the presence of intracellular α-synuclein protein aggregates in SN cell bodies. This neuronal loss leads to a deficit of available dopamine in the nigrostriatal pathway, which connects the substantia nigra pars compacta with the caudate nucleus and putamen, other areas in the basal ganglia. The nigrostriatal pathway is implicated in motivating behavior and motor function, both of which are disrupted in Parkinson’s. Loss of DA neurons is primarily concentrated in this region of the brain (Poewe et al., 2017).

While no genes have been identified as causal in sporadic PD, many are correlated with disease pathology. Point mutations and repeats in SNCA, the gene that
codes for \( \alpha \)-synuclein, are implicated in heritable PD, while an identified single-nucleotide polymorphism in \( \text{SNCA} \) is correlated with incidence of sporadic Parkinson’s (Nalls et al., 2014). These mutations have been linked to increased expression of \( \alpha \)-synuclein, a risk factor for the formation of protein aggregates.

Misfolded \( \alpha \)-synuclein proteins form toxic, insoluble Lewy bodies in the cytoplasm of affected cells, resulting in toxicity and damage (Del Tredici et al., 2002). Alpha-synuclein aggregation also affects mitochondrial function, resulting in oxidative stress and the blockage of normal axonal transmission. Specifically, protein aggregation in the cytoplasm leads to the dysfunction of the electron transport chain, causing decreased activity and production of adenosine triphosphate (ATP) (Schapira et al., 1998).

Nigral neurons are particularly vulnerable to oxidative stress because of their morphology. They have long unmyelinated axons and form many synapses, which require large amounts of energy to maintain (Poewe et al., 2017). Damage to these cells thus affects the functioning of their neighbors as well. Additionally, oxidative stress can lead to the depletion of the lysosomal-autophagy system (LAS), impairing the cell’s ability to remove toxic waste, namely \( \alpha \)-synuclein (Di Nottia et al., 2017).

Another characteristic that is found to play an increasing role in PD pathology is neuroinflammation. Links have been established between protein aggregates, certain genes, and neuroinflammation that result in a harmful self-perpetuating loop. Exposure to toxic \( \alpha \)-synuclein aggregates activates adaptive and innate immune processes. The consequent neuroinflammation can lead to increased misfolding of \( \alpha \)-synuclein (Gao et al., 2008; Ransohoff, 2016). Pro-inflammatory cytokines activated
by stress-induced changes in immune responses can be neurotoxic, suggesting that neuroinflammation modulates PD pathology (Kim and Won, 2017).

These neurotoxic effects of inflammation have also been tied to increases in psychological stress and depression (Yadav et al., 2005; Kim and Won, 2017), both of which are non-motor symptoms of PD. This connection between non-motor symptomatology and disease pathology suggests a potential mechanism for a self-perpetuating exacerbation of disease severity.

1.2.3 Interventions

1.2.3.1 Pharmacological Interventions

Pharmacological interventions for Parkinson’s are typically the first line of treatment, and are used widely. Because PD results in a loss of bioavailable dopamine, drug development targets different factors in the production, degradation, and regulation of dopamine. The “gold standard” of PD treatment is levodopa (L-DOPA), a dopamine precursor. Because dopamine itself cannot cross the blood-brain barrier (BBB), L-DOPA can be administered in pill form, cross the BBB, and be metabolized into dopamine once in the brain. L-DOPA is typically administered in combination with carbidopa, which keeps the precursor from being metabolized into dopamine before crossing the BBB (Poewe et al., 2017). Other preparations of L-DOPA include the addition of catechol-O-methyltransferase (COMT) inhibitors, which also work to maximize the amount of bioavailable dopamine.

One drawback of using L-DOPA is its short half-life, necessitating its regular consumption (Poewe and Antonini, 2015). Another more serious drawback is the fact
that persistent use of L-DOPA can result in dyskinesia, or uncontrollable excesses of movement (Olanow et al., 2006). Dyskinesia does not develop in every patient, yet is a frequently occurring side effect of L-DOPA treatment.

The two other major pharmacological interventions for PD are monoamine oxidase type B (MAOB) inhibitors and DA agonists. MAOB inhibitors are involved in the oxidation and clearance of synaptic DA. By inhibiting this clearance, these drugs prolong and increase the amount of bioavailable DA in synapses, enhancing its effect (Birkmayer et al., 1977). DA agonists mimic the effect of dopamine to provide some of the same benefits as L-DOPA, though with decreased efficacy. (Boyle and Ondo, 2015).

While not typically included in PD treatment plans, a pharmacological intervention that holds potential for affecting PD pathology is the use of nonsteroidal anti-inflammatory drugs (NSAIDs). NSAIDs are inhibitors of cyclooxygenase enzymes, which are activated by cytokines and inflammatory immune responses (Vane and Botting, 1998). As mentioned in the discussion of PD pathology, inflammatory cytokines can be neurotoxic and can lead to cell death and increased protein aggregation. Therefore, inhibiting the mechanism of action of cytokines could result in reduced inflammation, potentially reducing PD pathology. NSAIDs have also been found to decrease striatal dopamine deficiency and dopaminergic cell death in animal models of PD (Aubin et al., 1998; Ferger et al., 1999). A prospective study in humans found that regular use of NSAIDs reduced the risk of developing Parkinson’s by 45% when compared with a cohort of non-NSAID users (Chen et al., 2003). Although Chen et al., did not address existing PD pathology, these results
suggest that decreasing neuroinflammation may have a neuroprotective effect. Based on these findings, therapies that target or affect neuroinflammation could be beneficial to both pathology and symptomology.

1.2.3.2 Non-Pharmacological Interventions

Surgical intervention for the treatment of PD is also a common therapeutic avenue. The only current and widely available surgical intervention is deep brain stimulation (DBS). DBS is based on the finding that high-frequency stimulation of specific brain regions can effectively mimic a lesion, and that stimulating the subthalamic nucleus (STN), another basal ganglia structure, has pronounced anti-parkinsonian effects (Muthuraman et al., 2018). The internal globus pallidus (GPi), a basal ganglia structure involved in the control of voluntary movement, has recently gained popularity as a second DBS target (Rughani et al., 2018).

DBS can have dramatic results, making it a popular treatment choice for individuals with disabling motor symptoms. A drawback of this treatment is that not every PD individual is eligible for the procedure. Because the surgery is quite invasive and the risk for negative side effects is high, preexisting cognitive impairment is an exclusion criterion for DBS, as are dementia, depression, and psychotic symptoms (Bronstein et al., 2011). Younger patients are more likely to fulfill the inclusion criteria for the surgery, as they are less prone to adverse events during the procedure and recovery (Poewe et al., 2017). Because of these restrictions on eligibility and the fact that DBS only treats motor, and not non-motor, symptoms, it is not an all-inclusive treatment.
The limitations of pharmacological and surgical interventions have inspired the development of exercise-based therapies for PD. These therapies include boxing, swimming, dancing, and tai chi and have been shown to improve gait, balance, strength, speech, and quality of life (Seppi et al., 2011). These symptoms largely remain unaffected by other methods of treatment (Fox et al., 2011).

**1.2.4 Stress and Allostatic Load**

Another promising aspect of exercise-based therapies is their potential to reduce stress. Increased psychological stress has been linked to increased neuroinflammation and oxidative stress, both of which contribute to PD pathology (Kim and Won, 2017). While the diagnosis of PD alone can cause intense psychological distress, this stress is compounded by the effect of motor impairment on day-to-day activities. In fact, this impairment leads many PD individuals to participate less frequently in social activities due to social anxiety.

Although not conducted in a PD population, previous studies have assessed the effects of yoga on inflammation and oxidative stress (Yadav et al., 2005; Telles et al., 2012). Yoga integrates cognitive and physical processes through sequences of timed movements, usually to music, in a group setting. These techniques have been shown to reduce psychological stress. A study examining the effects of reduced stress on biochemical processes found that participation in yoga interventions led to decreased levels of markers of oxidative stress (Yadav et al., 2005). Given the role of oxidative stress in PD, this result suggests that interventions affecting psychological stress may have an impact on PD pathology.
Decreasing stress through movement, music, and social interaction may also have an effect on allostatic load. The concept of allostasis relates to the way the brain responds or adapts to stressful situations (Karatsoreos and McEwen, 2011). This adaptation is representative of the brain’s resilience and primarily involves aspects of the stress response such as cortisol regulation (McEwen, 2008). Increasing frequency of stressful situations contributes to allostatic load, which can be thought of as the cognitive wear and tear resulting from cumulative or incomplete allostatic responses. As allostatic load increases, the brain’s ability to properly regulate stress responses decreases (Karatsoreos and McEwen, 2011). Dysregulation of the stress response can result in increasing levels of cortisol and inflammatory cytokines. Therapies that decrease stress could simultaneously reduce allostatic load, leading to increased neural resilience and plasticity when the brain is faced with a stress-inducing situation.

Another approach to reducing stress is relaxation response (RR) therapy, which involves mind-body interventions aimed at inducing deep relaxation. Although not yet tested in a Parkinson’s population, RR therapies have been shown to decrease stress and anxiety in addition to affecting genomic markers and inflammatory responses (Bhasin et al., 2013; Kuo et al., 2015; Bhasin et al., 2018). One study examining the effects of RR therapy on healthy individuals found that the intervention changed temporal expression patterns of genes involved in mitochondrial function and inflammatory stress response pathways (Bhasin et al., 2013). A second study applied this therapeutic intervention to a disease population by examining the effects of RR therapy on individuals with irritable bowel syndrome (IBS). Consistent
with and expanding on the findings from the first study, this group found changes in
the expression of genes involved in oxidative stress response, inflammatory response,
and cell proliferation and growth following the intervention (Kuo et al., 2015).

These results demonstrate that decreasing stress can cause impactful changes
in gene expression patterns. If exercise-based therapies for PD are able to induce
effects similar to those of relaxation, it is possible that they could change gene
expression patterns involved in PD pathology in addition to reducing allostatic load.

1.2.6 Advantages and Disadvantages of Available Treatment

The available treatments for PD discussed above each have definite strengths
and weaknesses. The “gold standard” of treatment, L-DOPA, shows consistent results
and benefits motor symptoms. However, the major downside to this treatment is its
causal role in the development of dyskinesia. An alternative to L-DOPA is DBS, but
again this treatment only impacts motor symptoms and is not an option for all PD
individuals.

While there are drugs that can assuage some of the non-motor symptoms of
PD such as depression and sleep disorders, adding more drugs to an already strict
pharmaceutical routine is not an ideal solution. Alternative therapeutic methods need
to be developed to address these issues. There is potential in exercise-based therapies
that have been shown to benefit non-motor symptoms in addition to gait and balance.
Neither DBS nor L-DOPA have significant effects on these aspects of motor function,
so exercise-based therapies have promise as part of a more holistic therapeutic
approach.
Exercise-based therapies range from independent physical therapy programs to group boxing, swimming, and dance classes with live music. The remainder of this introduction will focus specifically on dance and its effects on Parkinson’s individuals.

1.3 Music and the Brain

In addition to being a form of art and exercise, dance plays an important social and cultural role because of its universality. Dance incorporates physicality and emotion. It requires learning sequences of movement, setting those movements to music, dancing cohesively with others, and expressing a sentiment or telling a story. As dance is usually social, it is often an integral part of communities and has been widely used in ritual and healing practices. Because of the multifaceted nature of dance and the fact that dance involves a wealth of different neural and sensorimotor processes, a large body of literature is dedicated to elucidating its underlying biological mechanisms (Karpati et al., 2015).

Dance is also typically performed to music, so rhythm perception and entrainment to a musical beat (discussed below) have been subjects of scientific investigation. Entrainment to a rhythm is at the heart of choreography and serves to drive sequences of movement. Rhythm is therefore fundamental in influencing the way that people dance. Here, I will discuss rhythm and then move into a discussion of the neural mechanisms involved in perceiving and producing dance.
1.3.1 Rhythm Perception

Music, like dance, is universal and holds similar cultural and social importance. Music tells stories, unites communities, and is passed down over generations. The concept of rhythm is an integral part of music and can be defined as the pattern of intervals between the onset of acoustic events, or musical components (Povel, 1984).

Generally, rhythm incorporates information about tempo and beat to build a pattern of structured temporal change (Ravignani et al., 2017). This pattern—also known as meter—is determined by the alternation of stronger and weaker beats (Tierney and Kraus, 2015; Ravignani et al., 2017). The coincidence of different musical characteristics at specific intervals leads to the establishment of a hierarchy of beats based on their relative strengths. Electroencephalogram (EEG) recordings have shown this hierarchy represented in patterns of neural activity. Listening to a variety of musical elements evokes different event-related potentials (ERPs) on EEG recordings (Schaefer et al., 2011), indicating that the brain identifies and responds differentially to hierarchical elements of rhythm.

Distinct responses to different aspects of rhythm contribute to the perception of temporal structure in music. As these patterns typically obey a regular structure, the progression of a given rhythm is predictable (Schaefer et al., 2011). Interestingly, there is evidence to support the notion that the ability to predict a sequence of beats or the rhythmic progression of a melody is related to the extent to which a listener enjoys a certain piece of music (Schaefer et al., 2011). In this sense, the perception of
rhythm, meter, and beat are important not only for music processing, but also for emotional and psychological responses to music.

Research investigating regions of neural activation during rhythm perception has shown that the supplementary motor area (SMA), premotor cortex, cerebellum, and basal ganglia are all activated during this task (Penhune et al., 1998; Ramnani and Passingham, 2001; Pastor et al., 2004; Grahn, 2009). After briefly discussing the process of entrainment, I will present findings from two studies that address this phenomenon. The first uses EEG recording to measure neural entrainment to different rhythms (Tierney and Kraus, 2015). The second examines the role of the basal ganglia in beat perception in a Parkinson’s population (Grahn, 2009).

1.3.2 Entrainment

Entrainment is a fundamental aspect of both rhythm perception and rhythmic movement. Neural entrainment refers to the phase-locking of neural oscillations with a given rhythmic structure (Tierney and Kraus, 2015). A widely influential model of rhythm processing relies on the synchronization of neural oscillations with regular external auditory cues (Grahn, 2012a). In this model, neural oscillations during music perception correspond with oscillations in beat saliency (Barnes and Jones, 2000), similar to the finding of differential ERP responses to hierarchical aspects of rhythm.

Entrainment translates from the micro neural scale to the macro scale of movement and dance. In fact, it is difficult to restrain from foot tapping, head bobbing, or moving another body part to a musical beat. For most people, this type of rhythmic movement can happen without much conscious effort and is elicited naturally by external auditory cues. While many animal species exhibit rhythmic
movement in nature, humans are the only primates to engage in synchronized movements in groups, a behavior that contributes to the development of culture and group cohesiveness (Merker et al., 2009).

Entraining physical movement to musical rhythm is the basis of dance. Just as the hierarchical structure of rhythm allows for the prediction of future temporal patterns, dance depends on rhythmic regularity for learning and performing choreography. I will elaborate further on the work investigating the neural basis of dance after completing my discussion of rhythm processing.

1.3.3 Studies Investigating Rhythm Processing

Tierney and Kraus (2015) tested the synchronization of neural oscillations with the beat of pop songs. The researchers played a sample of music for participants containing a superimposed beep track that either coincided directly with the beat of the song or fell 25% of the inter-beat interval away from it (Tomic and Janata, 2008; Tierney and Kraus, 2015). A musical sample with coinciding beeps was categorized as “on the beat”; samples with unaligned beeps were categorized as “off the beat”.

EEG recordings revealed that neural oscillations corresponded to the first harmonic of the “on the beat” samples, activity that was absent when the music stimulus was “off the beat”. This finding suggests that oscillatory activity was enhanced when the meter of the stimulus was consistent, providing evidence that neural oscillations are an important aspect of rhythm perception in popular music.

A second study involving rhythm perception directly assessed individuals with Parkinson’s disease. In 2009, Jessica Grahn reported results from a series of studies on the neural basis of rhythm and beat perception (Grahn, 2009). Functional
magnetic resonance imaging (fMRI) revealed differences in basal ganglia activation when healthy and PD populations listened to beat-based and irregular musical samples.

Healthy participants exhibited robust basal ganglia activation while listening to beat-based samples and were better able to identify changes in beat in these tracks than in the irregular samples. By contrast, PD participants showed decreased basal ganglia activation during beat-based listening and were unable to easily identify changes in beat in any musical sample, regardless of beat regularity. These findings, together with the fact that the basal ganglia are compromised in PD, implicate the basal ganglia in beat perception.

These two studies illustrate important points about the way the brain processes rhythm that are relevant to the current study. Another relevant aspect of rhythm perception and processing is musical groove, which can influence the way an individual both perceives and moves to a given piece of music.

1.3.4 Groove

Musical groove is defined as the pleasurable drive towards movement when listening to music (Janata et al., 2012). As mentioned before, the tendency to move one’s body when music is playing is often unconscious. However, the degree of organic movement to a certain piece of music may depend on a combination of objective and subjective measures, so determining what contributes to the relative enjoyment level of a song is important in understanding how people react to it.

An influential study aimed at characterizing the psychology of the groove through a number of research questions (Janata et al., 2012). This study assessed
subjective groove rating, potential factors that might influence groove perception, and the relationship between sensorimotor experience and groove level. Results revealed a positive correlation between enjoyment and groove level, supporting the idea that groove is linked to affect.

The researchers also tested the relationship between sensorimotor experience and groove using a simple tapping task. Participants were instructed to either tap isochronously to the perceived beat of the music or spontaneously, and asked to rate their opinion of the groove level of each song as either high, mid, or low groove. Tapping task results showed that high groove songs elicited the most spontaneous movement, suggesting that groove level is related to degree of organic movement while listening to music. Perceived groove level was also related to participants’ ability to synchronize movement to musical structure. Participants more accurately matched their movements with the beat of high groove music than they did to low groove songs.

These results suggest that groove is related to enjoyment and affects the ability of participants to entrain their movements to music. Janata et al., created a quantitative index of groove ratings based on their findings categorizing songs as high, mid, and low groove (Janata et al., 2012). The relationship between groove, entrainment, and affect will be further investigated in the current study.

1.3.5 Neural Differences between Musicians and Non-Musicians

Despite the universality of music, differences in beat and rhythm perception between musicians and non-musicians are found in patterns of neural activation while
listening to music (Grahn and McAuley, 2009; Grahn and Rowe, 2009; Grahn, 2012b; Bouwer et al., 2016).

Grahn et al., used fMRI to compare regions of brain activity in musicians and non-musicians during the perception of different types of beats (Grahn and Rowe, 2009). Musicians showed increased modulation in the coupling between premotor areas and primary auditory cortex when listening to music with accented beats, suggesting that music training enhances coupling between motor and auditory brain regions. This finding provides evidence that music training results in different patterns of neural activation during beat perception.

A second study investigated beat perception and identification in musicians and non-musicians using the Beat Alignment Test (BAT) (Grahn, 2012b). The BAT was developed as a means of testing beat sensitivity using musical stimuli with a superimposed beep track. Similar to the beep track used in a previously mentioned study on rhythm perception, the beeps fell either on the beat, 10% of the inter-beat interval (also called inter-tap interval, or ITI) before the beat, or 10% after the beat. Grahn found that sensitivity to the beat was influenced by music training, as musicians performed better on the BAT than non-musicians. This result, together with the findings from the 2009 Grahn study, suggests that music training impacts neural activation during both music listening and beat perception.

1.3.6 Music and PD

Because of music’s central role in culture, the human tendency towards spontaneous movement to music, and the positive affect associated with listening, music has been explored as a therapeutic tool in a number of settings. Most
extensively, it has been used as a means of managing stress, anxiety, and depression (Knight and Rickard Ph, 2001; Jensen and Bonde, 2018). Of special interest is the ability for musical rhythm to elicit spontaneous movement as a potentially therapeutic application in the treatment of movement disorders.

Parkinson’s disease is associated with a loss of internal cueing systems and a deficit in beat perception (Grahn, 2009; Bella et al., 2015). Because this loss of cueing systems affects rhythmic everyday movement, supplementing these cues could provide therapeutic benefit.

Bella et al., investigated the relationship between rhythmic auditory stimulation (RAS), which provides regular auditory cues, and gait improvement in people with Parkinson’s (Bella et al., 2017). Results from this study showed that gait speed and stride length increased after training with RAS. Common gait deficits in PD include the shortening of stride length and shuffling, so the combined improvement of speed and stride length reflects a multifaceted improvement in symptomology.

However, improvements in gait were not ubiquitous. Participants also completed a simple tapping task during which they tapped to the beat of a series of musical samples. Performance on the tapping task, measured in terms of the accuracy of movement synchronization to the musical beat, was found to be a predictor of gait improvement following RAS. This finding suggests that improvement from RAS is related to participants’ ability to synchronize movements with rhythm, also referred to as sensorimotor coupling ability.
A recent study assessed the effects of RAS on rates of falling in a PD population (Thaut et al., 2019). Falling in Parkinson’s patients could result from an inability to maintain rhythmic limb movements, as freezing and gait impairments are precursors to falls. This study found that RAS decreased rates of falling, supporting the use of external auditory stimulation as means of reestablishing deficits in rhythmic movement.

From these findings, it is clear that music and RAS can affect motor activity. However, the fact that improvement following RAS varies depending on participants’ sensorimotor coupling ability raises questions about the potential effects of this ability on the outcome of different therapeutic interventions—namely, dancing.

### 1.4 Dance and the Brain

Dance relies heavily on music, as entrainment to a rhythm is the framework for choreography. I will now discuss the processes of learning and performing choreography and the therapeutic effects of dance.

#### 1.4.1 Action Observation

Unless a dancer is improvising, he or she learns choreography by watching a teacher and imitating their actions. This observation of movement activates mirror neurons in the brain (Cattaneo and Rizzolatti, 2009). Mirror neurons are involved in a number of neural circuits and are primarily activated during the observation and production of goal-directed movement (Rizzolatti et al., 1996; Cattaneo and Rizzolatti, 2009; Ferrari et al., 2017). There are two major mirror neuron systems:
one is implicated in affective behaviors and involves limbic pathways; the other is involved in the recognition, comprehension, and production of motor activity and incorporates frontal and parietal regions (Cattaneo and Rizzolatti, 2009).

The latter—the parietofrontal mirror neuron system—is activated during the observation and subsequent production of movement. An fMRI study found that during the observation of motor activity, parietal and premotor cortices were activated somatotopically—the activation of brain areas corresponded with the parts of the body that were being observed in action (Buccino et al., 2001). These data suggest that watching others perform specific movements results in an internal mapping of the behavior onto the observer’s own body (Blasing et al., 2012). Patterns of neural activation during the observation of others are referred to as the human action observation network (AON) (Karpati et al., 2015).

While work elucidating the mechanisms involved in this network typically focuses on simple motor tasks, such as hand or mouth gestures (Rizzolatti et al., 1996; Buccino et al., 2001; Cattaneo and Rizzolatti, 2009), studies have also looked at brain activation during the observation of complex dance moves (Cross et al., 2006). Neuroimaging revealed that the rostral supplementary motor area (SMAr), ventral premotor cortex (PMv), inferior parietal lobule (IPL), superior temporal sulcus (STS), and primary motor cortex (M1) were activated during dance observation (Cross et al., 2006). Although M1 was activated infrequently as it is primarily involved in movement production, these five areas likely comprise a system of activation corresponding to an internal simulation of observed movement.
A number of studies have also investigated differences in neural activation when observing other humans versus observing nonhuman or artificial representations of actions. Work examining differential activation when observing human hand gestures and gestures of an artificially programmed hand revealed that mirror neuron systems were less activated during the observation of the artificial hand (Perani et al., 2001; Tai et al., 2004). Similar results were found in a study that compared AON activation while watching humans versus watching nonconspecifics (Buccino et al., 2004): AON activation was specific to observing other humans. Finally, a third study found that mirror neuron systems were only activated when the observed behavior was mechanically possible for the observer (Stevens et al., 2000).

Together, the results from these studies point to a set of requirements for mirror neuron and AON activation. These systems seem to respond based on the relationship between the observer and the object of observation. In other words, neural activation is associated with the degree to which an observer can relate to and perform the observed actions.

This finding has major implications for determining which factors may shape individual differences in observing dance. If activation of neural networks is related to how capable the observer is of performing those movements, dance training could impact neural responses.

1.4.2 Dance Performance

Dance execution is more difficult to study than dance observation, as imaging techniques typically require stillness. However, the dynamics of dance performance
alone provide some clues. Dance is often performed in groups, requiring constant attention to one’s surroundings in order to synchronize movements with others (Minvielle-Moncla et al., 2008; Blasing et al., 2012). Dancing also involves the coordination of different body parts to create smooth, complete movements.

Optimizing this coordination requires motor synergy, which integrates proprioceptive information with neural processes involved in motor activity and leads to reduced muscle tension and increased accuracy in choreographic performance (Blasing et al., 2012).

One study attempted to localize the neural structures involved in the performance and spatial patterning of complex dance steps using positron emission tomography (PET) (Brown et al., 2006). Although participants were lying down during imaging, they were able to move their feet on a board that registered the steps. While this experimental design is not wholly ecologically valid, it does present a partial solution to the aforementioned imaging challenges.

Participants were asked to perform dance steps in both metric (synchronizing movements with music) and nonmetric (no musical synchronization) conditions. In both conditions, PET imaging revealed activation of bilateral motor and premotor areas, somatosensory regions, right SMA, left superior parietal cortex, superior temporal areas, basal ganglia, and areas of the cerebellum (Brown et al., 2006). Also independent of condition was the somatotopic activation of the cerebellum corresponding to patterned leg movements.

PET imaging from the nonmetric condition showed decreased activity in subcortical auditory and cerebellar regions, implicating these structures in beat
processing and entrainment (Brown et al., 2006). This study ultimately takes a step towards identifying brain regions involved in metric, spatially patterned dance performance.

1.4.3 Neural Differences between Dancers and Non-Dancers

While it may be difficult to determine exactly what is going on in the brain during dance performance, a body of research has examined differences in brain structure and function between dancers and non-dancers. Results from one study revealed that dancers exhibited more activation in AON areas than non-dancers when observing dance (Calvo-Merino et al., 2005). Moreover, dancers experienced additional activation when watching the dance style in which they were experts. These results indicate that dancers and non-dancers experience different patterns of activation during dance observation.

A second study investigated differences in sensorimotor networks between a group of highly trained ballerinas and a control group without dance training (Hanggi et al., 2010). Hanggi et al., measured fractional anisotropy (a measure of connectivity) using structural MRI. When compared with non-dancers, dancers exhibited decreased fractional anisotropy in motor areas. This finding could be reflective of motor optimization synergy because as skills are refined, motor areas may undergo a neuroplastic pruning process to streamline motor function.

Dancers also exhibit increased functional connectivity in cortico-basal ganglia motor learning loops (Burzynska et al., 2017). Cortico-basal ganglia loops are implicated in the control of posture, movement, and action selection, and are therefore crucial for dance training and performance (Nambu, 2004).
Further supporting the claim that there are structural differences in the brains of dancers and non-dancers, Karpati et al., found differences in white matter diffusivity between the two groups (Karpati et al., 2018). Diffusor tensor imaging (DTI) from this study revealed increased diffusivity in the corpus callosum, corticospinal tract, and longitudinal fasciculus in dancers. Dancers were also found to have thicker gray matter in primary motor cortex and superior and middle temporal gyri. All findings from this study were related to degree of dance training and performance experience, further supporting the notion that dancing results in the restructuring of certain brain regions.

Taken together, these studies provide evidence that dance training induces neuroplasticity, resulting in structural differences in certain brain regions including motor and AON areas.

### 1.4.4 Dance and PD

Dance has recently gained popularity as an intervention for Parkinson’s disease because it provides external cueing systems that may lessen deficits in internal rhythm generation. Dance not only increases mobility, thereby activating and stretching muscles, but also requires the use of cognitive skills to learn and plan sequences of spatially patterned movement (Hashimoto et al., 2015). Because the diagnosis of PD can be isolating, the social aspect of dance classes may also be beneficial.

A number of studies have investigated the effects of dance on both motor and non-motor PD symptoms including balance, gait, quality of life, mood, and other cognitive measures (Hackney and Earhart, 2009, 2010b; Hashimoto et al., 2015;
McNeely et al., 2015; Lewis et al., 2016). One study found that balance, measured by the Berg Balance Scale (BBS), improved significantly following an Argentine Tango dance intervention (Hackney and Earhart, 2010a).

Another group compared the effects of a dance intervention incorporating jazz, tango, and classical ballet to the effects of a rote exercise program (Hashimoto et al., 2015). Both balance (again tested using the BBS) and gait (using the Timed Up-and-Go Test) were assessed before and after the intervention. Members of both the exercise and dance groups showed significant improvements in gait, but only members of the dance group showed improvements in balance. This result suggests that although general exercise benefited gait similarly to dance, dance alone improved balance.

While the majority of PD interventions focus on the treatment of motor symptoms, it is important to address non-motor symptoms as well. Promisingly, one study demonstrated that after attending social dance classes, participants with PD experienced improvements in fatigue, tension, vigor, and depression, reflecting a trend towards improvements in quality of life and cognitive function (Lewis et al., 2016).

Another potential benefit of dance classes could be related to stress. As mentioned when discussing current therapies for PD, both exercise-based therapy and music have been shown to decrease stress. In other disease populations, yoga and relaxation have resulted in changes in gene expression associated with inflammation and oxidative stress. As dance seems to incorporate aspects of each of these interventions, these findings could potentially translate to dance classes for PD.
In summary, dance has been shown to have distinct, measurable effects PD motor symptoms. Reports of the effects of dance on non-motor PD symptoms show a similar trend towards benefits in mood, cognition, and quality of life. Together, these data provide evidence that dance has a multifaceted beneficial effect on PD symptomology.

1.5 Current Study and Hypothesis

The current study aims to build on existing literature regarding the effects of dance and music on PD symptomology by investigating factors that could influence individual differences in responsiveness to dance classes. We investigated the effects of four months of weekly dance classes for Parkinson’s on disease severity, measured using the Unified Parkinson’s Disease Rating Scale (UPDRS). We also assessed sensorimotor experience, musical groove, and prior experience with music and dance in order to determine whether any of these factors influence therapeutic outcome.

Our assessment of sensorimotor experience was twofold. Participants first completed the Beat Alignment Test (BAT), which measures beat perception and identification. Next they performed a simple tapping task in which participants were instructed to tap along to the beat of a number of musical excerpts. The excerpts were chosen from the groove index created by Janata, et al., (2012) in order to test participants’ responses to differing levels of musical groove.

With this study design, we tested the hypothesis that groove and sensorimotor experience, as quantified by participants’ prior experience with music and dance, affect the therapeutic outcome of dance classes for PD.
2. METHODS

2.1 Procedure

2.1.1 Participant Recruitment

Participants (total n=30) were recruited directly from Dance for PD® classes in New York City, NY (n=18), San Rafael, CA (n=7), and Santa Rosa, CA (n=5). In New York, participants were recruited from classes held at the Mark Morris Dance Center (MMDC), Ballet Academy East (BAE), Juilliard, and The New School. In San Rafael, participants were recruited from classes held at Marin Dance Theatre. In Santa Rosa, participants were recruited from the class at Oddfellows Hall. Each dance class was taught by trained Dance for PD® instructors. The classes incorporated a range of dance styles including modern, ballet, jazz, and improvisation. Of the PD participants recruited, 7 are male and 23 are female.

Inclusion criteria included the diagnosis of Parkinson’s disease (PD) and the attendance of weekly Dance for PD® classes. Participants continued their weekly attendance of classes throughout the four-month course of the study. The exclusion criterion was the presence of a hearing impairment. Disease severity was not a factor in determining eligibility for participation, nor was individual treatment plan.

Members of the control group (n=19) were recruited from acquaintances of PD participants, as well as from healthy, non-PD individuals who attended the Dance for PD® classes. Eight members of the control group are male and 11 are female. Control participants were matched for age (average age: PD=72.7 years, control=72.6 years), handedness (% right-handed: PD=83.3, control=89.5), music experience (%
with music experience: PD=63.3, control=57.9), and dance experience (% with dance experience: PD=66.7, control=63.1).

Participants were recorded as having music experience (ME) and dance experience (DE), also referred to as music and dance training, if they had attended formal lessons for over one year.

2.1.2 Interview Procedure

All interviews took place either in the participant’s home, at the dance studio hosting the Dance for PD® class attended by the participant, or in an office or conference room at the Mark Morris Dance Center.

2.1.2.1 Initial Interview

All 30 participants with PD completed the initial interview, as did the 19 members of the control group. During the initial interview, each participant completed a series of tasks. After providing consent, each participant filled out a questionnaire (see 2.1.3). If the interviewee had Parkinson’s, he or she would then complete the Unified Parkinson’s Disease Rating Scale (see 2.1.4). Following this analysis of disease severity, each participant (both PD and control) performed the Beat Alignment Test (BAT, see 2.1.5) to assess beat perception. Finally, all participants performed a tapping task (see 2.1.6) that aimed to assess sensorimotor coupling ability.
2.1.2.2 Follow-Up Interview

Follow-up testing took place four months following the initial interview. We were thus able to assess the effects of the dance intervention—weekly dance class attendance for four months—on disease severity. At this point in the study, only 14 PD participants have completed the follow-up interview. Nine participants were enrolled in San Rafael and Santa Rosa in January 2019, so will not be eligible to complete the follow-up interview until May 2019. Once data for this group of participants is collected, our findings will be updated.

During the follow-up interview, each participant completed the Unified Parkinson’s Disease Rating Scale again. This score was then compared with scores from the initial interview in order to assess changes in disease severity. Participants also completed the BAT and the tapping task a second time.

2.1.3 Questionnaire

Participants completed a questionnaire that inquired about age, location, gender, handedness, hearing impairment, length of time on carbidopa/levodopa, other medications taken to treat PD, most recent dose of carbidopa/levodopa, music experience, and dance experience (see Results: Tables 3 and 4).

2.1.4 Unified Parkinson’s Disease Rating Scale

Each PD participant completed the Unified Parkinson’s Disease Rating Scale (UPDRS) as a means of measuring disease severity. The UPDRS is divided into four sections and assesses both motor and non-motor symptoms. The possible scores for
the UPDRS range from 0-199, with a score of 0 indicating no disability and a score of 199 indicating the most severe disability. Each question is scored on a scale of 0-4. A score of zero indicates normal or no problem, a score of one indicates minimal problem, a score of two indicates mild problem, three indicates moderate problem, and four indicates severe problem. Section I measures Mentation, Behavior, and Mood and is scored out of a possible 16 points; Section II measures Activities of Daily Life and is scored out of 52 points; Section III, the Motor Examination, is scored out of 108 points; Section IV measures Complications of Therapy and is scored out of 23 points. Section scores are summed to get a total score.

The UPDRS was administered during both the initial and follow-up interviews. Every participant who experienced distinct “on” and “off” phases (“on”=medication is active) due to treatment (carbidopa/levodopa) was “on” during UPDRS testing for both interviews. Video recordings UPDRS testing were not collected because many participants withheld video consent.

2.1.5 Beat Alignment Test (BAT)

The BAT (Iversen et al. 2008) was used to test auditory beat perception. Twelve music samples (Table 1) were played for participants, each of which had been selected from the list of musical stimuli developed by Iversen and Patel. Each track was played from the speaker of a 13” MacBook Pro. The 44.1 KHz (CD, mono) tracks had an average duration of 14.9 s with a standard deviation of 3.1 s (Iversen and Patel, 2008).
After the first five seconds of each musical excerpt, a beep track (1 KHz pure tones, duration=100 ms) was overlaid on the original music. The onset of the beep track was timed so that the beeps varied in their relationship to the beat of the underlying music. Beeps fell either directly on the identified beat, 10% of the ITI before each identified beat, or 10% after each beat. This way, musical excerpts were separated into “on the beat” and “off the beat” conditions. Five of the musical excerpts used in this study were categorized as “on the beat” and the other seven were “off the beat”.

While performing the BAT, participants were asked to identify whether the superimposed beeps were on or off the beat, and were then asked to rate their confidence in the answer on a scale of 1 to 3 (1=not confident, 2=somewhat confident, 3=very confident). Volume was adjusted for each participant in order to ensure comfort of listening. Participants were also required to give verbal confirmation that they could hear and identify the beep track and understood the task.

<table>
<thead>
<tr>
<th>Iversen and Patel Stimulus</th>
<th>On/Off the Beat</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTH_B0_v2</td>
<td>On</td>
</tr>
<tr>
<td>OWA_B-20_v2</td>
<td>Off</td>
</tr>
<tr>
<td>HSG_B20_v2</td>
<td>Off</td>
</tr>
<tr>
<td>KPS_B0_v2</td>
<td>On</td>
</tr>
<tr>
<td>NYN_B0_v2</td>
<td>On</td>
</tr>
<tr>
<td>ACL_B20_v2</td>
<td>Off</td>
</tr>
<tr>
<td>TJU_B20_v2</td>
<td>Off</td>
</tr>
<tr>
<td>SMA_B0_v2</td>
<td>On</td>
</tr>
<tr>
<td>SAS_B-20_v2</td>
<td>Off</td>
</tr>
<tr>
<td>RRW_B20_v2</td>
<td>Off</td>
</tr>
<tr>
<td>OCJ_B0_v2</td>
<td>On</td>
</tr>
<tr>
<td>PAN_B-20_v2</td>
<td>Off</td>
</tr>
</tbody>
</table>

Table 1. BAT stimuli as presented by Iversen and Patel. Each stimulus was designated as either “on the beat” or “off the beat”.
2.1.6 Tapping Task

To assess sensorimotor coupling ability, participants completed a simple tapping task. Eight songs were selected from Janata, Tomic, and Haberman’s groove index (Janata et al., 2012), which quantified musical groove on a scale of 0-127. The songs selected for the current study had groove index ratings ranging from 42.3 to 108.7 (Table 2). The four songs with the highest groove ratings were designated as “High Groove” (Mean=97.4, SD=9.4) and the four with the lowest ratings as “Low Groove” (Mean=52.0, SD=10.2). All “High Groove” songs were similarly designated as high groove in the Janata, et al. paper, and all the “Low Groove” songs were originally designated as either mid or low groove. Each song was imported into GarageBand version 10.3.2 on a MacBook Pro and edited down to a 30 second excerpt.

A KORG nanoPAD2 was connected via USB to the MacBook and used to record participants’ tapping. Participants were instructed to use one finger on their dominant hand to tap along to the beat of the music sample. They were asked to begin tapping as soon as they identified a beat of their choosing and to continue tapping until the music stopped. Tapping was recorded from the pressure participants applied to the nanoPAD2 as an instrumental track in GarageBand. The tapping track was then isolated and converted to an mp3 file for analysis. After tapping to each excerpt, participants were asked to rate their enjoyment of (1=not enjoyable, 2=somewhat enjoyable, 3=very enjoyable) and familiarity with the song (1=not at all familiar, 2=somewhat familiar, 3=very familiar). Each musical excerpt was played from the speakers of the MacBook Pro.
<table>
<thead>
<tr>
<th>Song Title</th>
<th>Artist</th>
<th>Genre</th>
<th>Groove Rating</th>
<th>Groove Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superstition</td>
<td>Stevie Wonder</td>
<td>Soul</td>
<td>108.7</td>
<td>High Groove</td>
</tr>
<tr>
<td>Sing Sing Sing</td>
<td>Benny Goodman and His Orchestra</td>
<td>Jazz</td>
<td>97.4</td>
<td>High Groove</td>
</tr>
<tr>
<td>In the Mood</td>
<td>Glenn Miller and His Orchestra</td>
<td>Jazz</td>
<td>96.9</td>
<td>High Groove</td>
</tr>
<tr>
<td>Cheek to Cheek</td>
<td>Frank Sinatra</td>
<td>Jazz</td>
<td>85.7</td>
<td>High Groove</td>
</tr>
<tr>
<td>What a Wonderful World</td>
<td>Louis Armstrong</td>
<td>Jazz</td>
<td>66.4</td>
<td>Low Groove</td>
</tr>
<tr>
<td>‘Til There was You</td>
<td>Etta Jones</td>
<td>Jazz</td>
<td>50.2</td>
<td>Low Groove</td>
</tr>
<tr>
<td>Carolina in my Mind</td>
<td>James Taylor</td>
<td>Rock</td>
<td>49.0</td>
<td>Low Groove</td>
</tr>
<tr>
<td>Comfortably Numb</td>
<td>Pink Floyd</td>
<td>Rock</td>
<td>42.3</td>
<td>Low Groove</td>
</tr>
</tbody>
</table>

Table 2. Musical excerpts used in the tapping task. Each excerpt has a unique groove rating as assigned by Janata, et al. The highest four groove ratings were designated as high groove and the lower four as low groove.

2.2 Data Analysis

2.2.1 UPDRS

The UPDRS was scored for each participant during both initial and follow-up interviews. Each section was scored individually, starting with Section I and moving through the test sequentially. Scores for Sections I and II were determined through conversation with the participants. Participants would describe their experiences as they related to the questions asked and the tester (Anna Krotinger) would then assign a score based on this oral data.

During Section III, participants were asked to perform a series of simple motor tasks. Scores were assigned to each motor task at the discretion of the tester.
Section IV was scored similarly to Sections I and II, as the tester asked questions about the participant’s history of therapy complications. The responses and subsequent scores for this section were based on historical data.

UPDRS section scores were summed individually and then added to get a total score. For participants who completed the follow-up interview, post-intervention UPDRS scores were subtracted from pre-intervention UPDRS scores to determine any changes in disease severity. UPDRS scores were entered into Microsoft Excel (version 14.6.3) spreadsheets and imported into RStudio (version 1.1.456). Data for changes in UPDRS scores were log-transformed to normalize skewed distributions and analyzed using one-way ANOVA and Spearman’s correlation.

It is important to reiterate that not every participant has completed both the initial and follow-up interviews. Participant 017 died due to congestive heart failure three months following the initial interview. Participants 006, 010, 014, and 020 were unable to contacted in order to schedule the follow-up interview. Participant 019 was hospitalized due to a fall resulting in a broken hip during the time she was eligible for the follow-up interview. These incidents resulted in missing data. Participants 022-030 are not yet eligible for the follow-up interview, as it has been less than four months since their initial interviews. Consequently, there were fewer degrees of freedom for statistical analyses assessing changes in UPDRS scores than there were for analyses relying on data from initial interviews.
2.2.2 BAT

As mentioned above, participants were asked to categorize each musical excerpt as either “on the beat” or “off the beat”. For each participant, the false alarm rate (FAR) and hit rate (HR) were calculated based on these responses. A false alarm was recorded if the participant identified an “off the beat” condition as “on the beat”. A hit was recorded if the participant correctly identified the “on the beat” condition.

Average FAR (PD=0.242, control=0.150) and HR (PD=0.773, control=0.843) were calculated for both experimental and control groups. Z-scores for both HR and FAR were then calculated by subtracting average HR or FAR from each participant’s respective rate and then dividing that value by the standard deviation of all rates. Participants’ FAR z-scores were subtracted from their HR z-scores to get d’. D’ was used as a measure of BAT performance, as higher d’ values indicated greater sensitivity to changes in stimuli.

D’, FAR, HR, and z-score values were entered into an Excel spreadsheet and then imported into RStudio (version 1.1.456) for analysis. BAT data was analyzed using one-way ANOVA.

2.2.3 Tapping Task

Mp3 files of recorded tapping were loaded into MATLAB (The MathWorks, Inc., Natick, MA, version 9.4.0). The MIDI Toolbox (Lartillot, 2007) was used to produce a waveform representation of each tapping track. Every waveform was then
analyzed to determine the onset of tapping events, and each onset was recorded as one data point.

Onset data were imported into Excel to calculate the inter-onset interval (IOI), or the time between each onset event. The first three IOI values for each tapping recording were omitted from analysis as a means of controlling for the period of time during which participants were becoming accustomed to the task.

IOI data were imported into RStudio and IOI distributions were visualized using ridgeline plots. IOI values greater than 3 seconds were omitted from analysis, as values this high were reflective of either a misunderstanding of the task or a failure of the KORG nanoPAD2 to register a tapping event. The coefficient of variation (CV) for each run of the tapping task was calculated and analyzed using one- and two-way ANOVA.

Polar histograms were constructed in MATLAB. IOI data was Hilbert transformed and then subtracted from standard tapping data produced by the tester. Significance levels for all analyses were characterized as following: $p<0.05^*$, $p<0.01^{**}$, $p<0.001^{***}$.

2.3 Adverse Events

No adverse events (AEs) took place during the interview process. As mentioned earlier, one participant died a few months after completing the first interview due to congestive heart failure. A second participant was hospitalized a few months after the initial interview because of a broken hip from a fall down a flight of
stairs. This hospitalization was brief and the participant soon returned home. Neither of these events was a result of participation in the current study.
3. RESULTS

3.1 Questionnaire

Each PD (n=30) and control (n=19) participant completed the questionnaire (See Tables 3 and 4). As mentioned in Methods, participants in the PD and control groups were matched for age (PD: average=72.7 years, SD=7.27, control: average=72.6 years, SD=8.95), handedness [PD: n right-handed=25 (83.3% of PD group), control: n right-handed=17 (89.5% of control group)], music experience [PD: n with music experience=19 (63.3% of PD group), control: n with music experience=11 (57.9% of control group)], and dance experience [PD: n with dance experience=20 (66.7% of PD group), control: n with dance experience=12 (63.1% of control group)] (Table 5). Participants in the two groups were not matched for sex.

These responses showed that the majority of participants had either previous dance experience (DE) or music experience (ME), and that almost half of the participants in both the PD and control groups had both ME and DE.
<table>
<thead>
<tr>
<th>GROUP</th>
<th>ID</th>
<th>AGE</th>
<th>LOCATION</th>
<th>SEX</th>
<th>HANDEDNESS</th>
<th>FIRST L-DOPA</th>
<th>OTHER PD MEDICATION</th>
<th>AGE OF FIRST MUSIC</th>
<th>INSTRUMENT</th>
<th>YEARS OF MUSIC</th>
<th>DANCE EXP</th>
<th>AGE OF FIRST DANCE</th>
<th>STYLE OF DANCE</th>
<th>YEARS OF DANCE</th>
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<tbody>
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<td>1</td>
<td>75</td>
<td>Juilliard</td>
<td>f</td>
<td>right</td>
<td>2015</td>
<td>N/A</td>
<td>yes</td>
<td>4</td>
<td>piano</td>
<td>yes</td>
<td>6</td>
<td>modern</td>
<td>3</td>
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<tr>
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<td>2</td>
<td>65</td>
<td>MMDG</td>
<td>m</td>
<td>right</td>
<td>2010</td>
<td>Pramipexole</td>
<td>yes</td>
<td>10</td>
<td>flute, piano</td>
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<td>23</td>
<td>jazz ballet</td>
<td>10</td>
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<tr>
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<td>3</td>
<td>65</td>
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<td>f</td>
<td>right</td>
<td>1992</td>
<td>Pramipexole</td>
<td>yes</td>
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<td>piano</td>
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<td>4</td>
<td>62</td>
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<td>f</td>
<td>right</td>
<td>N/A</td>
<td>Selegiline</td>
<td>yes</td>
<td>7</td>
<td>piano</td>
<td>yes</td>
<td>7</td>
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<td>5</td>
</tr>
<tr>
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<td>MMDG</td>
<td>m</td>
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<td>no</td>
<td>N/A</td>
<td>N/A</td>
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<td>f</td>
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**Table 3.** Questionnaire responses for PD participants.
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*Table 4.* Questionnaire responses for control participants.
Table 5. Responses to questions regarding experience with music and dance.

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<th>N with ME (% of group)</th>
<th>Average years of ME (SD)</th>
<th>N with DE (% of group)</th>
<th>Average years of DE (SD)</th>
<th>N with both ME and DE (% of group)</th>
<th>N with neither ME nor DE (% of group)</th>
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<td>19 (63.3%)</td>
<td>23.5 (22.8)</td>
<td>20 (66.7%)</td>
<td>7.4 (7.6)</td>
<td>14 (46.7%)</td>
<td>5 (16.7%)</td>
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<td>17.2 (15.1)</td>
<td>8 (42.1%)</td>
<td>4 (21.1%)</td>
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3.2 Initial UPDRS

Initial UPDRS scores for PD participants (n=30) ranged from 6 to 74 (mean=29.4, SD=14.7), representing the variability of disease severity and symptomology observed in Dance for PD® classes. Because the classes are open to anyone with PD, attendees range from individuals who appear completely healthy to those who are unable to move without assistance. UPDRS sections were scored independently and then summed (Table 6).

Table 6. Average UPDRS scores by section.

<table>
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<th>Average Score (SD, % of possible score)</th>
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<td>29.9 (14.7, 15.0%)</td>
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These results suggest that participants generally struggled most with activities of daily life, which include speech, salivation, swallowing, writing, cutting food, dressing, hygiene, and walking.

### 3.3 Beat Alignment Test (BAT)

BAT performance was analyzed by calculating the hit rate (HR), false alarm rate (FAR), z-scores for HR and FAR, and d’ (Table 7).

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<th>Average FAR (SD)</th>
<th>Average HR z-score (SD)</th>
<th>Average FAR z-score (SD)</th>
<th>Average d’ (SD)</th>
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<td>0.243 (0.156)</td>
<td>1.55e-04 (1.00)</td>
<td>-2.36e-04 (1.00)</td>
<td>1.70 (0.962)</td>
</tr>
<tr>
<td>Control</td>
<td>0.843 (0.147)</td>
<td>0.150 (0.111)</td>
<td>3.58e-05 (1.00)</td>
<td>-4.25e-05 (1.00)</td>
<td>2.29 (0.795)</td>
</tr>
</tbody>
</table>

Table 7. Analysis of BAT results.

Control participants had higher average HR and lower average FAR than PD participants, indicating more accurate beat perception. Control participants also had higher average d’ than PD participants, demonstrating increased sensitivity to changes in beat and supporting the finding that Parkinson’s impairs beat perception.

The distribution of d’ was plotted for PD and control groups by ME and DE to test the effects of these experiences on beat perception (Figure 1). One-way ANOVA revealed a significant difference between d’ values for PD participants with and without ME [F(1,28)=5.32, p=0.0281*], indicating increased beat sensitivity in participants with music training. While PD participants with DE had higher average
d’ than those without, this difference did not reach significance [F(1,28)=0.647, p=0.428].

No significant differences were found between control participants with and without ME [One-way ANOVA: F(1,17)=0.009, p=0.962] or between those with and without DE [F(1,17)=0.080, p=0.781]. These data suggest that neither the presence of music nor dance experience impacted beat perception in control participants.

Taken together, results from the BAT indicate that PD participants performed more poorly than controls during assessments of beat perception, sensitivity, and identification. BAT performance for PD participants also appeared to be modulated by the presence of ME, as those with ME performed better than those without. Perhaps due to the relatively small cohort, this experience-dependent effect was not found among control participants.
Figure 1. Distributions of d’ in BAT performance. The top two graphs show d’ distributions for PD participants separated by ME and DE. The bottom graphs show d’ distributions for the control group, again separated by ME and DE. One-way ANOVA revealed that ME significantly improved BAT performance in PD participants \( F(1,28)=5.37, p=0.0281^* \), but neither ME nor DE significantly affected performance in the control group.

3.4 Tapping Task

The tapping task was used to assess participants’ sensorimotor coupling ability. Participants tapped to eight songs: “Cheek to Cheek”, “In the Mood”, “Sing Sing Sing”, “Superstition”, “Carolina in my Mind”, “Comfortably Numb”, “’Til There was You”, and “What a Wonderful World”. The first four songs listed were designated as “High Groove” (Mean groove index=97.4, SD=9.4) and the last four were designated as “Low Groove” (Mean groove index=52.0, SD=10.2).
We first plotted the distribution of time intervals between tapping onsets, or inter-onset intervals (IOI), for each song per participant using ridgeline analysis (Figure 2). These plots enabled inter and intra-group comparisons of tapping consistency during initial testing. More consistent IOI values were indicative of enhanced ability to couple movements with a regular beat. Consistency of IOI values, representing tapping task performance, was determined by calculating the coefficient of variation (CV) of IOI. Larger CV values reflected decreased regularity, which we interpreted as a decrease in beat tracking accuracy and sensorimotor coupling ability. Consequently, as CV values decreased, sensorimotor coupling ability increased.

IOI distributions for PD tapping appeared to be more spread than those for control tapping. This difference suggests that controls moved more consistently to a regular beat than PD participants, indicating better sensorimotor coupling ability. We confirmed this observation with a comparison of CV values for PD and control participants. One-way ANOVA revealed that PD participants had higher average CV values than control participants [F(1,390)=13.7, p<0.001***], providing evidence that PD participants performed more poorly on the tapping task (Figure 3).
Figure 2. Ridgeline plots showing the distribution of inter-onset intervals (IOI) for each participant’s tapping performance to each song. A: Distribution of PD IOI values. B: Distribution of control IOI values.

Figure 3. Comparison of CV values for PD and control participants. One-way ANOVA revealed that PD participants had significantly higher CV values than controls [F(1,390)=13.7, p<0.001***].
We next assessed the effects of groove on both IOI and CV. First, we plotted the distribution of IOI for high and low groove songs using ridgeline analysis (Figure 4). For both PD and control participants, IOI values for high groove songs appeared to be smaller than low groove values. This observation was confirmed by one-way ANOVA, which revealed that high groove IOI values were significantly smaller than low groove values for both PD [F(1,10300)=2780, p<0.001***] and control groups [F(1,629)=3290, p<0.001***]. Participants were instructed to tap to the beat of their choosing, so these results indicate that high groove songs elicited more movement than low groove songs.

Figure 4. Ridgeline plots of inter-onset interval (IOI) distributions by groove. A: PD IOI distributions by groove. B: Control IOI distributions by groove.
Differences between PD and control CV values (Figure 3) were conserved after controlling for groove (Figure 5). Control participants had significantly lower CV values than PD participants for both high [F(1,194)=5.84, p=0.0166*] and low [F(1.194)=7.98, p=0.00521**] groove songs, indicating that groove did not affect the relationship between CV and group (PD or control). These results support the conclusion that PD participants performed more poorly on the tapping task than controls, suggesting impaired sensorimotor coupling ability.

![Figure 5](image_url)

**Figure 5.** Comparison of CV values for PD and control groups by groove. Control participants had significantly lower CV values for both high [F(1,194)=5.84, p=0.0166*] and low [F(1.194)=7.98, p=0.00521**] groove songs.

We next analyzed CV values for PD participants by both groove and presence of music and dance experience in order to assess the effects of these experiences on sensorimotor coupling ability (Figure 6). We found that although average CV values
were lower for participants with ME for both high and low groove songs, neither of these differences reached significance [One-way ANOVA: high groove: F(1,118)=0.003, p=0.958]; low groove: F(1,118)=0.009, p =0.926], suggesting that music experience did not affect tapping performance for either groove level.

However, we did see significant differences in tapping performance when comparing CV for PD participants with and without dance experience. PD participants with DE had significantly lower CV values for tapping to both high [One-way ANOVA: F(1,118)=18.6, p<0.001***] and low [F(1,118)=5.98, p=0.016*] groove songs, suggesting that dance experience improved tapping task performance for both levels of groove.

Together, the analyses of CV by groove suggest that dance experience, but not music experience, predicted stronger tapping task performance, and therefore sensorimotor coupling ability, for both groove levels in a PD population.
Figure 6. Coefficient of variation (CV) of IOI for PD participants by groove, ME, and DE. A: CV comparisons by ME for high [F(1,118)=0.003, p=0.958] and low groove [F(1,118)=0.009, p =0.926] songs. B: CV comparisons by DE for high [F(1,118)=18.6, p<0.001***] and low [F(1,118)=5.98, p=0.016*] groove songs. MUSICHIST = ME; DANCEHIST = DE.

After establishing that DE predicted enhanced sensorimotor coupling ability, we wanted to test whether number of years of experience in either music or dance impacted this effect.

We assessed the relationship between CV and years of ME by groove using Pearson’s correlation (Figure 7A). For high groove songs, CV was negatively correlated with years of ME (r=-0.173, p=0.136), while for low groove songs these variables were positively correlated (r=0.0948, p=0.416). Neither correlation reached significance, so sensorimotor coupling ability did not appear to be associated with length of ME.

We assessed the relationship between CV and years of dance experience in the same way (Figure 7B). For both high (r=-0.187, p=0.105) and low (r=-0.219, p=0.0578) groove songs, CV was negatively correlated with years of DE. However,
both correlations failed to reach significance, again suggesting that sensorimotor coupling ability was not affected by length of experience.

Figure 7. A: Correlation of CV and years of ME by groove (n=19). For high groove songs, CV was negatively correlated with years of ME (Pearson’s correlation: r=-0.173, p=0.136). CV and years of ME were positively correlated for low groove songs (r=0.0948, p=0.416). B: Correlation of CV and years of DE by groove (n=20). High groove CV was negatively correlated with years of DE (r=-0.187, p=0.105). Low groove CV was also negatively correlated with years of DE (r=-0.219, p=0.0578).
After analyzing CV and IOI values from the initial interview, we were curious if tapping changed from initial to follow-up time points and how groove might be implicated in comparisons between pre- and post-intervention sensorimotor coupling ability.

In order to further visualize the effects of groove on IOI, we created polar histograms to compare PD participants’ IOI values against a standard for initial and follow-up tapping. Standard tapping data was produced by the tester, who has experience with both music and dance and does not have PD. Histograms were constructed by performing a Hilbert transform on tapping onset data and then plotting the difference between standard and PD IOI values. In plotting this difference on a circular axis, we were able to visualize the distribution of tapping onsets in time. PD tapping became increasingly similar to standard tapping as histogram values approached zero.

In order to highlight the effects of groove on changes in IOI, we isolated polar histograms from tapping to “Superstition” (“High Groove” condition; groove index=108.7) and “Comfortably Numb” (“Low Groove” condition; groove index=42). These were the highest and lowest groove songs used in the tapping task, respectively, so we hoped they would be most representative of any groove-dependent changes in PD tapping. Figures 8A and B show the histograms for “Superstition” and “Comfortably Numb” tapping from a sample of eight PD participants and eight members of the control group. For both songs, two participants had dance experience and two did not. Control IOI values for these two songs were similar to standard data for both those with DE [Welch’s Two-Sample:
“Superstition”: t(163)=-0.687, p=0.493; “Comfortably Numb”: t(76.1)=-0.156, p=0.876] and without DE [“Superstition”: t(177)=0.720, p=0.473; “Comfortably Numb”: t(85.9)=-0.585, p=0.560].

We first examined the relationship between the initial, follow-up, and control histograms of tapping to “Superstition” (Figure 8A). While the high groove plots appeared consistent across each group, Welch Two-Sample t-tests revealed quantitative differences. These differences depended, however, on whether PD participants had DE. PD participants with DE tapped similarly to healthy controls during both initial [t(375)=0.102, p=0.919] and follow-up [t(208)=0.516, p=0.607] testing. PD participants without DE, though, had significantly different IOI values from control data at both the initial [t(135)=-8.83, p<0.001***] and follow-up [t(153)=-2.96, p=0.00355**] time points. In the follow-up comparison, we saw a decrease in level of significance, suggesting that participants without DE may have improved slightly after the dance intervention.

Quantitative changes in IOI were more obvious in the “Comfortably Numb” phase plots (Figure 8B), and visible increases in similarity between all PD and control tapping post-intervention were supported by quantitative analyses. During initial testing, PD participants both with DE [t(56.7)=5.50, p<0.001***] and without it [t(119)=−5.55, p<0.001***] tapped significantly differently than controls. These relationships changed for both groups post-intervention, as we found no significant differences between PD and control tapping during follow-up testing [PD participants with DE: [t(182)=0.221, p=0.825]; PD participants without DE: [t(107)=-0.0183,
These results indicate that all participants regardless of DE improved their tapping to “Comfortably Numb”, the lowest groove song, following the intervention.

These tapping comparisons revealed two patterns. For “Superstition”, PD participants with DE tapped similarly to controls at both time points. Participants without DE tapped significantly differently than controls at both time points, yet improved slightly post-intervention. The results from the “Comfortably Numb” analyses suggest that sensorimotor coupling with low groove songs was more sensitive to the effects of training, as all participants improved post-intervention.
**Figure 8A.** Polar histograms showing differences in tapping event onsets between standard tapping and initial PD tapping, follow-up tapping, and control tapping to “Superstition” (groove index=108.7).
Figure 8B. Polar histograms showing differences in tapping event onsets between standard tapping and initial PD tapping, follow-up tapping, and control tapping to “Comfortably Numb” (groove index=42.3).
Next, we looked further into the effects of DE on changes in sensorimotor coupling performance, as quantified by CV, post-intervention. We assessed changes in tapping task performance for all songs instead of looking only at the highest and lowest groove songs. We analyzed CV values by groove, time of testing, and DE in order to compare tapping task performance across each of these variables (Figure 9). Two-way ANOVA revealed significant effects of dance experience \([F(1,216)=76.2, p<0.001***]\) and time of testing \([F(1,216)=11.9, p<0.001***]\) on CV.

Post-hoc testing to correct for family-wise error revealed DE-dependent differences in high groove CV from initial to follow-up testing. Participants with dance experience showed almost no difference in CV between time points (Tukey’s HSD post-hoc test: \(\text{diff}= -0.0232, \text{lwr}= -0.128, \text{upr}= 0.0813, p \text{ adj}=0.99\)). However, participants without DE showed significant decreases in high groove CV post-intervention (\(\text{diff}= -0.130, \text{lwr}= -0.250, \text{upr}= -0.010, p \text{ adj}=0.0258^*\)).

Correspondingly, we found an increase in similarity between CV values for those with and without DE during follow-up testing. While participants with DE initially had significantly lower high groove CV than those without DE (\(\text{diff}= -0.210, \text{lwr}= -0.322, \text{upr}= -0.0963, p \text{ adj}<0.001***\)), this difference no longer reached significance post-intervention (\(\text{diff}= -0.103, \text{lwr}= -0.216, \text{upr}= 0.010, p \text{ adj}=0.102\)). These data indicate that for high groove tapping, only participants without prior dance training showed improved sensorimotor coupling ability after the dance intervention.
**Figure 9.** CV comparisons for PD participants with and without DE by groove and time of testing. For high groove tapping, there were significant differences between initial and follow-up time points for those without DE (Tukey’s HSD post-hoc test: diff=−0.130, lwr=−0.250, upr=−0.010, p adj=0.0258*) and between those with and without DE during initial testing (diff=−0.210, lwr=−0.322, upr=−0.0963, p adj<0.001***). For low groove tapping, there were significant differences between those with and without DE at both initial (diff=−0.217, lwr=−0.330, upr=−0.104, p adj<0.001***), and follow-up (diff=−0.114, lwr=−0.227, upr=−0.00130, p adj=0.0452*) time points.

We saw a similar pattern emerge in the low groove tapping data. While there were no significant differences between initial and follow-up low groove CV for participants with DE (diff=−0.0133, lwr=−0.118, upr=0.091, p adj=0.99), CV values for participants without DE decreased post-intervention (diff=−0.117, lwr=−0.237, upr=0.00413, p adj=0.067). Although this decrease failed to reach significance, it
reflected our findings from the high groove CV analyses. Additionally, while we found significant differences between participants with and without DE at both initial (diff=-0.217, lwr=-0.330, upr=-0.104, p adj<0.001**) and follow-up (diff=-0.114, lwr=-0.227, upr=-0.00130, p adj=0.0452*) time points for low groove tapping, the level of significance decreased post-intervention, indicating increased similarity between the groups.

These results varied from our IOI analyses, in which we had found different patterns of tapping improvement for the highest and lowest groove songs. In analyzing CV values for all high and low groove songs, we saw the same pattern of improvement for both groove levels.

Results from the CV analyses suggest that a lack of dance experience predicted improvement in sensorimotor coupling ability following the dance intervention, while the presence of DE was a predictor of CV consistency across time points. Although participants with DE had lower CV values during both initial and follow-up testing for all songs, their tapping never significantly changed and we failed to see improvements similar to those observed in “Comfortably Numb” tapping alone. Perhaps the effects of the lowest groove index on tapping improvement were lost when higher groove songs were included in the analysis. This may be suggestive of a scale of groove-dependent effects as an alternative to binary metric of high and low groove.
3.5 Change in UPDRS

In order to assess the effects of weekly dance classes on disease severity, we calculated the difference between participants’ follow-up and initial UPDRS scores. Currently, 14 participants have completed follow-up interviews.

We found that every participant had either no change in score post-intervention, resulting in a difference of zero, or experienced an improvement in score, resulting in a negative difference. Because of these characteristics, we took the absolute value of the difference in UPDRS scores so that larger values were indicative of greater improvement. We also log-transformed this data to normalize skewed distributions. With the transformed outcome data, we tested the hypothesis that groove, sensorimotor experience, and experience with music and dance affect the therapeutic outcome of dance classes.

We first correlated the transformed improvements in scores with initial CV values in order to assess the relationship between sensorimotor coupling ability and therapeutic outcome (Figure 10). We furthered controlled for groove and found that initial CV was negatively correlated with UPDRS improvement for both high (Spearman’s correlation: r=−0.465, p<0.001*** ) and low (r=−0.585, p<0.001*** ) groove songs. This result suggests that as sensorimotor coupling ability increased, therapeutic outcome improved.
Figure 10. Correlation of initial CV and log(UPDRS Improvement) from baseline to four months (n=14 PD participants) by groove. CV was negatively correlated with log(UPDRS Improvement) for both high (Spearman’s correlation: $r=-0.465$, $p<0.001^{***}$) and low groove songs ($r=-0.585$, $p<0.001^{***}$).

Next, we examined the relationship between follow-up CV and UPDRS improvement to see whether the relationship we observed with initial CV values was preserved post-intervention (Figure 11). We found that it was indeed consistent, as follow-up CV was negatively correlated with log(UPDRS Improvement) for both high (Spearman’s correlation: $r=-0.326$, $p=0.0238^*$) and low ($r=-0.349$, $p=0.0148^*$) groove songs. However, the correlations for both groove levels were weaker than they had been for the analysis using initial CV values. This difference is likely reflective of the post-intervention improvements in CV we saw in participants without dance experience.
Figure 11. Correlation of follow-up CV and log(UPDRS Improvement) from baseline to four months (n=14 PD participants) by groove. Follow-up CV was negatively correlated with log(UPDRS Improvement) for both high (Spearman’s correlation: r=-0.326, p=0.0238*) and low groove songs (r=-0.350, p=0.0148*).

Because we had found dance experience-dependent differences in improvements in CV, we were curious to see how changes in CV related to improvements in UPDRS. “Change in CV” was calculated by subtracting initial CV from follow-up CV, so lower “Change in CV” values were indicative of greater improvement in sensorimotor coupling. We found that “Change in CV” values were positively correlated with UPDRS improvement for participants with (Spearman’s correlation: r=0.0981, p=0.472) and without (r=0.258, p=0.108) dance experience (Figure 12). While failing to reach significance, these correlations suggest that consistency in sensorimotor coupling may have been associated with better therapeutic outcome.
Figure 12 also shows a relatively clear divide between participants with and without DE. Those with prior dance experience appear to have improved more than those without such experience. As consistency in CV values was also associated with greater improvements in UPDRS, this finding ties in to earlier results indicating that dance experience predicted increased sensorimotor coupling ability and consistency.

![Figure 12. Correlation of “Change in CV” values and log(UPDRS Improvement) by DE. Lower “Change in CV” values reflected increased improvement over time. “Change in CV” was positively correlated with log(UPDRS Improvement) for participants with (Spearman’s correlation: r=0.0981, p=0.472) and without (r=0.258, p=0.108) DE.](image)

We next tested the effects of music and dance experience on improvement in UPDRS scores using one-way ANOVA analysis. We found that while participants with ME had greater average improvements than those without ME, this difference did not reach significance [F(1,94)=0.995, p=0.321] (Figure 13A). However, PD
participants with DE exhibited significantly greater improvements in UPDRS scores than those without \[F(1,94)=73.4, p<0.001^{***}\], suggesting that the presence of dance experience predicted improved therapeutic outcome after four months of dance classes (Figure 13B).

Figure 13. Log(UPDRS Improvement) from baseline to four months (n=14) separated by ME and DE. A: Differences between participants with (n=12) and without (n=2) ME did not reach significance \[F(1,94)=0.995, p=0.321\]. B: Participants with DE (n=8) showed more improvement than those without \[n=6, F(1,94)=73.4, p<0.001^{***}\].

Although we saw dance experience-dependent effects on overall change in UPDRS scores, these effects were not conserved across independent UPDRS sections \[F(1,40)=3.52, p=0.067\]. For each section, PD participants with DE had greater improvements in scores than those without, but these dance experience-dependent differences were not significant. We did, however, see significant differences in overall improvement in scores between sections \[F(3,40)=3.59, p=0.0218*\]. After correcting for family-wise error using Tukey’s HSD post-hoc test, we found significant differences between improvements in Section III and Section I (diff=3.25,
lwr=0.222, upr=6.28, p adj=0.0312*) as well as between Section III and Section IV (diff=-3.17, lwr=-6.19, upr=-0.139, p adj=0.0374*) (Figure 14). Reflective of these differences, all participants regardless of DE improved most in Section III, the motor examination, suggesting that motor ability was most affected by and improved after the dance intervention.

The fact that significant dance experience-dependent differences only appeared when analyzing overall improvements in UPDRS scores may be a consequence of sample size. Because just under half of the participants have currently completed the follow-up interview, it is possible that increasing sample size will further elucidate the inter-section effects of DE. This lack of significance could also be due to the relatively small differences in scores for each section. Ultimately, these results indicate that the presence of dance experience affected overall improvement in UPDRS score, suggesting that dance experience was a predictor of the therapeutic outcome of dance classes for PD.
Figure 14. Improvements in each UPDRS section by dance experience. Overall improvements in scores were greatest for Section III, as these improvements were significantly larger than improvements in Sections I (diff=3.25, lwr=0.222, upr=6.28, p adj=0.0312*) and IV (diff=-3.17, lwr=-6.19, upr=-0.139, p adj=0.0374*)

3.6 Results Summary

Returning to the Beat Alignment Test, our results showed that PD participants with ME were more sensitive to changes in musical beat than participants without ME. DE did not impact BAT performance.

In the tapping task, dance experience had a significant effect on sensorimotor coupling ability. CV analyses revealed that the presence of dance experience was a predictor of enhanced sensorimotor coupling ability. ME did not have the same effect, as there were no significant differences in CV between those with and without ME.
We also assessed the effects of musical groove and DE on tapping task performance during both initial and follow-up testing. T-tests revealed both groove and DE-dependent changes in IOI values for tapping to “Superstition” and “Comfortably Numb” from pre- to post-intervention testing. When we analyzed changes in CV from initial to follow-up time points for all songs, we found that the absence of dance experience predicted improvement in sensorimotor coupling ability for high groove songs. Participants without dance experience also improved in low groove sensorimotor coupling, but this result failed to reach significance.

Finally, we assessed the relationship between improvement in UPDRS scores, groove, sensorimotor coupling ability, and experience with music and dance. While all PD participants either exhibited consistent or improved UPDRS scores during follow-up testing, stronger sensorimotor coupling ability was associated with greater UPDRS improvement. When investigating the relationship between changes in CV from initial to follow-up testing and UPDRS improvement, we found that increased consistency in sensorimotor coupling ability was weakly associated with greater improvement in disease severity.

We ultimately found that the presence of dance experience was a predictor of improvement in overall UPDRS score following the attendance of four months of weekly dance classes. The presence of music experience did not have this effect.
4. DISCUSSION

4.1 Findings

Our data show that sensorimotor experience and the presence of dance experience (DE) are predictors of improvement from dance classes for PD. DE is also a predictor of sensorimotor experience, as evidenced by increased accuracy of sensorimotor coupling ability in participants with previous dance training. While previous studies have shown that dance classes for PD can improve gait, balance, mood, and quality of life (Sharp and Hewitt, 2014; de Natale et al., 2017; Hulbert et al., 2017), not everyone experiences the same benefit and these differences have gone largely unaddressed. Our findings have implications for the identification and explanation of individual differences in the therapeutic outcome of dance classes for PD.

Our results from the Beat Alignment Test support previous findings that PD individuals exhibit impaired beat perception and sensitivity when compared with healthy controls (Grahn, 2009). This impairment is likely explained by previous imaging data implicating the basal ganglia and cortico-striatal circuitry in beat perception ability (Bella et al., 2017). As these neural structures are compromised in PD (Poewe et al., 2017), the deficit in PD individuals’ ability to perceive changes in musical beat could be a direct result of disease pathology.

Music experience does not seem to affect beat sensitivity in the control group, contradicting previous reports that musicians performed better on the BAT than non-musicians (Grahn and Rowe, 2013). This discrepancy may be due to sample size. We do, however, see music experience-dependent differences in the PD group. The
presence of ME appears to act as a predictor of increased sensitivity to changes in beat, suggesting strengthened neural circuitry involved in beat perception or increased capacity to utilize alternate cognitive resources for this task. Because this effect is only observed in the PD group, differences in beat sensitivity may emerge when typical neural circuitry supporting beat perception is compromised.

Results from the tapping task reveal more experience-dependent patterns. Healthy controls exhibit less variability in regular rhythmic tapping, a finding consistent with existing literature reporting impaired sensorimotor coupling ability in PD individuals (Merchant et al., 2008; Bella et al., 2017). Within the PD group, we see dance experience-dependent differences, as those with DE exhibit enhanced sensorimotor coupling ability. Because there are neither DE nor ME-dependent differences in the control group, this result is again suggestive of emergent experience-dependent differences in PD individuals.

While participants with music experience seem better able to utilize alternate cognitive resources during tests of beat sensitivity, participants with dance experience seem to exhibit this same ability during tests of sensorimotor coupling ability.

When examining changes in CV from initial to follow-up testing, we find that participants without prior dance experience improve after the dance intervention while those with DE tap similarly at both time points. Because PD participants with DE did quite well during initial testing, it may have been difficult to improve on their original performance. These data perhaps reflect two different processes: learning and plasticity in the case of participants without dance experience and utilization of existing neural circuitry in participants with dance experience.
The indication of learning in PD participants without DE raises questions about how improvements in sensorimotor coupling may affect responses to dance classes over longer periods of time. Extending the current study would address longer-term effects of changes in sensorimotor experience. There are anecdotal reports of Dance for PD® participants whose rhythmic movement has appeared to improve over time. One individual who has been attending the Dance for PD® classes for a number of years has just recently been able to coordinate rhythmic footwork. The accomplishment of rhythmic movement after years of dance classes suggests that there may be long-term effects of this intervention that are missed in shorter studies.

Our data show that after four months of attending weekly Dance for PD® classes, PD participants with dance experience show significantly greater improvements in disease severity than those without such experience. However, all 14 PD participants who completed the follow-up interview show either improvement or no change in overall UPDRS scores, supporting previous findings on the positive effects of dance classes for PD (Hackney and Earhart, 2010b; Hashimoto et al., 2015; McNeely et al., 2015; Lewis et al., 2016). All PD participants regardless of DE improve the most on UPDRS Section III, the motor examination. Although the motor tasks that participants are asked to perform during this section are simple, such as opening and closing fists and standing up from a chair, improvements here could perhaps be representative of changes in motor strategies used by participants. If participants learn how to access alternate, unimpaired cognitive resources during the dance intervention, they will likely be able to apply these strategies to movements
other than dance. One Dance for PD® participant reported planning her walk through a grocery store as a choreographed sequence of movements. This mindset enabled her to overcome freezing and complete her errand successfully. The strategy of translating dance choreography into everyday routines may contribute to the resulting benefit of dance classes.

Dance experience-dependent effects also manifest in the relationship between tapping task performance and improvement in UPDRS scores. We find that tapping task CV and improvement in UPDRS scores are negatively correlated, indicating that sensorimotor coupling ability is predictive of the therapeutic outcome of dance classes. This result is similar to findings reporting individual differences in response to rhythmic auditory stimulation (RAS) in a PD population (Bella et al., 2017). Bella et al., found that responsiveness to RAS was predicted by performance on a simple tapping task. Dance classes incorporate elements of RAS, as they provide external auditory cues intended as prompts for movement. Our work supports the finding that individual differences in response to dance classes for PD can be predicted by sensorimotor coupling ability.

The fact that PD participants with DE benefit more from dance classes than those without it may be reflective of individual differences in neural structure and function. Previous studies point to differences in brain connectivity and structure in dancers when compared with non-dancers. These differences include increased activation in the action observation network when observing others move (Calvo-Merino et al., 2005), specific pruning patterns in motor areas (Hanggi et al., 2010), and increased functional connectivity in cortico-basal ganglia learning loops.
Based on these findings, it is possible that PD participants with dance experience have some of these neural characteristics, and that their performances in the current study reflect these characteristics.

The concept of cognitive reserve may also partially explain differences in therapeutic outcome. Given our results regarding sensorimotor coupling ability and UPDRS improvement, it is possible that the presence of DE could contribute to the development of a sort of dance experience-dependent cognitive reserve in individuals with PD, acting as a buffer against disease pathology.

Cognitive reserve refers to individual differences in brain structure and function that affect the brain’s ability to resist or compensate for damage (Tucker-Drob et al., 2009; Armstrong et al., 2012). Cognitive reserve has been associated with PD pathology in previous work investigating the effects of IQ on the development of mild cognitive impairment in PD individuals (PD-MCI) (Armstrong et al., 2012). Armstrong et al., found that higher IQ was associated with decreased odds of developing PD-MCI, suggesting a role for cognitive reserve in protecting against PD neuropathology.

Cognitive reserve is also associated with the extent to which the brain has been challenged in different circumstances. Therefore, cognitive reserve increases as individuals participate in more activities, learn, and experience (Tucker-Drob et al., 2009). As dance training fits these criteria, DE could result in the development of dance-specific processes, which could perhaps be thought of as a task-specific subset of cognitive reserve. Dance training may strengthen neural pathways involved in motor entrainment and performance of choreography that could then be utilized as an
alternative to impaired motor areas. This dance-dependent strengthening could act to prime the brains of PD individuals with DE to better, or at least more quickly, respond to dance classes. If these circuits can act as a buffer against PD pathology, it would make sense that their strengthened stability would be associated with better responses to dance classes. Perhaps reflective of this stability, participants with DE perform consistently in sensorimotor coupling tasks whereas participants without DE exhibit plasticity in sensorimotor coupling ability.

This improvement in participants without DE is not mirrored in changes in UPDRS scores. As mentioned earlier, this could be the result of the timeframe of the study. If brain circuits involved in sensorimotor coupling ability are undergoing plasticity, they may only be able to support enhanced rhythmic movement on a small scale (a tapping task, for instance) until changes in circuitry are further stabilized. Perhaps testing these participants at a later date would reveal more consistency in sensorimotor coupling ability and a resulting enhanced responsiveness to dance classes for PD.

The effects of dance classes may also be impacted by socialization and a sense of community, although we did not test this directly. Because the disease can severely affect an individual’s ability to navigate public spaces and can draw unwanted attention, it is common for people with PD to experience anxiety, stress, and a lack of motivation to participate in activities. Providing a supportive environment of peers may assuage some of this stress and anxiety, resulting in reduced allostatic load. Allostatic load has been associated with inflammatory response (Karatsoreos and
McEwen, 2011), so it is possible that activities that reduce allostatic load could also reduce inflammation resulting from PD pathology.

Incorporating movement and social interaction with music could further decrease stress and anxiety and, consequently, neuroinflammation (Knight and Rickard Ph, 2001; Jensen and Bonde, 2018). As music can induce relaxation, which has been shown to affect gene expression patterns involved in inflammatory pathways and oxidative stress (Kuo et al., 2015; Bhasin et al., 2018), the integration of music and movement therapy could reduce pathological markers of PD. While unaddressed in the current study, these potential biological effects of dance deserve further investigation.

4.2 Limitations

This study has a number of limitations. While all PD participants were tested around the same time of day (late morning and midday), in an “on” phase during testing, and taking some form of dopaminergic, we did not control for individual differences in pharmacological routine. We also did not control for participation in additional therapies beyond the attendance of weekly dance classes because of the potential benefit other therapies may have provided.

Another limitation of this study is the fact that we were unable to conduct a randomized controlled trial. Because all PD participants were recruited directly from Dance for PD® classes, we could not randomly assign participants to experimental and control cohorts.

UPDRS scoring was also done without blinding. Many participants expressed resistance to signing the video consent form we provided. As a result, the UPDRS
could not be videotaped and scored by a third party, introducing potential bias to the scoring of the therapeutic outcome measure.

A final drawback to this study is a potential test re-test issue. Because participants completed the same tests (UPDRS, BAT, and tapping task) during both initial and follow-up interviews, they may have been more comfortable during the second round of testing, perhaps skewing results. Adding to the test re-test reliability issue is the possibility that participants were simply more comfortable with the tester, as the same person interviewed every participant at both time points.

4.3 Conclusion and Future Directions

Here, we provide further evidence that participation in the arts—in this case, dance—has impactful physical effects in a disease population. Our findings support the implementation of dance programs in PD communities, as dance classes create a supportive environment that can improve motor ability and decrease symptom severity. Our results also support involvement in dance for healthy individuals, as the presence of previous dance training, regardless of age, was enough to significantly affect the therapeutic outcome of movement therapy. The more accessible dance classes become, the better.

Looking ahead, it would be beneficial to extend the current study so that more PD communities could be invited to participate. Adding a third interview after follow-up testing may also further elucidate groove-related effects on sensorimotor experience and the effects of dance classes on participants without previous dance training.
In light of previous and current findings, more research is needed to investigate changes in the biomarkers of PD pathology such as levels of inflammatory cytokines, markers of oxidative stress, and cortisol. This analysis would deepen our understanding of the underlying mechanisms supporting the effects of the dance intervention and could help identify more factors that may influence therapeutic outcome.

Given the clear benefits of dance in a PD population, dance classes should be implemented in PD treatment plans and tested widely to see if these effects can translate to other disease populations.
Acknowledgements

This work would not have been possible without the efforts, enthusiasm, and support of my advisor, Psyche Loui. Dr. Loui’s willingness to take on this project has enabled me to investigate a topic I am passionate about under the best possible guidance. Her evident love for research and deep understanding of investigative and analytic methods are inspiring and have been a constant source of motivation. It has been an honor to work with her and learn from her throughout this process.

I want to thank David Leventhal, one of the founders of Dance for PD®, for being supportive of my study and for setting a standard of generosity, respect, and professionalism in the program. Thank you also to Jessica Grahn for her helpful advice and guidance on this project. I am lucky to have benefited from her expertise in rhythm perception and experience working with Parkinson’s populations.

I am also indebted to my parents, who have never wavered in their support of my passions. Their friendship and love have kept me on track and have taught me to prioritize the important things. I am especially grateful to my mom for introducing me to Dance for PD®. Since she first got involved with the program many years ago, it has been a joy and a privilege to watch her grow into the role as a teacher that she is so clearly meant for. I have loved dancing alongside her and hope to be able to carry the joy and kindness she exudes into a Dance for PD® community of my own.

Finally, thank you to my friends for their unconditional support. They have made Wesleyan into a home and I have benefited from their intellect and kindness each day. I owe much of who I am and what I have accomplished to their friendship.
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