CHOREOGRAPHING CHANGE: A LONGITUDINAL EXPLORATION OF COGNITIVE RESILIENCE AND NON-MOTOR WELL-BEING THROUGH COMMUNITY DANCE FOR PARKINSON'S DISEASE

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ABSTRACT

Parkinson's disease (PD) is a progressive brain disorder characterized by motor, cognitive, and non-motor symptoms that substantially impact quality of life. Medical treatments often target motor symptoms, indicating that alternative approaches to support cognitive and non-motor health are desperately needed. While reported benefits of dance indicate the potential to alleviate symptom burden, the existing literature has largely prioritized motor outcomes or short-term interventions. Focusing on cognitive and non-motor symptoms, this thesis first synthesized the literature on the effects of dance on motor, non-motor, and cognitive domains in PD, followed by two longitudinal observational studies examining global cognition, as well as sleep-related and overall non-motor symptom burden, over six years in individuals with PD participating in community dance compared to a non-dancing PD group. Findings of the present thesis demonstrate the benefits of sustained dance engagement, suggesting that community-based dance may support cognitive and non-motor health in PD.

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LIST OF ABBREVIATIONS

6MWT – Six-Minute Walk Test

ABC – Activities-Specific Balance Confidence

AD – Alzheimer's Disease

BDI – Beck Depression Inventory

BBS – Berg Balance Scale

BOLD – Blood-Oxygen-Level-Dependent

DfPD – Dance for Parkinson's Disease

EDS – Excessive Daytime Sleepiness

FAB – Frontal Assessment Battery

GEE – Generalized Estimating Equations

GLMM – Generalized Linear Mixed Models

H&Y – Hoehn & Yahr

JBI – Joanna Briggs Institute

LMM – Linear Mixed Models

LTA – Leisure Time Activity

M – Mean

MADRS – Montgomery-Asberg Depression Rating Scale

MCI – Mild Cognitive Impairment

MDS-UPDRS – Movement Disorders Society Unified Parkinson's Disease Rating Scale

[*Note.* Abbreviated as MDS-UPDRS and/or UPDRS]

Mini-BESTest – Mini Balance Evaluation Systems Test

MJFF – Michael J. Fox Foundation

MMSE – Mini-Mental State Examination

MoCA – Montreal Cognitive Assessment

MRI – Magnetic Resonance Imaging

NBS – National Ballet School (CANADA)

OLS – Ordinary Least Squares

ORE – Office of Research Ethics (York University)

PASE – Physical Activity Scale for the Elderly

PCC – Population, Concept, Context

PD – Parkinson's Disease

PDD – Parkinson's Disease Dementia

PDQ-39 – Parkinson's Disease Questionnaire 39

PPMI – Parkinson's Progression Marker's Initiative

PRISMA-ScR – Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews

PwPD – Persons with Parkinson's Disease

RCT – Randomized Controlled Trial

SD – Standard Deviation

TMT A/B – Trail Making Test (Parts A & B)

TUG – Timed Up and Go

CHAPTER 1

1. INTRODUCTION

1.1 Background and Rationale

Aging is a natural and inevitable part of the human experience, influencing how we live, function, and interact with the world. While many individuals age successfully, others may face obstacles that hinder their quality of life and shorten their lifespan (Hou et al., 2019). As the Canadian population ages, the number of seniors facing age-related health complications is also increasing (Government of Canada, 2022). The aging process is associated with several risk factors which may significantly impact the trajectory of our lives. As we begin to age, our susceptibility to neurodegeneration, that is, the deterioration of vulnerable brain cells, increases (Dugger & Dickson, 2017; Hou et al., 2019). Although seen in disease-free brains, neurodegeneration is a characteristic feature of neurodegenerative illnesses, such as Alzheimer's disease and Parkinson's disease (PD) (Hou et al., 2019; Wyss-Coray, 2016). As the second most common neurodegenerative disorder after Alzheimer's, PD presents a growing concern for healthcare systems and aging populations worldwide (Fereshtehnejad & Lökk, 2025). While PD is traditionally marked by motor impairments, many individuals suffer from additional non-motor symptoms, including cognitive impairments and sleep disturbances, which may significantly hinder quality of life (Kouli et al., 2018; Marinus et al., 2018). Given the lack of a cure, along with most existing treatments tailored to motor impairments, there is an increasing

interest in alternative approaches, such as dance, to halt disease progression and improve quality of life (Carapellotti et al., 2020; Church, 2021).

This thesis aims to explore how long-term engagement in a dance intervention influences cognitive and select non-motor symptoms in persons with PD (PwPD). The primary study demonstrates the impact of dance on global cognitive performance across a six-year period. Building on these findings, my second project investigates the effects of longitudinal dance on domain-specific cognitive outcomes and sleep disturbances within the same study population.

1.2 Understanding Parkinson's Disease

The term Parkinson's disease was coined by Jean-Martin Charcot in acknowledgement of James Parkinson, who originally described the condition as 'Shaking Palsy' in 1817 (Obeso et al., 2017). PD is a brain disorder which progressively worsens with age and is characterized by the loss of dopamine neurons in the substantia nigra, a region of the basal ganglia (Radhakrishnan & Goyal, 2018; Wu et al., 2012). Dopamine is partly responsible for balancing the direct and indirect pathways of the basal ganglia, with the loss of dopamine reducing activation of the direct (movement-facilitating) pathway and over-activating the indirect (movement-inhibiting) pathway, leading to motor dysfunction (Latif et al., 2021). As these brain changes begin early on, it is estimated that PwPD will have lost close to 70% of dopamine by the time motor symptoms appear (Bock et al., 2023; Radhakrishnan & Goyal, 2018).

PD affects both sides of the body, however, symptoms typically manifest on one side and lack symmetry (Radhakrishnan & Goyal, 2018). The Hoehn and Yahr Scale (H&Y), which was

published in 1967, is a measure of disease progression (Dallaire et al., 2024; Goetz, 2011). The scale is also used to differentiate between the unilateral and bilateral stages of the disease, with stage one indicating impairment on one side of the body, and stage two onward indicating impairment on both sides (Dallaire et al., 2024; Goetz, 2011). Bradykinesia (reduced motor speed), rigidity (muscle stiffness), and resting tremor, with postural instability (impaired balance and stability) appearing later on, are characterized as the hallmark symptoms of PD. As the disease progresses, PwPD may also experience secondary motor impairments, such as disturbances in gait, speech, and handwriting. Gait impairments, including shuffling and freezing of gait, are considered one of the most common secondary motor symptoms in PD (Mirelman et al., 2019; Moustafa et al., 2016). In addition, PD makes up approximately 80% of Parkinsonism conditions, which are brain disorders marked by various motor impairments, including bradykinesia and gait dysfunction (Hayes, 2019).

1.3 Prevalence and Impact on Public Health

Age is the most significant risk factor for PD. The approximate age of onset is 60 years (Kouli et al., 2018; Obeso et al., 2017). While most cases are idiopathic, some have been linked to genetic mutations (e.g., SNCA and PARK2) and environmental exposures such as pesticides and pollution (Bloem et al., 2021; Kouli et al., 2018). Interestingly, neuroprotective factors that may help in lowering the risk of PD include caffeine consumption, cigarette smoking, and engaging in physical activity (Bloem et al., 2021; Kouli et al., 2018).

PD alone affects approximately 0.5 to 1% of people between the ages of 65 and 69 years, increasing to almost 3% for those aged 80 years and up (Kouli et al., 2018). By 2016, there had

been over 6 million cases globally and close to 99,000 cases across Canada, rising to over 100,000 by 2021 (Bloem et al., 2021; Canada, 2014; Crighton et al., 2024). The prevalence of PD is considered a "rising tide" due to a decline in smoking, aging populations, and increased lifespans (Dorsey et al., 2018), with cases expected to double within the next five years (Marras et al., 2018). In Canada alone, cases are anticipated to increase by 65%, going past 160,000 by 2031 (Canada, 2014).

Beyond clinical implications, PD poses a financial burden on PwPD, their families, and the healthcare system (Maclagan et al., 2025). In 2024, the annual cost of PD in Canada exceeded $3 billion (Derksen, 2024). The cost of medical care for persons with PD (PwPD) vary greatly and are influenced by many factors, including disease progression, severity, and other complications. Major contributors to high medical expenses include hospitalizations, along with both residential and home care (Maclagan et al., 2025). In an investigation from 2009 to 2019, Maclagan et al. (2025) found that older PwPD (≥66 years) living in Ontario had higher costs, compared with younger PwPD (<66 years), as a result of more frequent hospitalizations, rehabilitation, and home care, as well as the need for nursing home placement. However, costs for additional healthcare services, including psychiatric care and visits to other healthcare professionals, were higher among younger PwPD (Maclagan et al., 2025).

1.4 Non-Motor Symptoms of Parkinson's Disease

The rising costs associated with PD may be attributed to the burden and complexity of the symptoms, which also includes an extensive range of non-motor symptoms (Maclagan et al., 2025). While PD is often defined by its motor symptoms, cognitive decline and additional non-

motor impairments have been found to significantly impact disease trajectory and quality of life (Kouli et al., 2018). Non-motor symptoms may appear decades before the onset of motor symptoms, and progressively worsen with disease progression which further contributes to disability and poor quality of life (Kouli et al., 2018; Radhakrishnan & Goyal, 2018). Non-motor symptoms often observed include cognitive decline, sleep dysfunction, and psychiatric disturbances, among others (see Table 1 below) (Kouli et al., 2018; Marinus et al., 2018).

Domain	Symptom/Example
Cognitive Dysfunction	Mild cognitive impairment Executive dysfunction Dementia
Autonomic Dysfunction	Orthostatic hypotension Urogenital dysfunction/urinary problems Constipation Sexual dysfunction Thermoregulatory dysfunction
Sleep Dysfunction	Insomnia Excessive daytime sleepiness Sleep attacks REM sleep behaviour disorder Restless legs syndrome Sleep fragmentation
Neuropsychiatric Disorders	Fatigue Apathy Depression Anxiety Impulsive-compulsive disorders Psychosis
Sensory Disorders	Colourvision deficits Abnormal sensations Olfactory impairment Stereopsis Musculoskeletal/neuropathic pain Akathisia discomfort

Table 1.1. List of non-motor symptoms commonly observed among PwPD (Pfeiffer, 2016; Wolters et al., 2008).

Sleep disturbances are among the most common non-motor symptoms and may include rapid eye movement sleep behaviour disorder, insomnia, excessive daytime sleepiness, and obstructive sleep apnea (Church, 2021; Radhakrishnan & Goyal, 2018). Excessive daytime sleepiness (EDS), characterized by the inability to stay alert and awake during typical waking hours, is one of the most common sleep-related disturbances, affecting as many as 60% of individuals with PD (Marinus et al., 2018; Rana et al., 2015). Risk factors for EDS include depression, insomnia, cognitive decline, higher scores on the H&Y scale, and the use of dopaminergic medications (Liu et al., 2022; Marinus et al., 2018; Rana et al., 2015). Moreover, EDS is further associated with poor non-motor and motor symptoms, as assessed by Part I and II of the Unified Parkinson's Disease Rating Scale (Yousaf et al., 2018). As a significant burden on quality of life, EDS can affect daily functioning, including vocational performance and psychological well-being. EDS may lead to a loss of independence, social isolation, low self esteem, cognitive decline, hallucinations, and insomnia (Marinus et al., 2018; Rana et al., 2015; Schapira et al., 2017; Shen et al., 2018).

Insomnia is another prevalent and distressing sleep disturbance, affecting up to 80% of PwPD (Loddo et al., 2017; Marinus et al., 2018; Wallace et al., 2020). It is characterized by the difficulty in falling and/or maintaining sleep, and/or waking up too early (Wallace et al., 2020). Motor symptoms of PD may contribute to sleep disruption (Amara et al., 2017; Duan et al., 2025). Bradykinesia and rigidity may interfere with turning in bed, while tremors may be present during brief awakenings, worsening the quality of sleep (Amara et al., 2017). Beyond motor

symptoms, neurodegenerative changes in PD may impact brain regions involved in sleep regulation, such as the hypothalamus and amygdala (Duan et al., 2025). Insomnia is associated with depression, disease duration, cognitive impairment, and EDS as well (Amara et al., 2017; Marinus et al., 2018). Despite being among the most prevalent and distressing non-motor symptoms, EDS and insomnia are likely to go undiagnosed as many PwPD may not report them (Minakawa, 2022; Zuzuárregui & During, 2020).

1.5 Cognitive Decline in Parkinson's Disease

PD also appears on the spectrum of neurological diseases with Lewy bodies, which encompasses PD-dementia and dementia with Lewy bodies (DLB) as well (Sekiya et al., 2025). Lewy bodies are abnormal protein deposits, consisting of misfolded alpha-synuclein, that disrupt functional activity within vulnerable brain regions. Despite a shared underlying Lewy body pathology, these disorders differ in their clinical features, with PD predominately characterized by motor symptoms (Schulz-Schaeffer, 2010). PD-dementia involves the progression of cognitive decline in pre-established PD, while DLB reflects early cognitive impairment with Parkinsonism present later on (Gonzalez et al., 2023). Pathophysiologically, Lewy bodies in PD are associated with the initial accumulation in the brainstem, with progression to additional brain regions and dementia emerging later on, aligning with the Braak staging of neurodegenerative disease progression (see Figure 1) (Braak et al., 2003; Haider et al., 2023; Johns, 2014; Walker et al., 2019). In DLB, however, severe cognitive decline precedes motor impairment with Lewy bodies initially present in the cerebral cortex (Haider et al., 2023; Mrak & Griffin, 2007), in addition to the brainstem and limbic system (Garcia-Esparcia et al., 2017).

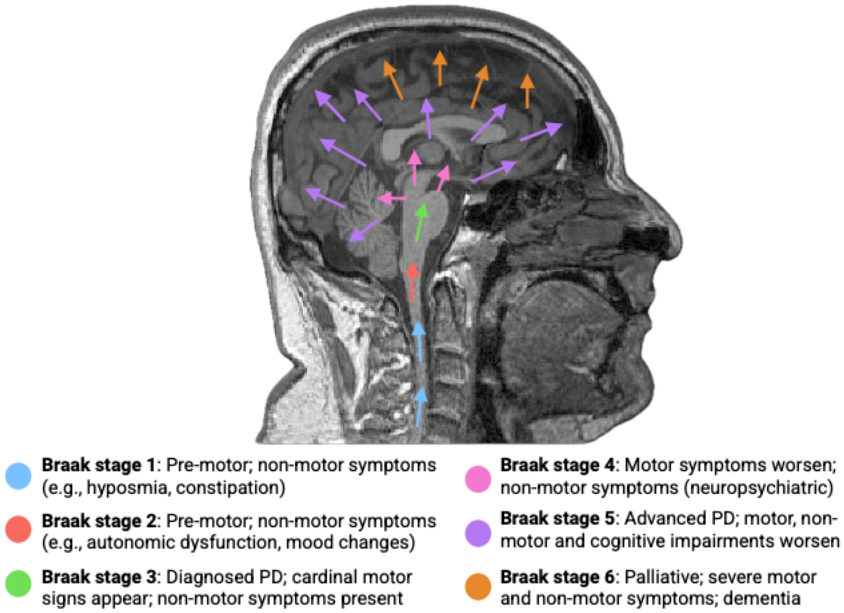

Figure 1.1. Medial view of the brain illustrating the Lewy body progression across the proposed Braak stages 1-6 in PD (Braak et al., 2003; Choudhury et al., 2022). Anatomical scan provided by a colleague, with visualization created in BioRender.com.

Cognitive decline is a major non-motor symptom of PD and may develop decades before the onset of motor symptoms (Kouli et al., 2018). PwPD are six times more likely to experience cognitive decline than the general population (Aarsland et al., 2021). A longitudinal study on PwPD who had normal cognition at baseline found that almost half developed cognitive impairments within five years, and those who developed mild cognitive impairment (MCI) eventually progressed to dementia (Davis & Racette, 2016). MCI is the period in between normal cognition and dementia, where cognitive impairment is more severe than would be expected for the person's age. Estimates from recent literature suggest that between 10 and 35% of PwPD have MCI at diagnosis, increasing to almost 50% after five years (Aarsland et al., 2021; Hattori et al., 2022). Additional research suggests that more than 80% of PwPD with MCI eventually

progress to dementia, further indicating that MCI may be a significant risk factor for dementia in PD (Aarsland et al., 2021; Fang et al., 2020).

Among PwPD without dementia, individuals may experience deficits in visuospatial, attention, working memory, executive and memory domains (Kulisevsky, 2000; Mckinlay et al., 2010; Pal et al., 2018). Executive dysfunction is regarded as a hallmark cognitive impairment in PD (Chiaravalloti et al., 2014), and comprises a range of cognitive skills, including working memory and attention (Parker et al., 2013). Working memory involves the maintenance, or storage, and manipulation, or reordering, of stored information (Hattori et al., 2022; Owen et al., 2005). In PwPD, deficits in working memory may stem from reduced storage capacity and/or the inability to process relevant information (Lee, 2023). Impairments in executive functioning may also lead to difficulties in problem solving, thinking, organization, planning, and attention (Kulisevsky, 2000). Executive functioning is an integral part of our daily lives because it involves the planning and execution of activities, some of which may not be structured or part of daily routine. Impairments in executive functions can make it difficult for PwPD to manage their daily lives with routines becoming disrupted. Even managing simple tasks, such as having or holding a conversation with a loved one, can become difficult for PwPD (Koerts et al., 2011). Such impairments may result in uncoordinated and unregulated behaviours, thus contributing to a poor quality of life. Executive dysfunction may further predict dementia in PwPD as suggested in previous literature (Lange et al., 2018).

Visuospatial ability is another cognitive skill under the umbrella of executive functions that may become compromised in PwPD, making it difficult when navigating the environment and interpreting surroundings (Oliveira et al., 2025). Visuospatial dysfunction may hinder driving capability, heighten fall risks (Oliveira et al., 2025), and simple tasks including reading

and writing become challenging for PwPD (Nieto-Escamez et al., 2023). As our ability to perceive and judge spatial locations relies on attentional engagement, visuospatial processing and attention, also part of executive functioning, are closely related (Kawashima et al., 2021). Attention is regarded as a core cognitive skill that is responsible for allocating cognitive capacity to task-relevant information (Pauletti et al., 2017). It has been further noted that the dopaminergic dysfunction seen in PD disrupts the balance between attention and working memory which contributes to attentional deficits and impairments in working memory processes (Botha & Carr, 2012).

PwPD may experience deficits across multiple aspects of memory, including recognition, recall, episodic and prospective memory (Whittington et al., 2006). An early study by Breen (1993) found that although recall may be impaired in PD, performance on tasks assessing recognition were similar across PwPD and healthy controls. In contrast, later studies have observed conflicting findings with some suggesting deficits in both recall and recognition (Siquier & Andrés, 2022), and others observing stability in recognition (Sugimura et al., 2025). Additionally, PwPD may perform worse on tasks assessing episodic memory, defined as the retrieval of information that is tied to a specific time and space (Lee, 2023). It has also been suggested that a decline in episodic memory during the early stages of the disease may predict further cognitive decline in PwPD (Dunet et al., 2019). Lastly, prospective memory, that is our ability to remember performing an action in the future, is an essential skill when performing daily tasks, such as remembering to turn on a kitchen appliance when the timer goes off, and may become hindered in PD (Whittington et al., 2006). Studies have also shown that reduced quality of life is associated with cognitive impairments, specifically with memory and attentional deficits (Fan et al., 2020).

1.6 Quality of Life and Current Treatment Limitations

Non-motor symptoms, including cognitive decline, significantly contribute to further impairment (Church, 2021). Disease progression coupled with symptoms worsening over time leads to poor quality of life, a lack of autonomy, and the need for caregivers to provide physical, emotional, and financial support (Martinez-Martin et al., 2012; Schrag et al., 2006). Lower quality of life is further associated with symptom fluctuations (Van Munster et al., 2024), cognitive impairment (Martinez-Martin et al., 2012), sleep and behavioural disturbances (Leroi et al., 2012; Zhao et al., 2021), impaired physical functioning, including gait disturbances, and additional non-motor symptoms, such as depression, apathy, and agitation (Martinez-Martin et al., 2012). The presence of cognitive decline and additional non-motor symptoms is linked to worse caregiver burden than motor symptoms which may lead to worse physical health in both PwPD and their caregivers (Aamodt et al., 2024).

While PD is incurable (Church, 2021), symptoms can be managed through pharmacological and surgical interventions (Kouli et al., 2018; Radhakrishnan & Goyal, 2018). Deep brain stimulation is a surgical procedure used to address motor symptoms during the advanced stages of the disease (Santos et al., 2023). Although deep brain stimulation is considered beneficial for improving quality of life and reducing symptom burden, the eligibility criteria typically require healthy cognition which may preclude PwPD-MCI and PwPD-dementia from receiving this treatment (Munhoz et al., 2016). Given Canada's aging population, another limitation reflects the country's capacity to provide this procedure for eligible patients, especially given the limited number of trained neurosurgeons available resulting in year-long waittimes (Santos et al., 2023).

Levodopa, which is a dopamine replacement strategy, is the current gold standard pharmacological therapy used to help alleviate motor symptoms, such as bradykinesia and rigidity (Gandhi & Saadabadi, 2025; Radhakrishnan & Goyal, 2018). Although Levodopa may aid in reducing the progression and disability associated with the disease, benefits are often limited to the management of motor symptoms and certain limitations arise, especially with sustained use (Radhakrishnan & Goyal, 2018). Long-term levodopa usage is associated with fluctuations of both motor and non-motor symptoms (Kouli et al., 2018; Radhakrishnan & Goyal, 2018; Scott et al., 2016). Previous research has also shown an increase in motor symptom fluctuations and the development of dyskinesia after approximately 7 years of levodopa-usage (Scott et al., 2016). Additionally, motor, and non-motor symptoms typically become resistant to levodopa during the advanced stages of the disease (Radhakrishnan & Goyal, 2018).

Numerous studies have also shown that Levodopa, for example, provides limited to no benefits for non-motor symptoms, including cognitive impairments (Aarsland et al., 2021; Carceles-Cordon et al., 2023; Yin et al., 2025). While the underlying mechanisms of cognitive decline remain unknown, the accumulation and spread of Lewy bodies are considered a key factor (Aarsland et al., 2021; Carceles-Cordon et al., 2023; Yin et al., 2025). Because Levodopa acts as a compensatory mechanism for the degeneration of dopaminergic neurons seen in PD, rather than targeting Lewy body pathology, it is generally considered ineffective in alleviating PD-related cognitive impairments (Yin et al., 2025).

Interestingly, with respect to sleep dysfunction, some dopaminergic therapies have been found to provide therapeutic benefits for sleep quality among PwPD (Amara et al., 2017; Ledda et al., 2024). However, the literature surrounding the benefits of dopaminergic therapies for sleep function are inconsistent and remain unclear, with additional studies suggesting they may worsen

insomnia and EDS (Amara et al., 2017; Scanga et al., 2023). Dopaminergic therapies may also contribute to sleep attacks among PwPD with EDS (Chaudhuri & Logishetty, 2009). Low doses of some dopamine medications have been shown to improve sleep quality, however, higher doses may induce insomnia among PwPD (Chaudhuri & Logishetty, 2009). Nevertheless, sleep disturbances, as a whole, represent a prevalent and crucial non-motor symptom, affecting over 90% of PwPD and highlighting the need for adequate treatment (Amara et al., 2017).

1.7 The Promise of Alternative Approaches

Given the complications associated with current medical treatments available for PwPD, such as pharmacological and surgical options, there has been a growing interest in alternative approaches to better support this population. Researchers have been exploring alternative and innovative therapies, such as dance, to halt disease progression and improve quality of life. Bearss & DeSouza (2021) recently demonstrated improved motor and non-motor outcomes in PwPD who engaged in community dance classes over a three-year period. Compared to traditional exercise and music-based therapies, dance uniquely combines physical activity with rhythm, music, and social interaction, while stimulating brain regions involved in cognitive and motor functions. Through the incorporation of external cues, dance also taps into psychological and emotional aspects that are crucial for improving quality of life in PwPD (Earhart, 2009).

Importantly, qualitative studies have suggested that community-based dance programs have led to improved psychosocial well-being, especially after receiving a PD-diagnosis (Jola et al., 2022). Structured programs, such as the Dance for PD (DfPD) project founded by the Mark Morris Dance Group, are tailored for PwPD to ensure their classes are designed to maximize benefits. DfPD classes, which are a combination of various dance styles, consist of seated warm-

ups, standing ‘barre’ movements, ending with travelling (across the floor) choreographic sequences. Such programs are generally offered at no cost and encourage the participation of caregivers, fostering a sense of social support and community (Westheimer et al., 2015). In contrast, traditional exercise programs often require gym memberships, which may present a financial barrier. Participation in traditional exercise typically does not require a partner, thus offering fewer opportunities for social engagement as well (Bremer, 2007). Furthermore, the intensity of traditional exercise may be physically challenging, resulting in early discontinuation (Zhang et al., 2019).

Although numerous studies have investigated the impact of dance on PD, the majority have primarily focused on motor outcomes. As a movement disorder, motor manifestations are a major component of PD, however, this narrow focus seems to overlook the burden of cognitive and non-motor symptoms while disregarding early clinical descriptions of the disease. Back in 1817, James Parkinson had documented sleep dysfunction among PwPD in his original essay (Parkinson, 2002). Similarly, in his understanding of PD, Jean Charcot had suggested some degree of cognitive decline as well (Merello & Starkstein, 2002; O’Callaghan & Lewis, 2017). Despite the initial observations of James Parkinson and Jean Charcot, much of the literature has continued to focus on motor manifestations of PD. This gap in the literature highlights the need for a comprehensive synthesis of the effects of dance on cognitive and non-motor outcomes in PD. Accordingly, the present thesis first provides a scoping review on the distribution of motor, non-motor and cognitive outcomes across dance-based interventions in PD, followed by empirical analyses examining cognitive and non-motor symptom outcomes across a six-year community-based dance intervention.

CHAPTER 2

2. DANCE AS REHABILITATION IN PARKINSON'S DISEASE: A SCOPING REVIEW OF COGNITIVE, MOTOR AND NON-MOTOR OUTCOMES

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Author Contributions: Simran Rooprai was responsible for the study conceptualization, methodology, data extraction, interpretation of findings, visualization, manuscript writing. Nicholas Ramcharran and Caitlin van den Hoorn assisted as independent reviewers as required by the scoping review guidelines. The supervisory committee (Drs. Jenna Smith-Turchyn, Nicole D. Anderson, and Joseph FX DeSouza) provided guidance and manuscript revisions.

Abstract

Background: Dance is regarded as a multimodal experience which integrates movement, music, cognitive, and social engagement, potentially providing a non-pharmacological care approach for persons with Parkinson's disease (PwPD). While numerous studies have investigated the benefits of dance for motor outcomes, less is known about the influence on cognitive and non-motor symptoms.

Objective: To explore the scope and characteristics of dance-based interventions for PD, focusing on how cognitive and non-motor domains are represented relative to motor outcomes.

Methods: Guided by the Joanna Briggs Institute (JBI) methodological framework for scoping reviews, three databases were searched to identify relevant literature, followed by title, abstract, and full text screening by three independent reviewers. Data were extracted on study and intervention characteristics, outcome domains, and reported effects.

Results: Thirty-eight studies met the inclusion criteria. The most used interventions were tango and Dance for Parkinson's Disease (DfPD) programs, typically delivered in community settings, twice weekly, for approximately 60 minutes per session. In contrast to motor symptoms, which were assessed most frequently (89%), non-motor and cognitive symptoms were assessed in 76% and 47% of studies, respectively. Motor outcomes demonstrated the most consistent improvements (84%), followed by non-motor improvements (53%) and cognitive gains (32%). Collectively, non-motor and cognitive outcomes were increasingly assessed within the last decade and demonstrated variable findings.

Conclusion: Although cognitive and non-motor symptoms have a well-documented impact on quality of life in PD, these domains have received less attention than motor outcomes within the dance-based literature. Measures of cognitive and non-motor outcomes, alongside longer-term

interventions with larger samples, should be incorporated in future protocols for a better understanding of the multidimensional impact of dance in PD.

2.1 Introduction

Historically, dance has been an inherent part of human behaviour, stretching back thousands of years and across many cultures (Blacking, 1983; Cirelli & Kragness, 2025). Throughout the centuries, dance has played an important role in healing, yielding significant benefits for our physical, social, psychological, and neurocognitive health (Block & Kissell, 2001). Healing circles, for example, are a traditional practice in Indigenous cultures across Canada where different art forms, including dance, are incorporated to promote the journey of healing while fostering relationships and support (Mehl-Madrona & Mainguy, 2014). In many cultures, dance is described as a medium for non-verbal communication, further symbolic of strengthening communities through storytelling and personal expression (Wu, 2023). In South Asian communities, traditional folk dances, like Bhangra, are deep-rooted in cultural heritage and are often performed during celebrations (Schreffler, 2013). Ancient Middle Eastern dance forms, such as 'belly dancing', are further associated with women's empowerment, providing an avenue for socialization and sisterhood (Moe, 2012). Generally, dance embodies creativity and rhythmic movements integrated with core features, including social relationships, physiological harmony, musical engagement, and mindfulness (Sansom, 2011; Zygmont et al., 2023). Compared to traditional exercise, the rhythmic movements performed during dance transcend normative bodily movements (Foster Vander Elst et al., 2023). Beyond the holistic mind-body experience, modernization has also led to the conceptualization of dance as a therapeutic activity in the 20th century (Kormos, 2023).

Researchers initially began investigating the restorative potential of dance to better understand its influence on different aspects of well-being, including social, physical, and mental health, during the 1940s and 50s (Du et al., 2025; Kormos, 2023). In the context of therapy, the embodiment theory, which emphasizes the impact of bodily movements on the mind, has been previously applied to dance as well (Piran et al., 2023). As a healing art, dance extends beyond traditional physical activity and functions as a multimodal practice with the potential to enhance health and improve quality of life (Cox & Youmans-Jones, 2023; Dhami et al., 2015). The therapeutic and health-promoting properties of dance have also led to the development of evidence-informed programs aimed at supporting community well-being (Westheimer, 2008; Westheimer et al., 2015). One such condition where dance-based programs have gained recognition is Parkinson's Disease (PD), an incurable neurodegenerative condition that progressively impairs physical, cognitive, psychological, and social health (Vaseinasrabadi & DeSouza, 2025). Given the multidimensional aspects of dance, numerous studies have posited dance as a non-pharmacological intervention to address the complex symptomatology of PD. Spanning both motor and non-motor disturbances, persons with PD often experience bradykinesia, tremors, rigidity, cognitive impairments, sleep disturbances, autonomic dysfunction, and mood symptoms, among others (Hasan et al., 2022; Vaseinasrabadi & DeSouza, 2025; Ventura et al., 2016).

While treatments are available, pharmacological approaches to care may not be suitable for all persons with PD (PwPD) given the heterogeneous profile of the disease (Carapellotti et al., 2020; Gyrling et al., 2021; M.E. McNeely et al., 2015). Alternative strategies in use across clinical and community settings include music-based therapies, physical exercise, and cognitive training, however, dance uniquely combines music, movement, and cognitive stimulation,

offering a single multimodal experience (Jola et al., 2022). The neuroscience behind dance suggests several interconnected brain regions become engaged and activated to initiate and perform choreographic sequences (Foster Vander Elst et al., 2023; Hackney et al., 2024). These brain areas include the motor cortex, for the planning and execution of movements, the basal ganglia and cerebellum, for attention and executive control, the limbic system, for emotion and motivation, as well as the auditory cortex, for rhythmic and musical processing (Basso et al., 2021; Foster Vander Elst et al., 2023). Interestingly, research has shown that dance engages the action observation network, consisting of the premotor and parietal brain areas, which become active during the observation of dance performances (Lesourd et al., 2023; Orgs et al., 2024). Dance can be further positioned as a learning exercise as the memorization and recall of movements activate our learning and memory processes. As a group activity, dance engages our social cognition while activating working memory and visuospatial functions when executing movements alongside a partner or other dancers (Hackney et al., 2024). While these neural features highlight dance as a multidimensional activity with the potential to address the complex symptom profile seen among PwPD, much of the literature surrounding PD tends to overlook symptoms that go beyond motor manifestations (Aarsland et al., 2021; M.E. McNeely et al., 2015).

Given this critical gap in the literature concerning cognitive and non-motor impairments, this scoping review aimed to map the existing literature on dance-based interventions for PwPD, with attention to how cognitive, non-motor and motor outcomes are prioritized. The objective was to identify the scope, characteristics, and reported effects of dance interventions used within this population, with a primary focus on examining the extent to which cognitive and non-motor

symptoms have been explored, and a secondary focus on how frequently these domains are explored compared to motor outcomes.

Research Questions

1) What types of dance interventions have been used in PD and how are these interventions delivered (e.g., length, duration, frequency, and setting)?
2) What outcomes are most assessed in dance-based studies for PD, and how frequently are motor, cognitive, and non-motor domains evaluated?
3) What is known about the effects of dance-based interventions on motor, cognitive, and non-motor outcomes in PwPD?

2.2 Methods

This scoping review was conducted in accordance with the methodological framework outlined by the Joanna Briggs Institute (JBI) for scoping reviews (Peters et al., 2020). The review followed the Population, Concept, Context (PCC) framework and addressed clearly defined objectives and research questions. Reporting was in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) protocol (Tricco et al., 2018).

Eligibility Criteria

Studies were selected according to the PCC framework recommended by JBI. The selected *population* includes older adults diagnosed with PD at any stage of the disease, with no other neurological conditions. Eligible studies include individuals with idiopathic PD and varying levels of cognitive function, including healthy cognition, mild cognitive impairment

(MCI), or Parkinson's disease dementia (PDD). The *concept* focused on dance-based physical activity interventions, including but not limited to tango, ballet, contemporary, and adapted dance. Eligible interventions were required to use dance as the primary mode of movement. Studies were excluded if the intervention was not dance-based, e.g., general exercise, yoga, tai chi, or music-based therapies without dance.

The *context* included any setting, such as clinical, community-based, or home environments, with no restrictions on delivery format (e.g., in-person, virtual, or hybrid). Only studies published in the English language were eligible. With respect to types of *sources*, eligible study designs were those providing quantitative outcome data, such as randomized controlled trials (RCTs), quasi-experimental, longitudinal, observational, pre-post without a control group, cohort, and pilot studies. Animal studies and qualitative research, including reviews, commentaries, and case reports, were excluded. Because the focus of this scoping review was to isolate the effects of dance alone, studies involving participants with health conditions other than PD (e.g., Alzheimer's disease) were excluded.

Search Strategy

A three-step search strategy was employed in accordance with the JBI methodology for scoping reviews. First, an initial limited search of PubMed was conducted to identify relevant articles on dance-based interventions for PD. The text words contained in the titles and abstracts of these articles, along with MeSH and index terms, were analyzed to inform the full search strategy. Second, the full search strategy was adapted for and applied across three major databases: PubMed (MEDLINE), PsycINFO (via ProQuest), and Web of Science. The search strategy included Boolean operators (AND, OR) and database-specific indexing terms (e.g.,

MeSH in PubMed). Search terms included but were not limited to: “Parkinson’s disease,” “Parkinsons,” “dance,” “dance therapy,” “dance-based,” “cognition,” “cognitive function,” “cognitive impairment,” “motor function,” “motor impairment,” and “non-motor symptoms.” These terms were selected to align with the objectives of this review, and the search was designed to capture a broad range of relevant studies on motor, cognitive, and non-motor outcomes associated with dance-based interventions for Parkinson’s disease. The complete search strategies for each database, including all keywords and indexing terms, are provided in Appendix A. The date range for the search was limited to studies published between January 2000 and January 2025, reflecting the period in which dance began emerging as a therapeutic intervention for PD.

Study Selection

Following the completion of the database searches, all retrieved citations were imported into Covidence for duplicate removal. The de-duplicated list of studies was then uploaded into Zotero for citation management. A two-stage screening process was used to determine study eligibility. In the first stage, three reviewers completed the title and abstract review to exclude irrelevant records. In the second stage, full-text articles were retrieved and reviewed by two reviewers for inclusion based on the predefined eligibility criteria. Both stages of screening were conducted in accordance with the guideline for PRISMA-ScR scoping reviews and were completed in duplicate by all three independent reviewers. Reasons for full-text exclusion were documented. The selection process was summarized and visually presented using a PRISMA-ScR flow diagram.

Data Extraction

Data were extracted from included studies using a customized data charting form created in Microsoft Excel. The form was designed to capture key characteristics and findings relevant to the scoping review objectives. Extracted information included details on author(s), year of publication, and country. Study design and sample sizes were recorded, along with a description of the dance intervention, including the dance styles, frequency, duration, and setting. Participant characteristics such as age, sex, disease severity were also collected. Outcomes assessed were categorized as motor, cognitive, or non-motor, and the specific instruments or scales used to measure each outcome were recorded. Lastly, key findings relevant to each outcome domain were summarized and documented for synthesis. The charting form was refined iteratively as new variables emerged during the extraction process, consistent with JBI guidance. No critical appraisal or risk of bias assessment was conducted, in accordance with the objectives of scoping review methodology.

2.3 Results

Study selection

The database searches identified 246 records across PubMed, PsycINFO, and Web of Science. After removal of duplicates, 182 articles were screened by title and abstract of which 45 full texts were retrieved and assessed for eligibility. Following full-text review, 38 studies satisfied the inclusion criteria and were included in the final synthesis. The most common reason for exclusion were interventions that were not dance-based with one study only publishing a

protocol of a future study. A PRISMA-ScR flow diagram summarizing the selection process is presented in Figure 2.1.

Characteristics of included studies

The 38 included studies were published between 2009 and 2025 with a noticeable increase in publications after 2020 (see Appendix B for general study characteristics). Across the experimental literature (n = 20), where participants were randomized into groups, seven were conducted in the United States (Abraham et al., 2024; Duncan & Earhart, 2012; Hackney & Earhart, 2010, 2009; Jehu et al., 2025; McKee & Hackney, 2013; Marie E. McNeely et al., 2015), followed by Brazil (n = 4) (Dos Santos Delabary et al., 2020; Haas et al., 2024; Moratelli et al., 2022, 2023) and Australia (n = 3) (Haputhanthirige et al., 2023; Kalyani et al., 2020, 2019), with fewer studies conducted in Italy (n = 2) (De Natale et al., 2017; Volpe et al., 2025), Canada (n = 1) (Rios Romenets et al., 2015), Japan (n = 1) (Hashimoto et al., 2015), India (n = 1) (Mehta et al., 2024), and Belgium (n = 1) (Bouquiaux et al., 2022). A similar pattern was noticed across non-experimental literature (n = 18), involving non-randomization of participants across groups, the majority of studies originated from the United States (n = 5) (Fontanesi & DeSouza, 2021; Harrison et al., 2020; Krotinger & Loui, 2021; Prewitt et al., 2017; Westheimer et al., 2015), followed by the United Kingdom (n = 3) (Carapellotti et al., 2022, 2025; Jola et al., 2022), Brazil (n = 2) (Duarte et al., 2023; Tillmann et al., 2020), Canada (n = 2) (Bearss et al., 2017; Bearss & DeSouza, 2021), Germany (n = 2) (Dahmen-Zimmer & Jansen, 2017; Heiberger, 2011), Spain (n = 1) (Valverde-Guijarro et al., 2022), Korea (n = 1) (Kang et al., 2022), Greece (n = 1) (Elpidoforou et al., 2022), and one study conducted across three locations: USA, UK, and Italy (Sistarelli et al., 2023).

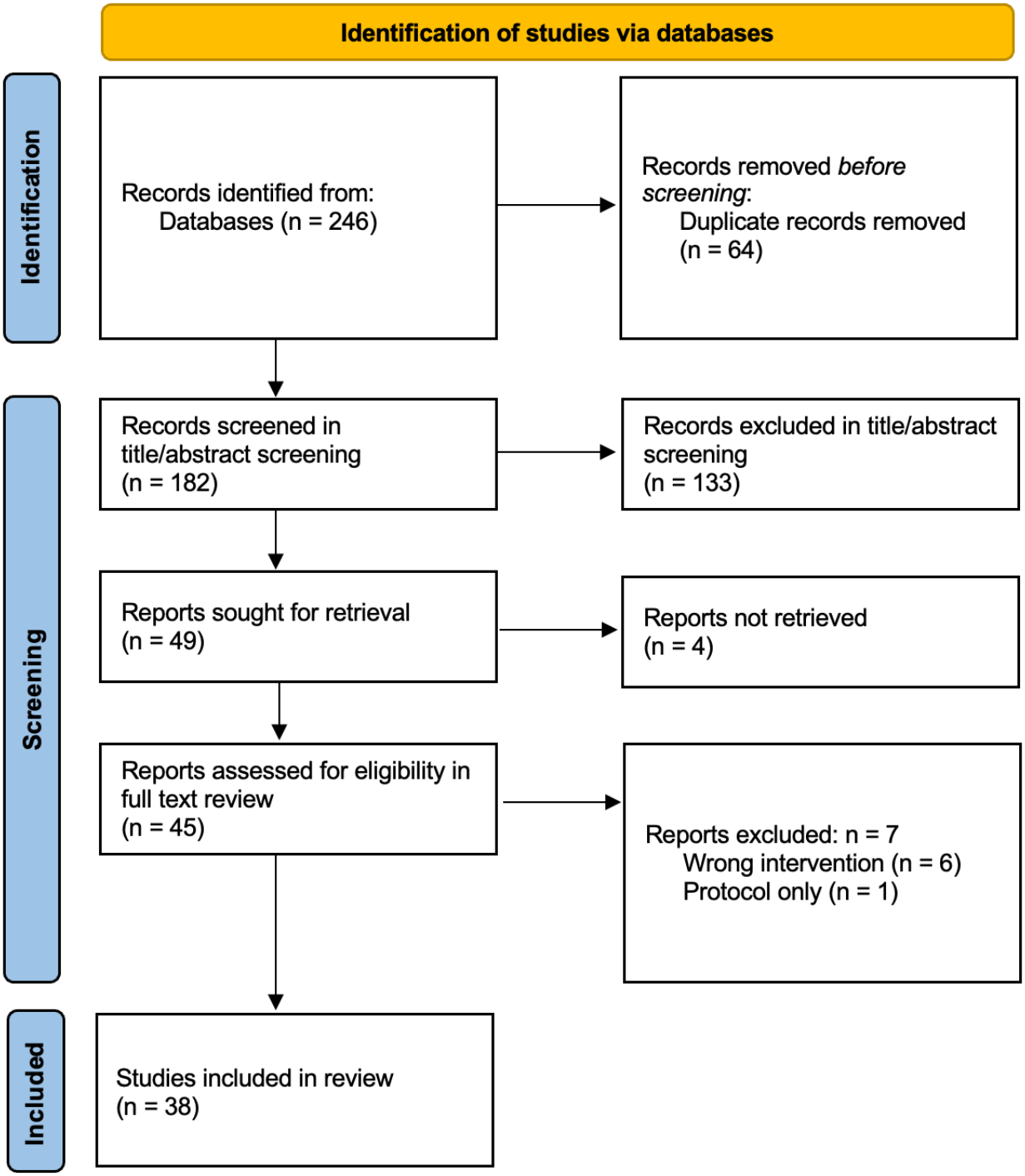

Figure 2.1. PRISMA flow diagram of the study selection process for the present scoping review.

Participant characteristics

Across the included studies, there were a total of 1143 participants with relatively small sample sizes, typically around ~30 subjects (see Appendix B). All participants had a clinical diagnosis of idiopathic PD with no additional neurodegenerative conditions. Mean ages typically ranged from mid-60s to early-70s with most participants falling between stages I and III of the Hoehn & Yahr scale, reflecting mild to moderate disease severity. Where sex distribution was reported, most studies generally recruited slightly more males than females. On average, males accounted for approximately 55% of the total sample size across 36 studies. Sex distribution was not provided by two studies (Fontanesi & DeSouza, 2021; Tillmann et al., 2020).

Characteristics of dance interventions

The most commonly used dance styles were adapted or Argentine Tango (n = 8; 21%) or based on the Dance for Parkinson's Disease (DfPD) method (n = 11; 28%), with a study by McNeely. (2015) incorporating both. A smaller number of interventions included contemporary dance (n = 3; 7%), mixed dance styles (e.g., line dance, Waltz and ballroom; n = 3; 7%), other dance programs for PD (n = 5; 13%), and additional dance styles (e.g., general or rhythm dance; n = 2; 5%), including Brazilian (n = 4; 10%) and Indian dances (n = 1; 2%) (see Table 2.1 for brief overview and Appendix B for further details). Most interventions were instructor-led (~33 studies; ~86%) involving professional dance instructors or therapists with specialized training in certain dance styles, including tango, contemporary, Feldenkrais, ballroom, and PD-related dance programs. While intervention durations varied widely, ranging from 4 weeks to 3 years, most were approximately 4 to 12 weeks. Where frequency was reported, most sessions were held up to 2 times per week and the majority of individual sessions typically lasted 60 minutes in

length. Interventions were primarily delivered in the community (~22 studies; ~57%), with some delivered in clinical or controlled settings (~12 studies; ~31%).

Dance Styles	Included Studies
DfPD (n = 12)	Bearss et al., 2017; Bearss & DeSouza, 2021; Carapellotti et al., 2022; Carapellotti et al., 2025; Elpidoforou et al., 2022; Fontanesi & DeSouza, 2021; Haputhanthirige et al., 2023; Heiberger, 2011; Kalyani et al., 2019; Kalyani et al., 2020; McNeely et al., 2015*; Westheimer et al., 2015
Adapted or Argentine Tango (n = 9)	Abraham et al., 2024; De Natale et al., 2017; Duncan & Earhart, 2012; Hackney & Earhart, 2009; Hackney & Earhart, 2010; Jehu et al., 2025; McKee & Hackney, 2013; McNeely et al., 2015*; Rios Romenets et al., 2015
Other PD-dance programs (n = 5)	Duarte et al., 2023; Jola et al., 2022; Kang et al., 2022; Sistarelli et al., 2023; Volpe et al., 2025
Brazilian dance (n = 4)	Dos Santos Delabary et al., 2020; Haas et al., 2024; Moratelli et al., 2023; Tillmann et al., 2020
Contemporary (n = 3)	Harrison et al., 2020; Krotinger & Loui, 2021; Valverde-Guijarro et al., 2022
Mixed dance styles (n = 3)	Dahmen-Zimmer & Jansen, 2017; Hashimoto et al., 2015; Prewitt et al., 2017
Rhythm dance (n = 1)	Moratelli et al., 2022
Indian (n = 1)	Mehta et al., 2024
General dance (n = 1)	Bouquiaux et al., 2022

Table 2.1. Dance styles used across the 38 included studies and corresponding references. *Note.* An asterisk indicates studies that incorporate more than one dance style and are therefore listed under more than one dance category.

Outcomes assessed and distribution

Table 2.2 provides an overview of the outcomes evaluated in the 38 included studies, along with the number of studies demonstrating improvement in each domain (see Appendix C for further details). The most frequently reported outcome domains were motor (n = 34; 89%) and non-motor (n = 29; 76%) outcomes. Motor outcomes showed the most consistent improvements, with 32 studies (84%) reporting significant improvements in at least one motor domain (Abraham et al., 2024; Bearss et al., 2017; Bouquiaux et al., 2022; Carapellotti et al., 2022, 2025; Dahmen-Zimmer & Jansen, 2017; De Natale et al., 2017; Dos Santos Delabary et al., 2020; Duarte et al., 2023; Duncan & Earhart, 2012; Elpidoforou et al., 2022; Fontanesi & DeSouza, 2021; Haas et al., 2024; Hackney & Earhart, 2010, 2009; Haputhanthirige et al., 2023; Harrison et al., 2020; Hashimoto et al., 2015; Heiberger, 2011; Jehu et al., 2025; Jola et al., 2022; Kalyani et al., 2020; Kang et al., 2022; Krotinger & Loui, 2021; McKee & Hackney, 2013; Marie E. McNeely et al., 2015; Mehta et al., 2024; Moratelli et al., 2022, 2023; Rios Romenets et al., 2015; Valverde-Guijarro et al., 2022; Volpe et al., 2025), with one study reporting no significant decline in motor function across three years of community dance engagement (Bearss & DeSouza, 2021). Common areas of significant improvements included gait speed, stride, balance, functional mobility, and overall motor symptom burden. Non-motor improvements were reported in 20 studies (53%) (Abraham et al., 2024; Bouquiaux et al., 2022; Carapellotti et al., 2022, 2025; Duarte et al., 2023; Elpidoforou et al., 2022; Fontanesi & DeSouza, 2021; Hashimoto et al., 2015; Heiberger, 2011; Kalyani et al., 2020, 2019; Kang et al., 2022; Mehta et al., 2024; Moratelli et al., 2023; Prewitt et al., 2017; Rios Romenets et al., 2015; Sistarelli et al., 2023; Tillmann et al., 2020; Volpe et al., 2025), most commonly reporting significantly better mood, reduced depressive symptoms, enhanced quality of life, improvements in fatigue and

activities of daily living. One study also reported no significant decline in non-motor symptoms following a three-year dance intervention (Bearss et al., 2017). Cognitive outcomes were assessed less frequently (n = 18 studies; 47%) with only 12 studies (32%) showing significant improvements (Abraham et al., 2024; Carapellotti et al., 2025; Dahmen-Zimmer & Jansen, 2017; De Natale et al., 2017; Duarte et al., 2023; Elpidoforou et al., 2022; Hashimoto et al., 2015; Kalyani et al., 2019; Krotinger & Loui, 2021; McKee & Hackney, 2013; Prewitt et al., 2017; Volpe et al., 2025). Areas where significant gains were observed included executive functioning, spatial memory, and global cognition.

Domains Evaluated	Common Measures Administered	Assessment Count n/total (%)	Improvement Observed n/total (%)
Motor	UPDRS III, TUG, 6MWT, BBS, Mini-BESTest, gait speed	34/38 (89%)	32/38 (84%)
Non-Motor	PDQ-39, BDI, MADRS, fatigue scales, ABC	29/38 (76%)	20/38 (53%)
Cognitive	MoCA, TMT A/B, FAB, Corsi block task	18/38 (47%)	12/38 (32%)

Table 2.2. Summary of outcome domains evaluated across the included studies, including the number of studies demonstrating improvements across each domain. *Note.* Abbreviated terms: UPDRS = Unified Parkinson's Disease Rating Scale; TUG = Timed Up and Go; 6MWT = Six-Minute Walk Test; BBS = Berg Balance Scale; Mini-BESTest = Mini Balance Evaluation Systems Test; PDQ-39 = Parkinson's Disease Questionnaire 39; BDI = Beck Depression Inventory; MADRS = Montgomery-Asberg Depression Rating Scale; ABC = Activities-Specific Balance Confidence; MoCA = Montreal Cognitive Assessment; TMT = Trail Making Test (Parts A & B); FAB = Frontal Assessment Battery.

Across the studies, motor outcomes were consistently evaluated throughout the 2009-2025 period. In contrast, cognitive and non-motor outcomes were infrequently assessed prior to 2015 with a noticeable increase in evaluations within the last decade. However, cognitive outcomes received the least attention in the literature across time when compared to the distribution of motor and non-motor evaluations (see Figure 2.2).

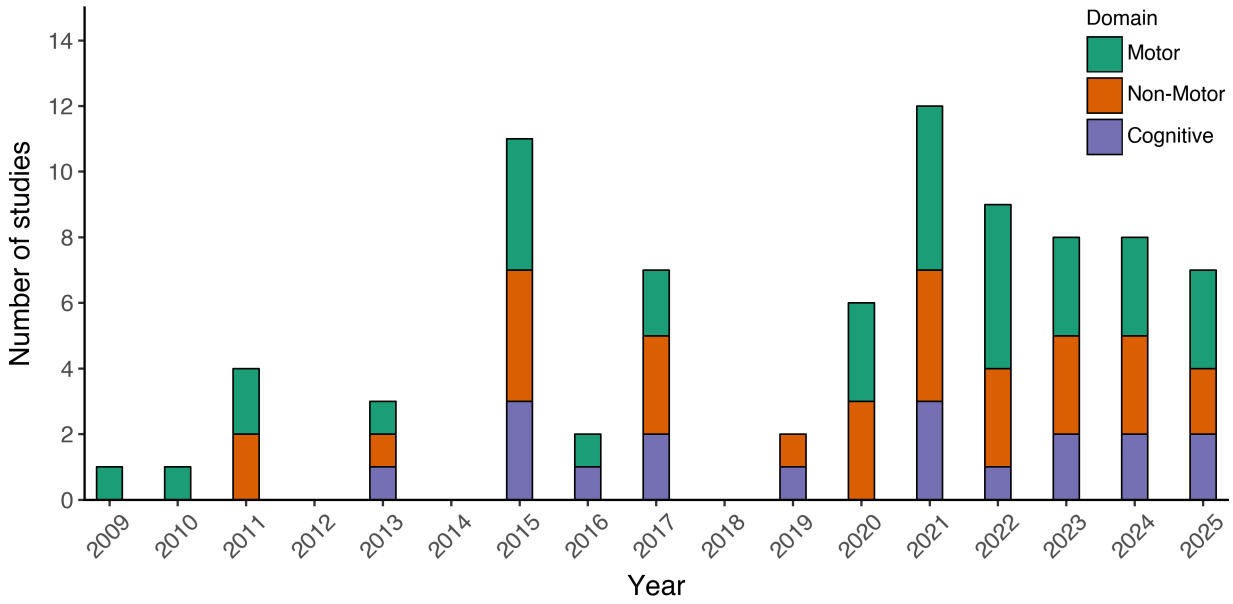

Figure 2.2. Distribution of the included studies assessing cognitive (purple), motor (green), and non-motor (orange) outcomes across the reported publication years (2009-2025).

2.4 Discussion

The present scoping review provided a comprehensive synthesis of the existing literature surrounding dance-based interventions for PwPD, with an emphasis on motor, non-motor, and cognitive outcomes. In doing so, this review further assessed the degree to which non-motor and cognitive domains were evaluated in comparison to motor symptomatology. Across 38 eligible studies, the majority of interventions were primarily instructor-led with Argentine tango and the

DfPD program being amongst the most commonly used dance styles. Sessions were largely community-based rather than performed within clinical or controlled settings. While the duration of interventions varied, most sessions were approximately 60 minutes and completed twice per week. Across the 16-year publication period, motor outcomes, on average, were the primary or sole objective of most studies. In comparison, non-motor and cognitive domains gained more recognition within the last decade. Motor outcomes were relatively consistent, with the majority of studies demonstrating improvements, whereas approximately half of non-motor and cognitive studies reported meaningful changes. Collectively, these findings suggest that while several features of dance interventions are relatively consistent, variability remains in intervention dose, duration, and outcome domains.

Rehabilitative exercises, such as dance, are designed to offer targeted training. For example, the tango involves varying levels of speed and rhythm which may improve motor manifestations such as balance and bradykinesia (Hackney & Earhart, 2010). Whole body coordination and the movement of limbs through exercise may further target impairments including postural instability, gait dysfunction, and disturbances in manual dexterity and stride length (Hackney & Earhart, 2010; Kalyani et al., 2020). Previous research has also demonstrated that improvements in physical functioning are linked to better quality of life among PwPD (Bognar et al., 2017). The psychosocial benefits of dance, such as enjoyment, engagement, and support, may also lead to increased motivation and lower fatigue, depressive symptoms, and feelings of isolation (Bognar et al., 2017; Hashimoto et al., 2015). Interestingly, approximately half of the included studies reported no meaningful changes across non-motor and cognitive domains, potentially attributed to symptom fluctuations over the disease course (Kehagia et al., 2010; Levin et al., 1991; Oliveira et al., 2025; Rodriguez-Blazquez et al., 2021). Short-term

interventions and low sample sizes may have also reduced the ability to detect meaningful changes as most interventions were less than 3 months and recruited between 10 and 24 participants (Carapellotti et al., 2022; Haputhanthirige et al., 2023; Harrison et al., 2020; Marie E. McNeely et al., 2015; Prewitt et al., 2017; Rios Romenets et al., 2015; Westheimer et al., 2015). While dancing has been reportedly linked to improved cognitive functioning, interventions of shorter duration may not be sufficient to induce such changes (Huang et al., 2023; Meulenberg et al., 2023). The limited number of individual sessions held weekly may further play a role as previous research suggests higher frequency is essential for achieving cognitive gains (Huang et al., 2023). Collectively, the variability in measurements likely did not influence findings as most motor, non-motor, and cognitive outcomes were assessed using validated tools that are commonly administered in clinical and research settings.

In our pool of eligible studies, non-motor and cognitive outcomes gained more attention following 2015, whereas motor outcomes were consistently evaluated across the 16-year publication period. While PD is generally referred to as a movement disorder with hallmark motor impairments, the disease profile is heterogeneous, reflecting a wide range of symptoms which go beyond the cardinal motor signs (Marinus et al., 2018). Non-motor and cognitive dysfunction play a crucial role throughout disease progression, contributing significantly to the burden of the disease (Bugalho et al., 2021; Roheger et al., 2018), yet are often overlooked in both research and clinical practise (Chaudhuri & Odin, 2010; Fang et al., 2020; Li et al., 2024). Although a clinical diagnosis requires the presence of hallmark motor symptoms, non-motor and cognitive impairments may be considered biomarkers due to their presence during the prodromal stage of the disease (Kouli et al., 2018; Palanivel et al., 2025; Radhakrishnan & Goyal, 2018). Non-motor symptoms that may present prior to a diagnosis include a range of psychiatric

symptoms, including anxiety and depression, autonomic and olfactory dysfunctions, as well as sleep disorders (Obeso et al., 2017; Pellicano et al., 2007). Furthermore, cognitive decline at disease onset is considered a significant risk factor for developing dementia (Biundo et al., 2016; Roheger et al., 2018), with additional research suggesting that most PwPD experience varying degrees of cognitive dysfunction across disease progression (Mack & Marsh, 2017; Marinus et al., 2018; Rana et al., 2015). Given their significant impact on quality of life, non-motor and cognitive symptoms have been considered more debilitating than motor impairments as well (Li et al., 2024; Marinus et al., 2018; Rana et al., 2015; Roheger et al., 2018). While the multifaceted nature of the PD encompasses not only motor impairments, but a spectrum of non-motor and cognitive challenges, much of the existing literature has focused on movement-based limitations associated with the disease, limiting PwPD's ability to receive the appropriate and comprehensive care they need (Carroll et al., 2021). Across the 38 eligible studies included within this scoping review, we identified 18 and 29 articles which assessed cognitive and non-motor outcomes, respectively. In contrast, Gil et al. (2024) conducted a recent systematic and meta-analysis examining cognitive performance of PwPD following dance, including only 10 articles. Similarly, Wang et al. (2022) identified 9 studies in their systematic and meta-analysis on non-motor trajectories following dance among PwPD. Although there is a growing interest in cognitive and non-motor symptoms (Li et al., 2024), an imbalance may exist as motor manifestations have historically dominated the literature (Jones et al., 2020).

Consistent with the methodological framework used to guide this scoping review, a risk of bias assessment was not conducted. As a result, we did not critically examine the limitations or quality of the 38 included studies. The literature search was also restricted to research published in the English language from 2000 onwards, limiting the inclusion of literature that

may have been published in non-English languages or prior to 2000. In addition, this review excluded qualitative studies which may have limited potential insights from participants. Despite these limitations, there are several key strengths that should be acknowledged. The present scoping review provided a comprehensive synthesis of dance interventions that are commonly used in PD-literature across a 16-year publication period from 2009-2025. The sole focus on dance isolated its influence on PD-related symptomatology while providing an overview of outcome distributions, including cognitive, motor, and non-motor domains. In doing so, the review highlighted the gap in the literature concerning the limited attention given to non-motor and cognitive domains. While cognitive and non-motor outcomes were increasingly analyzed in more recent years, these domains were evaluated less frequently when compared to motor outcomes, thus suggesting further research is needed. As such, future studies should prioritize longer-term interventions, larger sample sizes, and the inclusion of cognitive and non-motor measures. In doing so, this may provide a better understanding of the influence of dance on outcome domains and ensure future interventions capture the full spectrum of symptoms experienced by individuals living with the disease, while strengthening conclusions regarding the broader therapeutic potential of dance.

CHAPTER 3

3. DANCING THROUGH TIME: COGNITIVE CHANGES OVER SIX-YEARS OF COMMUNITY DANCE IN PARKINSON'S DISEASE

Rooprai S, Dogra H, Karimi A, Rafique R, D'Alessandro E, Bearss K, Robichaud S, Bar RJ, DeSouza JFX. (2025) Dancing through time: Cognitive changes over six years of community dance in Parkinson's Disease. *Journal of Alzheimer's Disease*. https://doi.org/10.1177/13872877251393640

Author Contributions: Simran Rooprai was responsible for data analysis, visualization, manuscript writing. Harsimran Dogra assisted with data analysis and writing. Ashkan Karimi assisted with data analysis and visualization. Dr. Rafia Rafique aided with manuscript writing. Emily D'Alessandro was responsible for data curation. Drs. Karolina Bearss and Joseph FX DeSouza led the conceptualization of the study, and were responsible for the investigation, methodology, and providing manuscript revisions. Sarah Robichaud and Dr. Rachel J Bar assisted with project administration. Dr. Joseph FX DeSouza also assisted with data analysis.

The final publication is available at Journal of Alzheimer's Disease via https://doi.org/10.1177/13872877251393640

Abstract

Background: Parkinson's disease (PD) is the most common neurodegenerative disorder after Alzheimer's disease, and is characterized by motor and non-motor symptoms, including gait dysfunction and cognitive decline. Dance has emerged as a promising intervention for improving motor and non-motor symptoms in persons with PD (PwPD), yet long-term effects remain underexplored.

Objective: To assess changes in cognitive function and gait performance over six years among PwPD who participated in a weekly dance program, compared to a Reference group who remained physically inactive.

Methods: This six-year longitudinal observational study included 43 PwPD who attended weekly dance classes and were evaluated using the Mini-Mental State Examination (MMSE) and Movement Disorder Society–Unified Parkinson's Disease Rating Scale (MDS-UPDRS). A Reference group of 28 PwPD, matched on age, gender, and Hoehn & Yahr scores, were selected from the Parkinson's Progression Marker Initiative, and assessed using the MDS-UPDRS and Montreal Cognitive Assessment (MoCA). Cognitive scores were standardized. Generalized estimating equations were used to compare cognitive and gait outcomes across time.

Results: The Dance group was significantly different from the Reference group ($p < 0.001$), with improved cognitive scores in 2016, 2017, and 2018. The Dance group had worse gait at baseline, however, the Reference group showed significantly poorer gait performance by 2018. In a subset of our data (n=10), no significant association was found between gait and cognitive scores.

Conclusion: After two years of weekly dance, the Dance group showed improvements in cognition and maintained stability in gait performance. The findings highlight the potential neuroprotective benefits of continued dance engagement over six years.

Keywords

Alzheimer's Disease, Parkinson's Disease, dancing, cognition, gait, quality of life

3.1 Introduction

Parkinson's Disease (PD) and Alzheimer's Disease (AD) are regarded as the most prevalent age-related neurodegenerative disorders, affecting millions around the world (Gómez-Gómez & Zapico, 2019; Han et al., 2018). Although the pathophysiology of both conditions differs, PD and AD may share overlapping neuropathological features (Weintraub et al., 2012). AD is defined by the progressive loss of cognitive functions, including memory and learning (Gómez-Gómez & Zapico, 2019), while PD, initially documented by James Parkinson as "Shaking Palsy" in 1817 (Parkinson, 2002), is now primarily characterized as a movement disorder with hallmark motor symptoms, including bradykinesia, tremors, and rigidity (Kouli et al., 2018). Similar to AD, the prevalence of PD is also age-related, impacting approximately 1% of persons between the ages of 65 and 69 years, increasing to approximately 3% for individuals at 80 years of age and older (Kalia & Lang, 2015; Li et al., 2022). In the absence of a cure, the prevalence and societal burden of PD is expected to increase as the global population continues to age, signifying the need for therapeutic interventions (Dorsey et al., 2018; Kouli et al., 2018; Pardo-Moreno et al., 2023).

Aside from the classic motor signs of PD, persons with PD (PwPD) may suffer from additional motor and non-motor symptoms (Goetz, 2011). Gait disturbances are among the most debilitating motor symptoms of PD, affecting nearly all individuals as the disease progresses

(Eldeeb & Abdelraheem, 2021; Wilson et al., 2020). Greater fall risks are associated with impaired gait, which contributes to the need for residential care and loss of independence (Balash et al., 2005). Furthermore, non-motor symptoms, particularly cognitive impairment, including mild cognitive impairment (MCI) and dementia, are relatively common in PD. A decline in cognition is regarded as a predictor of reduced quality of life and increased morbidity as well (Aarsland et al., 2021; Weintraub et al., 2012). Gait and cognitive dysfunction often overlap, especially in dual-task situations requiring attention and executive function, which exacerbates the need for interventions that address both motor and cognitive domains simultaneously (Hausdorff et al., 2003; Maidan et al., 2016). Recently, Zhou et al. (2024) found that dopaminergic dysfunction in the prefrontal cortex may contribute to the cognitive-motor dual-task impairments that are seen among PwPD. Furthermore, advances in neuroimaging, including studies that have employed resting-state functional MRI, have also enhanced our understanding of the neural mechanisms driving cognitive decline in PwPD (Guo et al., 2021).

As researchers continue to investigate ways to support brain health in PwPD, Dhami, Moreno, and DeSouza (2015) proposed a framework emphasizing dance as a multimodal form of neurorehabilitation that combines physical and cognitive stimulation with music and emotional engagement. Dance, which also integrates rhythm and social engagement, has become a promising intervention for PwPD, with numerous studies demonstrating improvements in motor and non-motor symptoms of PD, including cognitive and gait functioning (Duncan & Earhart, 2012; Hackney & Earhart, 2009). Dance is associated with neural plasticity, which may lead to improved motor planning and execution (Hackney & Bennett, 2014). Recent findings have demonstrated consistent improvements in gait variability, stride length, and dual-task performance among PwPD after dance engagement, which highlight the neuroprotective benefits

of dance (L. Wang et al., 2022). Moreover, Fiorenzato et al. (2024) explored the complexity of brain dynamics in PD as a marker of cognitive decline, offering a framework for exploring the effect of dance on neural reorganization and cognitive resilience. Studies have shown dance may lead to improved cognition, particularly among the executive, attention, and memory domains (Duncan & Earhart, 2012; Sihvonen et al., 2017). A recent study by Chen et al. (2024) also highlights the relevance of spontaneous brain activity in hippocampal areas as a potential biomarker for cognitive dysfunction, providing new avenues to examine how dance can improve cognitive outcomes by altering these neural processes.

Further research has also shown improvements among additional non-motor symptoms, such as anxiety and depression, in PwPD after dance engagement (Bearss et al., 2024; L. Wang et al., 2022). Through creativity and artistry, the Dance for Parkinson's Disease program may promote physical, emotional, and social engagement, which extend beyond the limitations and challenges of the disease (Fontanesi & DeSouza, 2021). With these encouraging findings we examine the long-term impact of dance on motor and cognitive abilities which is essential to optimize therapeutic interventions and ultimately improve quality of life in PwPD.

3.2 Methods

Study participants

Volunteers were recruited from Canada's National Ballet School and Trinity St. Paul's Church in Toronto, Ontario, Canada. The study sample included a total of 43 PwPD across the six-year study period from 2014 to 2019 (Dance group; N_{male} = 25; M_{age} = 70.0, SD = 7.0), with mild severity ($M_{H\&Y}$ = 1.3, SD = 0.8). All 43 PwPD in the Dance group underwent a minimum of one data collection session between 2014 to 2019. However, the gait analysis was limited to a

subsample of n = 10 people who completed the Movement Disorders Society–Unified Parkinson's Disease Rating Scale (MDS-UPDRS) at least twice. The study was approved by the Office of Research Ethics Committee (ORE) of York University (approval numbers 2013-211 & 2017-296) on November 07, 2013 & September 29, 2017. Written informed consent was obtained from all volunteers in accordance with the approved protocol.

A Reference group of PD-non-dancers was selected from a larger cohort of PwPD from the Parkinson's Progression Marker Initiative (PPMI), a longitudinal study aimed at identifying biomarkers for PD and funded by the Michael J. Fox Foundation (MJFF). Matching was prioritized to ensure comparability between groups, and a total of 28 people with PD were chosen for the Reference group and were matched on key factors such as age (M_{age} = 66.7, SD = 7.3), gender (N_{male} = 21) and scores on the H&Y scale ($M_{H\&Y}$ = 1.4, SD = 0.8), to reduce baseline differences. Because the present study was observational in nature, randomization of the Reference group was not feasible. Matching the Reference and Dance groups on key demographic characteristics was prioritized instead.

The Reference group was further selected based on the Leisure Time Activity (LTA) subscale of the Physical Activity Scale for the Elderly (PASE). The PASE questionnaire is a reliable tool used to assess physical activity levels in those aged 65 years and up. The LTA sub-scale served to identify subjects based on their engagement in physical activities. To reduce the influence of external factors, the Reference group consisted of participants who, based on responses to questions 2-6 of the LTA sub-section, did not engage in any form of physical activity, including dance-based exercises, during the duration of the study period. These questions assessed a wide range of activities, including walking (e.g., for errands, fun or exercise), recreational activities (e.g., light exercise, such as golfing and bowling, and moderate

sports, such as ballroom dancing and ice skating), strenuous sports (e.g., aerobic dance and cycling), and strength-related endurance exercises (e.g., weightlifting). As our focus was on the LTA subscale, which specifically addresses purposeful physical activity, we excluded household tasks (e.g., light cleaning). Additionally, the inactivity was not assigned, and no interventions were withheld, therefore, no ethical concerns related to the Reference groups' activity levels arose. Furthermore, we did not verify whether participants in the Reference group engaged in physical therapy, as we considered this to be part of usual care rather than an additional form of structured exercise. As such, participants receiving physical therapy would still be considered physically inactive for the purpose of the present study.

Measures

Baseline cognitive and motor data for the Dance group were collected from each volunteer regardless of the number of dance classes attended. The Mini-Mental State Examination (MMSE) was administered before each dance session. Before each dance session, part III of the Movement Disorder Society–Unified Parkinson's Disease Rating Scale (MDS-UPDRS), which assesses motor aspects of daily living, was collected, with gait being specifically scored using item 3.10 of the motor examination. At the end of each session, the remaining parts I, II, and IV, which assessed non-motor symptoms, aspects of daily living, and complications, were evaluated. Item 3.10, labelled gait, of the UPDRS was scored by four raters, all of whom were trained following the completion of The International Parkinson and Movement Disorder Society online certificate training program.

Cognitive and motor data for the Reference group were obtained from the PPMI database for the years 2014 to 2019. Cognitive scores were assessed using the Montreal Cognitive

Assessment (MoCA), and motor scores were collected using the UPDRS. At the time of data collection 2014, the two groups were not intended to be compared. After our data collection was abruptly stopped following COVID-19 restrictions, the decision to compare both groups and include a Reference group for this secondary analysis was made in 2020, thus explaining why a singular cognitive assessment was not chosen.

Procedure

The Dance group participated in 75-min weekly dance classes based on the Dance for Parkinson's program (Westheimer et al., 2015) and were led by two trained dance instructors. These classes were offered as part of the Sharing Dance Parkinson's program at Canada's National Ballet School and the Dancing with Parkinson's program at Trinity St. Paul's Church, both located in Toronto, Ontario, Canada. Each class began with a seated warm-up, followed by "barre" exercises, and sessions ended with floor-work dances. The Dance group also learned a specific choreography in preparation for an upcoming performance (see Bearss et al., 2017 for the full dance protocol) during the first years.

Statistical Analyses

To allow for a fair comparison of cognitive scores between both groups, raw MMSE scores (Dance group) and MoCA scores (Reference group) were standardized into z-scores within each group. While both the MMSE and MoCA assess global cognition, their sensitivity and scoring structures differ which was accounted for by standardizing raw scores prior to analysis. Standardization was performed using the formula: $z = (x - M) / SD$, where x is the participant's raw cognitive score, M is the group mean, and SD is the group standard deviation.

This approach was the preferred method for comparing scores from different cognitive tests as it has been applied in previous research (Andrade, 2021; Mejía Arango et al., 2015).

In the present study, standardized cognitive scores were calculated using the mean and standard deviation from the entire dataset where all participants and timepoints were pooled together. This approach ensures that the reference frame for standardization is constant across the six-year study period. Therefore, changes in standardized scores reflect the absolute change relative to the overall sample distribution, rather than a redefined mean and standard deviation at each timepoint. The primary rationale for standardizing raw scores was to enable cross-group comparisons between the Dance group (assessed via MMSE) and the Reference group (assessed via MoCA), given the lack of a shared cognitive assessment. This approach has been used in previous research to align different cognitive assessments when direct score equivalence and comparison is not possible (Andrade, 2021; Mejía Arango et al., 2015). All statistical analyses were performed using standardized z-scores, and not raw scores.

A generalized estimating equations (GEE) model allowed for group comparisons between cognitive scores, gait scores, and the relationship between cognitive and gait scores across time, while accounting for repeated measures across all participants in both groups. GEE is a statistical approach that is designed to analyze longitudinal and repeated-measures data (Wang et al., 2016). Compared to additional approaches, such as general mixed models, which largely focus on individual-specific outcomes, GEE estimates average trends or responses at the group-level (Li & Kong, 2023). The robustness of GEE provides efficiency and consistency in data analysis and can accommodate data that are not distributed normally, while accounting for missing data as well (Lipsitz et al., 2020). Given that our primary analytic goal was to examine group-level trends in cognitive performance across time, rather than individual trajectories, GEE was the

most appropriate choice. As the design of the present study was observational, involving unbalanced and varying sample sizes at different timepoints across the six years, GEE was further selected to accommodate the incomplete longitudinal dataset while still producing valid group-level estimates. All data analyses and statistics were performed using Python (JupyterLab, version 3.6.3).

3.3 Results

Descriptive Statistics

The mean MMSE scores for the Dance group were 28.34 (*SD* = 2.10), as shown in Figure 3.1, ranging from 21.0 to 30.0. The number of PwPD with MMSE scores per year were: 2014 (*n* = 10), 2015 (*n* = 9), 2016 (*n* = 23), 2017 (*n* = 12), 2018 (*n* = 24) and 2019 (*n* = 5). In the Reference group, the mean MoCA score was 25.86 (*SD* = 2.83), with scores ranging from 16.0 to 30.0, as shown in Figure 3.2. The number of people with PD with MoCA scores per year were: 2014 (*n* = 14), 2015 (*n* = 17), 2016 (*n* = 18), 2017 (*n* = 21), 2018 (*n* = 18), and 2019 (*n* = 18). To mitigate the concern raised regarding potential loss of sensitivity to within-group gains, raw score trajectories were also examined and are presented in Figures 3.1 and 3.2 to support interpretation of within-group patterns of change. In addition to the quantitative analyses, this approach provides a qualitative visualization of individual trends observed in each group across the six-year study period. In addition, this helps the reader to compare scores to existing literature which does not typically use standardized z-scores. Allowing for a group comparison, Figure 3.3 shows the mean standardized cognitive scores for the Dance group were 0.82 (*SD* = 0.23), and 0.70 (*SD* = 0.20) for the Reference group. For gait scores, the Dance group had a

mean of 0.7 (*SD* = 0.4), ranging from 0.0 to 1.25. The Reference group had a mean of 0.6 (*SD* = 0.6), ranging from 0.0 to 3.00 for gait scores.

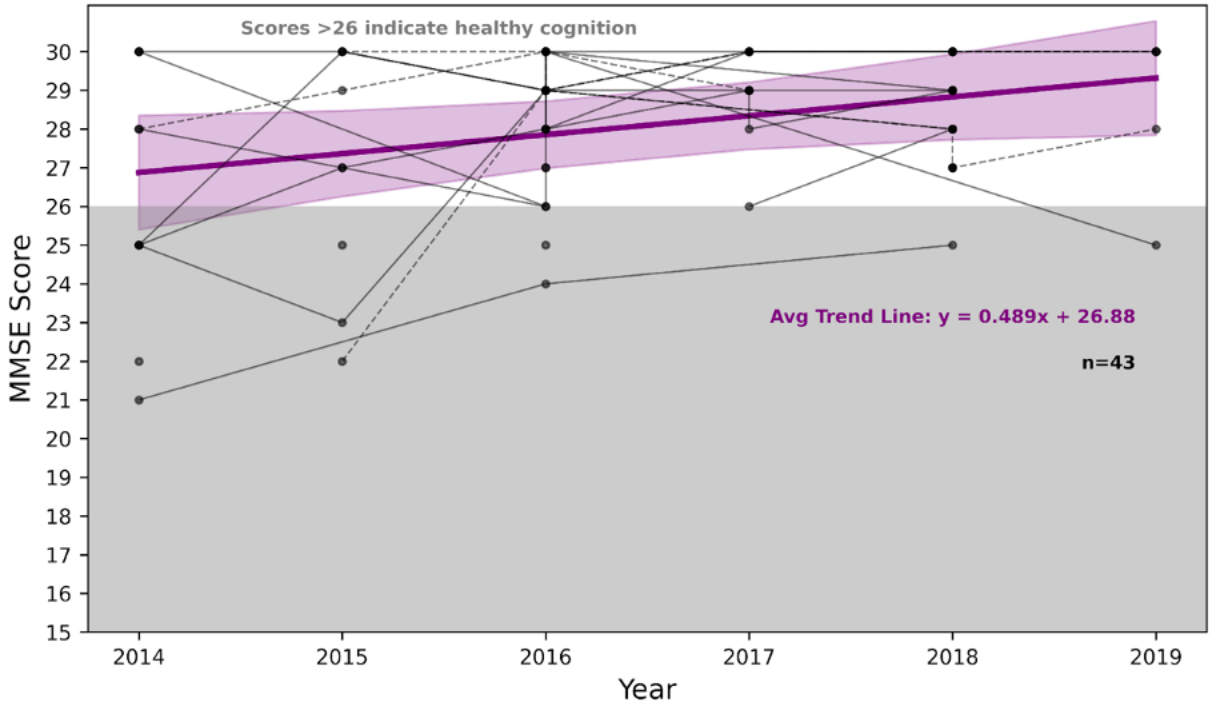

Figure 3.1. MMSE scores for the Dance group (*n* = 43) across time. The number of people with PD with MMSE scores per year were: 2014 (*n* = 10), 2015 (*n* = 9), 2016 (*n* = 23), 2017 (*n* = 12), 2018 (*n* = 24) and 2019 (*n* = 5). The bold purple line shows the average trend in MMSE scores across time, with the surrounded shaded area representing the 95% confidence interval. The intercept reflects the observed baseline mean. Points within the shaded grey area indicate cognitive impairment. Solid lines represent male people with PD, dashed lines represent female PwPD.

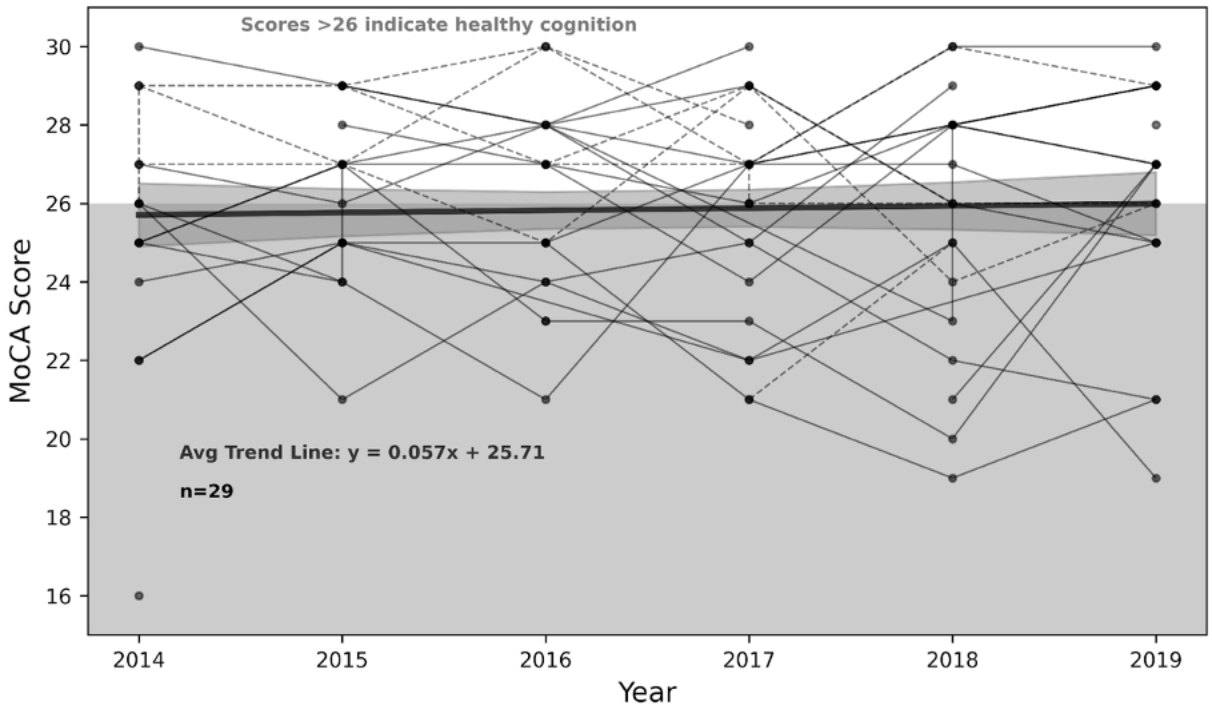

Figure 3.2. MoCA scores for the Reference group (n = 28) across time. The number of people with PD with MoCA scores per year were: 2014 (n = 14), 2015 (n = 17), 2016 (n = 18), 2017 (n = 21), 2018 (n = 18), and 2019 (n = 18). The bolded black line shows the average trend in MoCA scores across time, with the surrounded shaded area representing the 95% confidence interval. The intercept reflects the observed baseline mean. Points within the shaded grey area indicate cognitive impairment. Solid black lines represent male PwPD, while dashed lines represent female PwPD.

Cognitive Score Differences Over Time

Generalized Estimating Equations (GEE) revealed a significant difference in cognitive scores between the Dance and Reference groups over time, with the Dance group demonstrating higher scores overall ($p < 0.001$). As shown in Figure 3.3, cognitive scores in the Dance group were significantly higher in 2016 ($\beta = 0.2391$, $p = 0.028$), 2017 ($\beta = 0.3145$, $p = 0.007$), and

2018 (β = 0.2675, p = 0.010), although this improvement was no longer significant in 2019 (β = 0.2444, p = 0.096). Figures 1-3 further illustrate that the Dance group showed greater improvement over the six years compared to the Reference group.

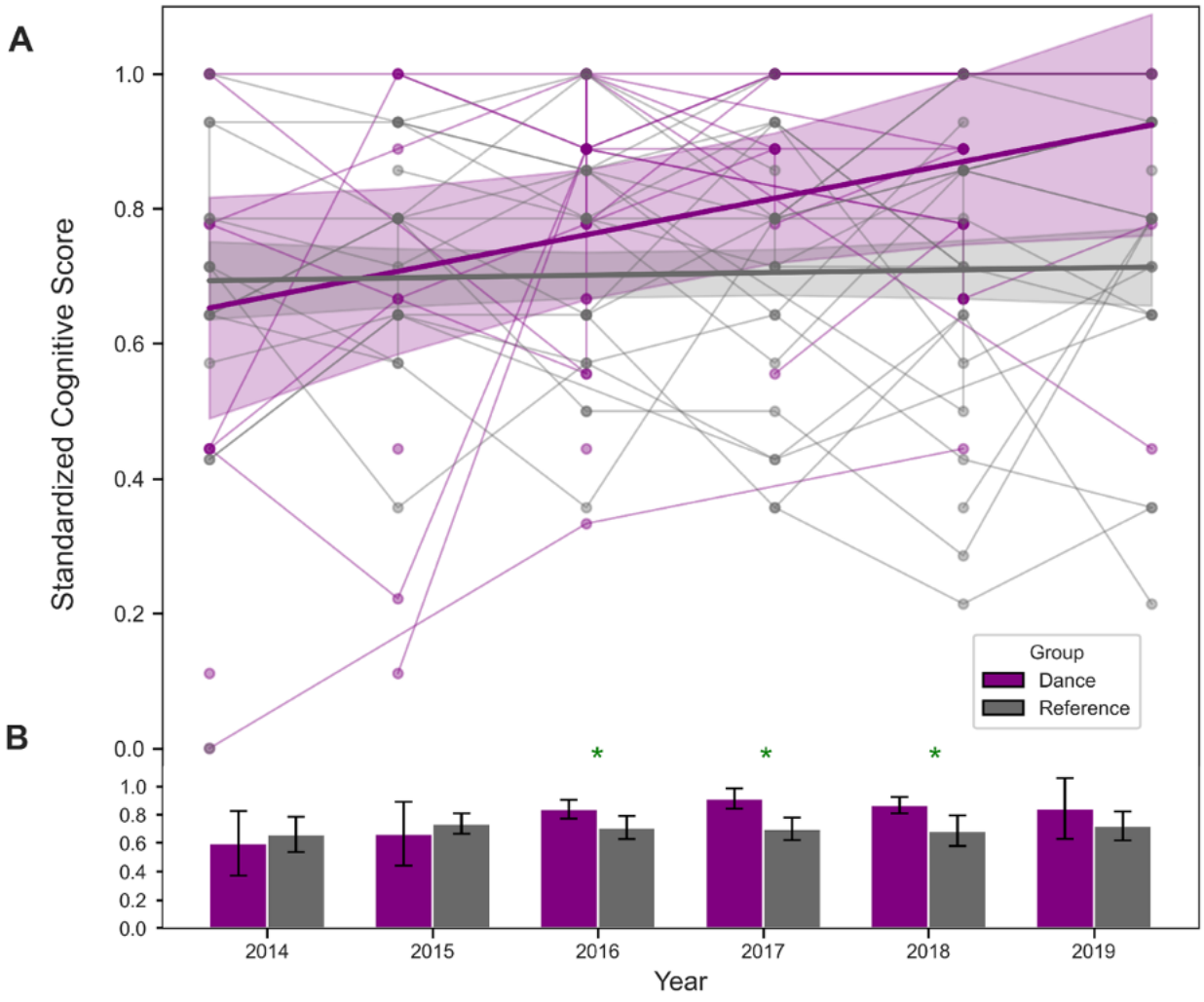

Figure 3.3. A: Standardized cognitive scores for the Dance group (purple) and Reference group (grey) plotted individually across time (from Fig 3.1 and 3.2). The bolded purple and grey lines represent the average trends in standardized cognitive scores for the Dance and Reference groups, respectively, across time. Shaded regions surrounding each line represent the 95% confidence intervals. The intercepts reflect model fits rather than baseline values as trend lines

were estimated from group means per year. **B:** Group-level standardized scores for the Dance and Reference group, showing significant cognitive improvements for the Dance group in 2016, 2017, and 2018 compared to the Reference group. An asterisk signifies a significant difference between group means. Error bars represent the 95% confidence intervals.

Group and Time Effects on Cognition

The Group x Year interaction terms from the GEE model found no significant cognitive score differences between the Dance and Reference groups from 2014 to 2015 ($\beta = 0.0095$, $p = 0.950$), as shown in Figure 3.3. In 2016, the Reference group had a trend towards lower cognitive scores compared to the Dance group, but this was not statistically significant ($\beta = -0.1907$, $p = 0.134$). In 2017, cognitive scores of the Reference group were significantly lower than the Dance group ($\beta = -0.2751$, $p = 0.036$). This trend continued in 2018 with the Reference group scoring lower than the Dance group, although this difference was marginally significant ($\beta = -0.2415$, $p = 0.058$). No significant difference was found between the two groups in 2019 ($\beta = -0.1841$, $p = 0.258$).

To further explore group differences at each time point, Mann-Whitney U tests with Bonferroni correction were conducted. These post hoc comparisons assessed differences between both the Dance and Reference groups within each year and not changes relative to baseline. No significant differences were found at our 2014 baseline ($p = 0.977$) and 2015 ($p = 0.938$). Most importantly, the Dance group scored significantly higher than the Reference group in 2016 ($p = 0.008$), 2017 ($p = 0.001$), and 2018 ($p = 0.0042$). No significant group differences were found in the last year of 2019 ($p = 0.1758$).

Analysis of Gait Over Time

A GEE model was performed to assess the effects of group and year on gait performance. The model included main effects for group, year, and their interaction. An independent correlation structure was used to account for repeated measures. The results showed that the intercept was significantly different from zero ($\beta = 0.8571$, $p < 0.001$), suggesting that the Dance group had worse gait performance at baseline (2014). This suggests there were baseline differences in gait between both groups. As shown in Figure 4, the Reference group had lower gait scores, indicating better gait performance at baseline, compared to the Dance group. The GEE analysis confirmed this difference was statistically significant ($\beta = -0.3665$, $p = 0.012$). In 2018, the Reference group had significantly higher gait scores, indicating worse gait performance, compared to the Dance group ($\beta = 0.4946$, $p = 0.007$), which is consistent with the trend shown in Figure 3.4 where higher scores denote greater impairment. Additionally, no other group differences reached significance.

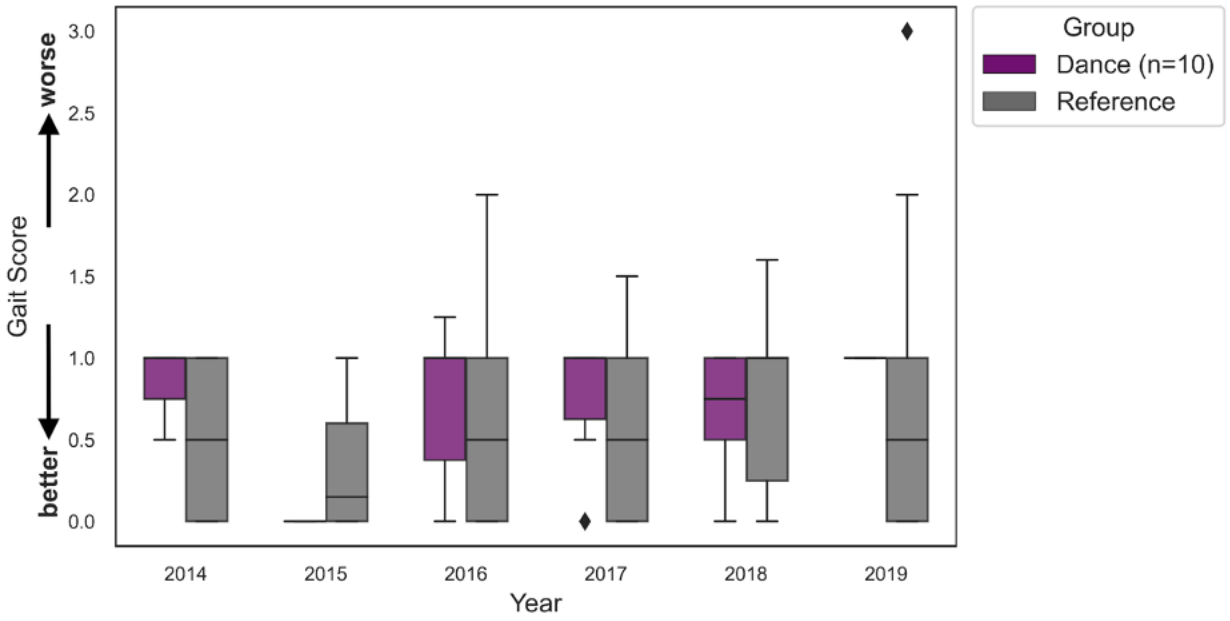

Figure 3.4. Gait scores over time for a subset of the Dance group (n = 10, purple) and Reference group (grey). Higher scores indicate worse gait performance. Boxplots represent the distribution of gait scores for each group from 2014 – 2019.

Group and Gait Effects on Cognition

A separate GEE model was conducted to examine cognition as a function of gait, group, and year. The results showed that the intercept for cognition was significantly different from zero ($\beta = 0.7392$, $p < 0.001$), thus indicating the Dance group had better cognition at baseline. There was no significant main effect of group ($\beta = -0.0524$, $p = 0.630$), and no significant association was found between gait performance and cognition ($\beta = -0.0476$, $p = 0.307$), suggesting that gait performance was not directly associated with cognitive function.

3.4 Discussion

Our findings demonstrate that long-term dance participation was associated with improved cognitive outcomes in PwPD. At baseline (2014) and in 2015, there were no significant differences observed between both groups. From 2016 to 2018, cognitive scores of the Dance group were significantly higher compared to those of the Reference group. However, this significance was no longer meaningful by 2019, likely attributed to a decline in participation in the Dance group, leading to reduced statistical power. The upward trend observed in the Dance group demonstrates the potential cognitive benefits of dance for PwPD, which is consistent with previous literature. McKee and Hackney (2013) conducted a 12-week adapted tango intervention that showed improvements in spatial cognition and executive functioning in PwPD, as measured by the MoCA, Reverse Corsi Blocks, and Brooks Spatial Task. Similarly,

Michels et al. (2018) reported a mean increase of 0.44 in MoCA scores in PwPD following a 10-week dance intervention, compared to a mean decrease of 0.50 in the control group, although the study did not test for statistical significance. Duarte et al. (2023) also reported significant improvements in executive functioning among PwPD following a six-month dance-based intervention, as measured by the Frontal Assessment Battery. Given that most dance-based studies assessing cognitive function in PwPD are relatively short (Gil et al., 2024), the present study provides a better understanding of the long-term cognitive impact of dance, with findings suggesting preservation of global cognition among PwPD over a six-year period.

The cognitive benefits observed in the Dance group may be explained by several underlying mechanisms. As a form of physical activity, dance engages motor learning with coordination, balance, rhythm, memory, and learning, all of which stimulate various brain regions (Basso et al., 2021). Recent literature has also suggested a potential association between dance and neuroplastic changes (Foster Vander Elst et al., 2023). A recent case study by Simon et al. (2024) observed greater blood-oxygen-level-dependent (BOLD) signals among the superior temporal gyri, supplementary motor area, and bilateral insula of a 69-year-old individual with PD who participated in dance classes over a 29-week period and was scanned with functional MRI. In a cross-sectional expert dancers' study, Burzynska et al. (2017) found greater BOLD signals across multiple brain areas, including the putamen, thalamus, premotor cortex, and the superior frontal gyri, among expert dancers compared to controls. Bar & DeSouza (2016) also found that expert dancers who visualized dance-related sequences with music showed heightened BOLD fMRI activity within the supplementary motor area, bilateral superior temporal gyri, and subcortical basal ganglion regions across a 34-week period. Although activation in the supplementary motor area and the left superior temporal lobe had decreased by 34 weeks, the

authors suggested this may reflect increased neural efficiency and habituation once the choreography became overlearned. Building on these findings, Karimi et al. (2025) further demonstrated functional and structural changes in language associated regions, including Broca's area and supplementary frontal language in individuals with PD. Beyond functional changes, Rehfeld et al. (2018) also found greater increases in brain volume across several brain regions, including the cingulate and sensorimotor cortex, among older adults following six months of dance compared to an active control group.

Alongside neuroplasticity, dance may also contribute to the preservation or improvement of non-motor symptoms, including depression, in PwPD. A recent study reported a gradual reduction in depression scores, as measured by the Geriatric Depression Scale, among PwPD over an 8-month dance intervention (Bearss et al., 2024). Similarly, a 12-week dance-movement therapy program led to reduced loneliness, depression, and negative mood, with daily functioning showing improvement among individuals with dementia (Ho et al., 2018). As a social activity, dance may promote participation and interpersonal engagement as well. For example, Foster et al. (2013) observed increases in participation and further engagement in new social activities among PwPD following a 12-month Argentine tango intervention, suggesting potential benefits for quality of life. Together, these findings highlight the benefits of dance as an innovative and non-pharmacological intervention for PwPD. In the present study, the preservation of cognitive function over a six-year period is significant given the trajectory of cognitive decline in PD (Bock et al., 2023). Additionally, dance programs are accessible, community-based, and typically offered at no cost to participants, making them a feasible addition to usual care. By providing both motor and cognitive stimulation in an engaging format,

dance may offer a valuable strategy for improving quality of life and potentially halting disease progression.

These findings may translate to AD and other neurodegenerative conditions as well. Through motor learning, dance engages certain areas of the brain involved in memory and executive functioning, which may promote neural resilience (Barnstaple, 2021). Previous research has shown that dance-based interventions led to improved cognitive outcomes, specifically within memory, executive functioning, and other cognitive domains among persons with mild cognitive impairment, AD, and dementia (Tao et al., 2023; Zhu et al., 2020). Additional research has further demonstrated that dance may lead to improved mood and quality of life among persons with AD (Ruiz-Muelle & López-Rodríguez, 2019), and gait speed among persons with dementia (Bracco et al., 2023). Abreu and Hartley (2013) also found significant improvements in functional ability in a case study involving an individual with AD and other comorbidities.

As demonstrated by Bearss & DeSouza (2021), dance may help to maintain mobility in PwPD. While gait performance in the Dance group was relatively stable across time, our results should be interpreted with caution. A post-hoc power analysis revealed that with our sample of 10 volunteers who had both gait and cognitive measurements, the study had only 3.3% power to detect the observed effect size ($\beta = -0.0377$), indicating that the analysis was severely underpowered to detect potentially meaningful associations between these variables. In comparison to the Dance group, the Reference group ($n = 28$) showed a significant decline in 2018. Given that dance involves complex movements and postural control (Błaszczyk & Fredyk, 2024), it is possible that improvements in gait performance within the Dance group may not have been fully captured by the single item gait measure (UPDRS item 3.10) used in the present study.

Additionally, the small sample size for this gait analysis overlapped with volunteers from our Bearss & DeSouza (2021) study, which included a larger sample from the Dance group (n= 16) and assessed motor symptoms using the complete UPDRS Part III motor examination.

Despite the literature suggesting a relationship between gait and cognition in PD (Amboni et al., 2018; King et al., 2015; Lord et al., 2014), our analysis did not find a significant association between these two variables because of this small subset of 10 PwPD. Previous literature by Morris et al. (2019) found that specific aspects of gait, mainly pace and turning, are linked to distinct cognitive domains, including attention, executive functioning, and memory. Further research has also demonstrated a relationship between specific aspects of gait, such as gait speed, and distinct cognitive domains, particularly executive dysfunction (Kim et al., 2018; Sousa & Macedo, 2019). In contrast, our study assessed global cognition, rather than individual cognitive domains, and analyzed gait as a single measure in a subset of our population. In addition, the lack of a significant association between gait and cognition in our study may be attributed to the limited number of gait assessments available for analysis, as well as the reduced sample size.

Strengths and Limitations

To our knowledge, this is the first study to assess the long-term effects of dance on cognition among PwPD across a six-year period. The longitudinal design of the present observational study provides valuable insights into the benefits of long-term dance engagement as a non-pharmacological intervention, in addition to standard treatment practices. Additionally, the use of a community-based dance program highlights real-world applicability which may help to refine future research methodologies, however, there are a few limitations that should be

acknowledged in our present study. As the study was observational, the Reference group was not randomized. Although individuals in the Reference group were matched to the Dance group on key demographic and disease-related variables, unmeasured differences between groups may still influence results. While this approach reduces some bias, the lack of randomization may serve as a potential limitation affecting the interpretation of study findings.

Participation in the Dance group was also non-restrictive, resulting in variability in class attendance across the six-year period, leading to relatively small and uneven sample sizes at each time point. Only five participants in the Dance group completed the MMSE in 2019, whereas in previous years, there were between 12 to 24 participants. This variability, along with participant attrition over time and an increased margin of error, made it difficult to analyze subgroups and individual trajectories based on attendance without reducing statistical power. Due to the lack of systematic data collection on class attendance and engagement, it was not possible to assess these factors as covariates. As a result, PwPD with lower engagement may not have experienced the same level of cognitive benefits as those with higher engagement. Additionally, volunteers who continued to attend the dance classes until the end of the study in 2019 may have differed from those with lower engagement in terms of advancing symptoms, decreased motivation, or lower overall function due to the detrimental nature of PD. Because of the limited individual-level engagement data, we were unable to formally test this hypothesis. Future studies would benefit from tracking such variables to better understand the relationship between continued participation and long-term cognitive outcomes.

Furthermore, we did not track participant withdrawals in formal logs. While the Results section provides a breakdown of how many individuals contributed cognitive performance data, this does not reflect the number of dance classes attended by each volunteer. The present study

was observational and conducted through community-based dance classes hosted by NBS, rather than in a university laboratory or clinical trial. Participants were volunteers who self-selected into different components of a larger study (e.g., EEG, MRI, cognitive testing), thus volunteers were not enrolled in a controlled trial nor was formal recruitment conducted. The NBS Sharing Dance Parkinson's classes and Dancing with Parkinson's programs continue to be offered and remain open to any individual with PD, independent of our data collection. As such, volunteers who no longer attended classes during data collection were not considered to have formally withdrawn from the study. Based on our initial objective to assess the overall effect of long-term dance participation on global cognitive performance, we focused on group-level trends over time rather than subject-specific ones. While this approach allowed us to identify general trends, it did not account for potential differences in outcomes based on the frequency of class participation. Subgroup analyses would require larger and balanced sample sizes to produce reliable findings, which were not feasible given the longitudinal nature of the data and attrition across the six-year study period. As such, our findings should be interpreted as reflecting group-level effects rather than participation-specific differences, which may represent a limitation of the chosen model. Future research should also monitor attendance frequency and enroll larger sample sizes for subgroup comparisons as well.

In addition, the observed differences in gait scores between the Dance and Reference groups may potentially reflect differences in how gait was scored in both studies. In the Dance group, gait was scored by four independent raters, who completed the Movement Disorders Society-Unified Parkinson's Disease Rating Scale Certificate Training Program. The use of four raters may have resulted in a more rigorous evaluation of motor symptoms. While we do not have specific information regarding the rater methodology used in the PPMI dataset for the

Reference group, differences in scoring procedures between both groups and variability in motor symptoms may have contributed to the trend shown in Figure 3.4. However, it is important to note that the gait analysis for the Dance group included a small sub-sample of participants (n = 10) who had completed the gait item from the MDS-UPDRS Part 3 at least twice, as only those with a minimum of two testing sessions were included in the gait analysis to assess pre- and post-changes in gait performance, limiting the statistical power for detecting changes in gait across time. Additionally, as confirmed by the GEE analysis, no significant year effects were found for the Dance group.

Lastly, the type of cognitive assessments used differed between the two groups, which, despite standardization, may introduce subtle differences in sensitivity to cognitive changes. The Dance group was assessed using the MMSE while MoCA was administered in the Reference group. Although both assessments were standardized, the MMSE has shown reduced sensitivity to cognitive changes in PwPD when compared to the MoCA (Chou et al., 2014; Hu et al., 2014; Kim et al., 2019; Sousa & Macedo, 2019). However, the MMSE has demonstrated good test-retest reliability when assessed among older individuals with normal cognition (Snyder et al., 2021). Truong et al. (2024) found that MMSE scores among cognitively healthy older adults remained consistent with memory performance throughout a six-year period. While older adults with dementia may show retest effects, as demonstrated by Gross et al. (2018), these effects are substantially smaller when compared to older adults with normal cognition. This suggests that cognitive impairments may limit participants' ability to benefit from familiarity with the assessment tool (Hu et al., 2014). Although retest effects using the MMSE among PwPD have not been explored, the difference in measurement sensitivity between the MoCA and MMSE may have influenced our findings. As the Reference group, assessed using the MoCA, showed a

trend towards poorer cognitive performance over time, it is possible that similar changes in the Dance group may not have been fully captured due to the limitations mentioned above of the MMSE.

Given the range of cognitive problems experienced by PwPD, future research should further investigate the effectiveness of dance for improved cognitive functioning using more sensitive cognitive assessments for PwPD, using attention, language, working memory tasks and social cognition with incorporating neuroimaging and biomarkers to assess neural mechanisms of cognitive changes. To better understand the relationship between cognitive and gait outcomes following long-term dance engagement, future research should utilize more comprehensive gait assessments as well.

Acknowledgements

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Advanced Research Company, Takeda, Teva, UCB, Vanqua Bio, Verily, Voyager Therapeutics, the Weston Family Foundation and Yumanity Therapeutics.

CHAPTER 4

4. MOVING TOWARDS STABILITY: SLEEP AND COGNITION ACROSS SIX YEARS OF COMMUNITY DANCE IN PARKINSON'S DISEASE

Abstract

Background: Non-motor symptoms, including sleep and cognitive dysfunction, are major contributors to reduced quality of life in people with Parkinson's disease (PwPD). To better support PwPD, dance has been proposed as a promising intervention to improve quality of life. Previously, we examined the longitudinal trajectories of global cognition following community-based dance, however, little is known about its long-term influence on sleep-related non-motor symptoms and their relationship with global cognitive performance.

Objective: We examined the six-year trajectories of sleep and overall non-motor symptom severity among PwPD participating in weekly community-based dance classes compared to a sedentary Reference group. As a secondary objective, we evaluated their association with global cognitive performance as a functional outcome.

Methods: This longitudinal observational study followed PwPD engaged in community dance participation and matched sedentary controls from the Parkinson's Progression Markers Initiative database over six years. General estimating equations (GEE) were used to model group-level

trends, with sensitivity analyses of individual trajectories conducted to assess the robustness of the findings.

Results: Non-motor outcomes showed that insomnia worsened significantly within the Reference group (p = .003) but improved among dancers (p = .005), with daytime sleepiness remaining stable across both groups. When sleep was used as a predictor of cognition, global cognitive performance improved in the Dance group (p = .078) and declined mid-period in the Reference group (p = .014). In addition, overall non-motor symptom severity worsened in the Reference group (p = .011) while remaining stable in the Dance group.

Conclusion: The present study demonstrates that community-based dance may support select non-motor symptoms, including insomnia, and cognitive resilience in PwPD. Findings reinforce dance as a valuable, real-world, non-pharmacological approach to slow functional decline in PD.

4.1 Introduction

Cognitive and non-motor symptoms represent a crucial aspect of Parkinson's disease (PD). Although traditionally marked by motor signs, such as rigidity, tremors and bradykinesia, PD is further characterized by a number of non-motor symptoms and cognitive impairments, which may present years to decades before the emergence of motor symptoms (Kouli et al., 2018). Cognitive decline may further evolve into mild cognitive impairment, a significant risk factor for PD-dementia, which affects up to 80% of PwPD over time (Fang et al., 2020). It is estimated that almost all persons with PD (PwPD) will experience some degree of cognitive impairment at any stage of the disease.

Cognitive impairments may include a decline across the executive functioning, working memory, attention, visuospatial or memory domains, and can hinder independence and reduce

quality of life, significantly impacting daily functioning (Fang et al., 2020). The inability to understand spatial relationships between objects, known as visuospatial dysfunction, may lead to a difficulty in carrying out certain activities, such as household chores, including personal hygiene, cooking, feeding, and dressing (Fernández-Baizán et al., 2022; Nieto-Escamez et al., 2023). Impairments in memory, which are suggested to largely affect recall and recognition (Chiaravalloti et al., 2014; Lee, 2023), may result in general forgetfulness, slower memory processing, and difficulty with facial recognition among PwPD (Woods & Kneebone, 2017). Executive functions, including attention and working memory skills, are a hallmark cognitive impairment in PD. PwPD with attentional deficits may struggle to carry out tasks that rely on effortful processing (Thomas Holtgraves & Cadle, 2016). For example, Allcock et al. (2009) noted that an increase in fall risks was associated with attentional deficits in PwPD. Deficits in working memory, defined as the short-term storage and manipulation of information, are another prevalent impairment seen among PwPD (Giehl et al., 2020). Given that working memory is a fundamental cognitive skill that intersects with abilities including problem solving and language, a decline in working memory may hinder functional independence (Zokaei & Husain, 2019). As a whole, executive dysfunction including both attentional and working memory impairments may disrupt the ability to carry out daily tasks, including household chores, finances, and medication management (Bode et al., 2024).

Sleep disturbances contribute substantially to disease burden as well. Insomnia, defined as the inability to fall or remain asleep, and excessive daytime sleepiness (EDS), defined as the inability to stay awake during waking hours, are commonly experienced sleep-related non-motor symptoms, affecting up to 80% and 60% of PwPD, respectively (Marinus et al., 2018; Rana et al., 2015; Wallace et al., 2020). A longitudinal study by Zhu et al. (2016a) examining excessive

daytime sleepiness in PwPD found that 46% of those who did not present with EDS at baseline developed this symptom within 5 years. In another study, Zhu et al. (2016b) showed that approximately 51% of PwPD had developed insomnia at some point across a 5-year period. Furthermore, sleep disturbances are linked to reduced quality of life and are recognized as risk factors for cognitive decline (Ledda et al., 2024), while cognitive decline may predict the development of sleep dysfunction as well (Amara et al., 2017). The pathophysiology seen in PD involves the widespread accumulation of Lewy bodies which may impact processes relating to both sleep and cognition, thus leading to sleep and cognitive dysfunction (Stavitsky et al., 2012). Sleep also plays a critical role in cognition (Jiang et al., 2024), with additional research demonstrating that sleep dysfunction in healthy individuals is linked to cognitive deficits (Stavitsky et al., 2012). Although research on the relationship between cognition and sleep quality in PwPD is limited, previous studies have shown an association between sleep dysfunction and worsening health-related quality of life (Knie et al., 2011), including cognitive impairments (Hermann et al., 2020). Goldman et al. (2013) found that PwPD with worse excessive daytime sleepiness had greater cognitive impairment. With respect to domain specific analyses, Stavitsky et al. (2012) demonstrated that attentional and executive dysfunction was associated with poor sleep quality in PwPD, whereas the memory domain was not.

In response to the limitations and challenges associated with pharmacological approaches, such as dopaminergic therapies, which mainly address motor impairments (Radhakrishnan & Goyal, 2018), there is a growing body of literature surrounding innovative and non-pharmacological approaches, such as structured and community dance programs, to alleviate symptom burden, thus improving quality of life (Bearss & DeSouza, 2021; Dhami et al., 2015). The complexity of dance, which integrates movement and music along with social

engagement, has been recognized as a potential novel approach for slowing down PD progression (Jola et al., 2022). In our previous analysis, we observed improved global cognitive outcomes in PwPD who engaged in weekly dance classes across a six-year period, whereas a sedentary PD-Reference group exhibited no changes (Rooprai et al., 2025). Building on these findings, the present analysis examines sleep disturbances and overall non-motor symptom burden, as well as their association with changes in global cognition over time following dance. Exploring the relationship between dance participation, global cognition, and select non-motor symptoms may provide greater insights and a richer understanding of community-based interventions to better support PwPD.

The primary objective of this study was to examine longitudinal changes in sleep and overall non-motor symptoms severity between a Dance and sedentary Reference group. Our secondary objective was to examine the impact of overall non-motor symptom severity, including sleep disturbances, on global cognitive performance across time. We hypothesized that volunteers in the Dance group would demonstrate improvements across sleep-related and overall non-motor symptom outcomes, with better sleep and non-motor symptoms associated with improved global cognitive performance, relative to the sedentary Reference group over the six-year study period.

4.2 Methods

The present study utilizes the same longitudinal and observational study design and participant cohort described in Rooprai et al. (2025), consisting of 43 volunteers with PD (Dance group; N_{male} = 25; M_{age} = 70.0, SD = 7.0; $M_{H\&Y}$ = 1.3, SD = 0.8) enrolled in community-based dance programs in Toronto, Ontario, Canada, and 28 inactive-PwPD (Reference group; N_{male} =

21; M_{age} = 66.7, SD = 7.3; $M_{H\&Y}$ = 1.4, SD = 0.8) from the Parkinson's Progression Markers Initiative (PPMI) database. The PPMI is a longitudinal study funded by the Michael J. Fox Foundation, with a primary goal of identifying biomarkers for PD. Reference group participants were characterized as sedentary based on their responses on the Physical Activity Scale for the Elderly (PASE) (Washburn et al., 1993) questionnaire, where no engagement in physical activity was reported, including structured (e.g., dance or exercise programs) or non-structured exercises (e.g., walking). The Dance group participated in weekly dance classes, each lasting 1 hour and 15 minutes, over the six-year period (2014-2019; see Bearss et al. 2017 for the full dance protocol). In order to avoid redundancy, methodological components that differ from the published protocol are described in detail below.

Outcome Measures

Cognition. Volunteers in the Dance group completed the Mini-Mental State Examination (MMSE) (Gallegos et al., 2022) at one or more time points across the six-year period. Given the observational study design, the number and timing of assessments varied across volunteers and therefore, all available observations were included regardless of the number of assessments completed. For the Reference group, cognitive data was retrieved from the PPMI database for the same study period (2014-2019). The Montreal Cognitive Assessment (MoCA) (Ang et al., 2023) was administered for an assessment of cognitive performance. The MoCA was not chosen for the Dance group because the decision to compare both groups was not made prior to data collection. Because the MMSE and MoCA are scored on different scales, limiting a direct comparison, global cognitive scores were standardized by converting raw scores to z-scores to enable between-group analyses (see Rooprai et al., 2025 for the full protocol).

Non-Motor and Sleep. For an assessment of non-motor symptoms, aspects of daily living, and PD-related complications, parts I, II, and IV, respectively, of the Movement Disorder Society—Unified Parkinson's Disorder Rating Scale (MDS-UPDRS) (Goetz et al., 2008) were administered at the end of each dance class. As the MDS-UPDRS was not administered in 2015 for the Dance group, data for that year were unavailable. As with cognitive assessments, the number and timing of the MDS-UPDRS assessments varied across volunteers, therefore, all available observations were included regardless of the number of assessments completed. For the Reference group, MDS-UPDRS data was retrieved from the PPMI database for the same study period (2014-2019). For both groups, sleep-related disturbances were assessed using items 1.7 and 1.8, labelled sleep problems (i.e., insomnia) and daytime sleepiness, respectively, of the MDS-UPDRS Part I Patient Questionnaire, which was self-completed by volunteers. A total sleep score was computed as the sum of sleep problems (i.e., insomnia) and daytime sleepiness to capture the overall sleep disturbance.

Statistical Analyses

Standardized scores of global cognition were retrieved from our previous analysis (Rooprai et al., 2025), and used in the present study to examine associations with the MDS-UPDRS non-motor outcomes, including sleep disturbance. Higher cognitive scores indicate better cognitive performance. Part 1 of the MDS-UPDRS is an assessment of PD-related non-motor symptoms and is divided into two subsections (Goetz et al., 2008). Data for most items in the first subsection were not available for the Dance group, thus only the second subsection (Patient Questionnaire) was analyzed for both groups to maintain comparability. Individual non-motor items from the Patient Questionnaire were examined separately, and a half total score,

which represents the sum of all items from this subsection, was used as an indicator of overall non-motor symptom burden. Group-level analyses were also conducted individually for non-motor and sleep-related variables, given the consistency of the assessment tool across the Dance and Reference groups. Higher sleep burden scores indicate worse symptom severity.

Longitudinal changes were modelled using generalized estimating equations (GEE), which account for correlations in repeated measures. GEE was the chosen statistical approach because it provides group-level estimates and accommodates unbalanced data structures in observational study designs (Wang et al., 2016). All primary models were baseline-adjusted by including initial observations as covariates in GEE models to control for between-group imbalances at baseline, with year treated as a categorical variable to accommodate missing and unbalanced observations as well. The year was further collapsed into three periods to improve model stability: Early (2014-2015), Mid (2016-2017), and Late (2018-2019). Models assumed an independence working correlation structure, with specified robust standard errors, as the goal was to obtain population-level estimates, rather than individual-level trajectories. Sensitivity analyses were also conducted to assess the robustness of study findings under alternative assumptions. Linear mixed models (LMM) were employed with year treated as a categorical predictor to analyze trends across time. All statistical analyses were performed using JupyterLab (version 3.6.3). All tests were two-tailed with statistical significance set at $p < 0.05$.

4.3 Results

Descriptive Statistics

Table 4.1 provides the descriptive statistics for demographic and clinical variables. At baseline, the Dance and Reference groups did not differ significantly in disease severity, as measured by the Hoehn & Yahr scale, and MDS-UPDRS Part I (Patient Questionnaire) scores, including total sleep. Standardized global cognitive scores differed at baseline, with higher scores observed in the Dance group.

	Dance volunteers (n = 43), mean (SD)	Reference participants (n = 28), mean (SD)	*p*-value
Mean age (years)	70.0 (7.0)	66.7 (7.3)	0.064
Gender (F/M)	18/25	7/21	0.205
Hoehn & Yahr	1.3 (0.8)	1.4 (0.8)	0.609
Standardized Cognition	0.82 (0.23)	0.70 (0.20)	0.023
UPDRS Part I Patient Questionnaire	7.24 (3.85)	6.38 (4.62)	0.166
Total Sleep Score	2.25 (1.42)	2.26 (1.64)	0.311

Table 4.1. Descriptive statistics for demographic, clinical, cognitive, and non-motor variables of the Dance and Reference groups.

Sleep and Non-Motor Outcomes

Group-level trends of insomnia and daytime sleepiness are presented in Figure 4.1. At baseline in 2014, the baseline-adjusted GEE model found no significant differences between the Dance and Reference groups for insomnia (β = 0.29, 95% CI [-0.09, 0.67], p = .136) or daytime sleepiness (β = -0.07, 95% CI [-0.35, 0.21], p = .607). A significant positive effect of year (β =

0.15, 95% CI [0.05, 0.25], p = .003) indicated that insomnia worsened over time in the Reference group. The Dance group, however, demonstrated an improvement in insomnia symptoms over time compared to the Reference group (group x year interaction: β = -0.20, 95% CI [-0.35, -0.06], p = .005). For daytime sleepiness, neither group demonstrated significant change across the study period (Reference β = -0.006, 95% CI [-0.10, 0.09], p = .893, interaction β = 0.07, 95% CI [-0.07, 0.20], p = .314), indicating stability across time in both groups. Results were consistent across the primary baseline-adjusted GEE and sensitivity LMM analyses. For insomnia, both models revealed significant worsening over time in the Reference group. In addition, both models found no significant change in daytime sleepiness between both the Dance and Reference groups.

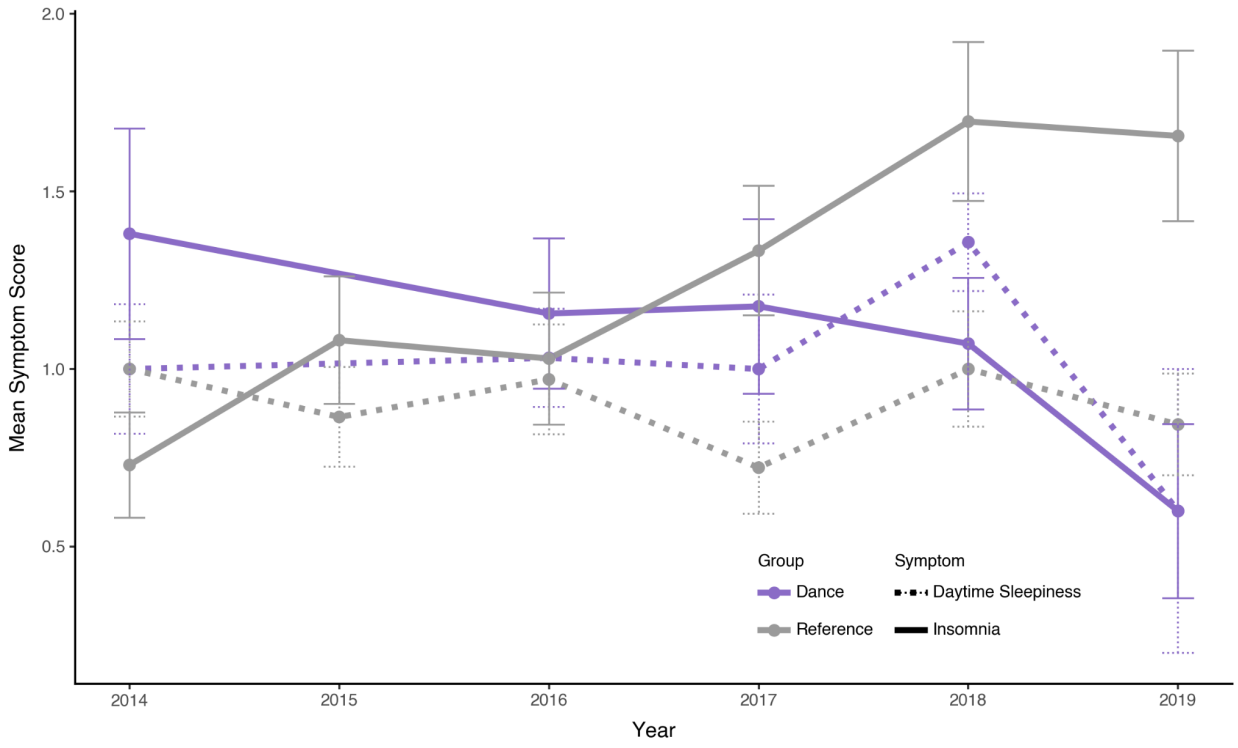

Figure 4.1. Mean scores of insomnia and daytime sleepiness across six years for the Dance and Reference groups. Line plots display annual group-level trajectories for insomnia and daytime

sleepiness from 2014-2019. The Dance group is shown in purple, while the Reference group is shown in grey. Dotted lines are used to represent daytime sleepiness, while insomnia is depicted by solid lines. Higher scores reflect greater symptom severity. Error bars indicate the standard error around the yearly mean score for each group and symptoms.

Baseline-adjusted GEE models found no significant difference in non-motor symptom burden between the Dance and Reference groups (β = -0.2334, 95% CI [-0.808, 0.341], p = .426) at baseline in 2014. The Dance group demonstrated no significant decline in MDS-UPDRS scores across the six-year study period, with no significant change observed during the early to mid (β = -0.26, 95% CI [-1.12, 0.59], p = .547), or late periods (β = -0.24, 95% CI [-1.48, 1.01], p = .711). A group-by-period interaction revealed a trend towards higher symptom burden in the Reference group during the Mid period (β = 1.06, 95% CI [-0.10, 2.21], p = .073) and significant worsening in the late period (β = 2.45, 95% CI [0.55, 4.35], p = .011) compared with the Dance group (see Figure 4.2). A LMM was used to compare the robustness of the GEE findings. No significant group difference was observed at baseline (p = .35), and no significant main effects of period were detected (all p > .68), aligning with the primary analysis. Instead, a significant interaction effect was observed during the Late period, indicating higher MDS-UPDRS non-motor symptom severity in the Reference group relative to the Dance group. The interaction at the Mid period showed a similar trend, although this did not reach statistical significance (p = .14). Findings of the sensitivity analysis were consistent with the primary GEE results, demonstrating a gradual increase in non-motor symptom burden within the Reference group, while the Dance group remained stable across the six-year study period. Most individual non-motor symptoms remained stable across time within the Dance group and between both the Dance and Reference groups (all p > 0.05). However, two significant group-by-period

interactions revealed worsening of insomnia and constipation in the Reference group, when compared to the Dance group, during the later years of the study. Full model outputs of all individual non-motor symptoms are presented in Table 4.2.

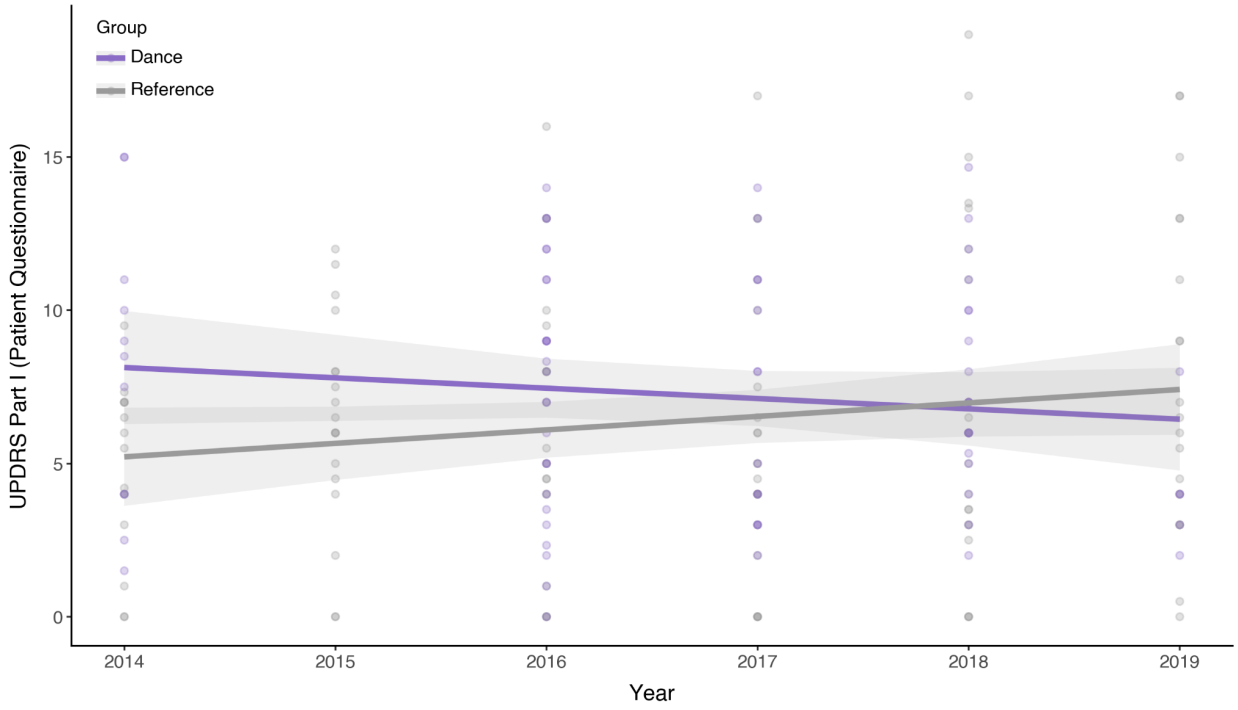

Figure 4.2. Dance vs Reference Longitudinal UPDRS Part 1 Patient Questionnaire scores from 2014-2019. Scatterplots show individual yearly scores for the Dance and Reference groups, with solid lines depicting fitted linear trends and shaded regions representing the 95% confidence intervals. The Dance group is shown in purple, and the Reference group is shown in grey. Higher scores reflect greater symptom severity. Trends are shown to illustrate overall group-level change across the six-year period.

Variable	Predictor	Group(s)	Beta	p-value	95% CI
Insomnia	Baseline	Dance vs Reference	-0.0118	0.925	-0.256, 0.232
	Mid vs Early	Dance	-0.0839	0.506	-0.331, 0.163

	Late vs Early	Dance	-0.1629	0.343	-0.500, 0.174
	Group x Mid	Dance vs Reference	0.2245	0.197	-0.116, 0.566
	Group x Late	Dance vs Reference	0.6775	***0.018***	0.119, 1.236
Daytime Sleepiness	Baseline	Dance vs Reference	-0.0389	0.673	-0.220, 0.142
	Mid vs Early	Dance	0.0741	0.402	-0.099, 0.248
	Late vs Early	Dance	0.1836	0.308	-0.170, 0.537
	Group x Mid	Dance vs Reference	-0.1189	0.359	-0.373, 0.135
	Group x Late	Dance vs Reference	-0.0811	0.743	-0.565, 0.403
Pain/Other Sensory	Baseline	Dance vs Reference	-0.0746	0.617	-0.367, 0.218
	Mid vs Early	Dance	-0.2182	0.175	-0.533, 0.097
	Late vs Early	Dance	-0.2358	0.297	-0.679, 0.207
	Group x Mid	Dance vs Reference	0.2411	0.237	-0.158, 0.640
	Group x Late	Dance vs Reference	0.2778	0.339	-0.291, 0.847
Urinary Problems	Baseline	Dance vs Reference	0.1012	0.147	-0.035, 0.238
	Mid vs Early	Dance	0.0966	0.259	-0.071, 0.264
	Late vs Early	Dance	0.0794	0.588	-0.208, 0.367
	Group x Mid	Dance vs Reference	-0.109	0.454	-0.395, 0.177
	Group x Late	Dance vs Reference	0.1677	0.448	-0.266, 0.601

Constipation	Baseline	Dance vs Reference	-0.0178	0.75	-0.127, 0.092
	Mid vs Early	Dance	0.0312	0.822	-0.241, 0.303
	Late vs Early	Dance	-0.2724	0.033	-0.523, -0.021
	Group x Mid	Dance vs Reference	0.0943	0.576	-0.236, 0.425
	Group x Late	Dance vs Reference	0.5709	***0.012***	0.127, 1.015
Light Headedness	Baseline	Dance vs Reference	-0.011	0.935	-0.276, 0.254
	Mid vs Early	Dance	-0.075	0.455	-0.272, 0.122
	Late vs Early	Dance	-0.0791	0.568	-0.351, 0.193
	Group x Mid	Dance vs Reference	-0.0875	0.531	-0.361, 0.186
	Group x Late	Dance vs Reference	0.2188	0.348	-0.239, 0.676
Fatigue	Baseline	Dance vs Reference	0.024	0.85	-0.224, 0.272
	Mid vs Early	Dance	-0.1582	0.134	-0.365, 0.049
	Late vs Early	Dance	0.036	0.779	-0.216, 0.288
	Group x Mid	Dance vs Reference	0.2451	0.126	-0.069, 0.559
	Group x Late	Dance vs Reference	0.1342	0.5	-0.256, 0.524

Table 4.2. Baseline-adjusted GEE results for individual non-motor symptoms (UPDRS Part 1 Patient Questionnaire). The table summarizes model estimates for each symptom, including predictor term, group(s) examined, beta coefficients, p-values, and 95% confidence intervals.

Cross-Domain Associations

Variable	Predictor	Group(s)	Beta	p-value	95% CI
Cognition	Baseline	Dance vs Reference	0.0281	0.516	-0.057, 0.113
	Mid vs Early	Dance	0.1415	***0.028***	0.016, 0.267
	Late vs Early	Dance	0.0943	0.085	-0.013, 0.202
	Group x Mid	Dance vs Reference	-0.1614	***0.016***	-0.293, -0.030
	Group x Late	Dance vs Reference	-0.0978	0.148	-0.230, 0.035
	Baseline Cognition	Dance vs Reference	0.6426	<***0.001***	0.484, 0.801
	UPDRS (centered)	Dance vs Reference	-0.0029	0.341	-0.009, 0.003

Table 4.3. Standardized Cognition Predicted by UPDRS Part 1 Patient Questionnaire (Between Groups). Displayed values include the predictor term, group(s) examined, beta coefficients, p-values, and corresponding 95% confidence intervals.

Baseline-adjusted GEE models demonstrated that cognition improved significantly in the Dance group during the Mid (β = 0.146, 95% CI [0.020, 0.272], p = .023) and showed a non-significant upward trend in the Late period (β = 0.0977, 95% CI [-0.011, 0.206], p = .078) compared to the Early period. Relative to the Dance group, the Reference group demonstrated a significant decline in cognitive performance during the Mid period (β = -0.1657, 95% CI [-0.298, -0.033], p = .014). Although the downward trend continued in the Reference group, it was no longer significant by the Late period (β = -0.104, 95% CI [-0.239, 0.031], p = .13). Sleep burden was not significantly associated with standardized cognition across groups (β = -0.0033, 95% CI

[-0.021, 0.015], p = .72), indicating that higher sleep-related symptom severity did not predict poorer global cognitive performance.

Consistent with the baseline-adjusted GEE findings, a LMM found that cognition improved significantly in the Dance group during the Mid and Late periods compared with Early. In comparison, the Reference group demonstrated significantly lower cognitive performance in both the Mid (β = -0.21, 95% CI [-0.34, -0.08], p = .001) and Late (β = -0.16, 95% CI [-0.29, -0.02], p = .024) periods. Baseline cognition remained a strong positive predictor of subsequent performance (β = 0.68, 95% CI [0.55, 0.81], p < 0.001). Sleep burden was not associated with standardized cognition (β = 0.001, 95% CI [-0.02, 0.02], p = .952).

4.4 Discussion

Across six years, PwPD who engaged in weekly community-based dance classes demonstrated significant improvements and preservation in global cognition relative to baseline, aligning with previous literature demonstrating the cognitive benefits of dance (Hackney, 2025; Kalyani et al., 2019; Vaseinasrabadi & DeSouza, 2025; Vitale et al., 2024). The high executive demands of dance, particularly stemming from the ability to process, sequence, and recall complex movements, likely contributed to the cognitive improvements observed in the Dance group (Foster Vander Elst et al., 2023; Huang et al., 2023). Neuroimaging research further indicates that dance may induce neuroplastic changes, observed among older adults, within the prefrontal cortex, a region that is heavily involved in working memory processes (Basso et al., 2021), thus suggesting dance may modulate executive functioning. Following a 40-week dance intervention, Doi et al. (2017) also found significant improvements in measures of recall and

registration and MMSE scores among older individuals with MCI. In contrast, a sedentary Reference group exhibited a mid-period decline in global cognition, similar to prior evidence suggesting that sedentary behaviour may present as a risk factor for cognitive impairments (Jones et al., 2022). A three-year longitudinal investigation by Jones et al. (2022) reported that physically active PwPD, or those who became increasingly more active, were at lower risk of severe cognitive decline, whereas those with sedentary lifestyles were at elevated risks for MCI and dementia. Similar findings were demonstrated by Ellingson et al. (2019) who found that higher engagement in sedentary behaviours were associated with worse self-reported scores on the cognitive subscale of the Parkinson's Disease Questionnaire-39.

In alignment with prior literature (Amara & Memon, 2018; Prusynski et al., 2022; Rabinovich et al., 2021), insomnia worsened significantly in the Reference group while remaining stable or slightly improving in the Dance group, leading to a significant group-by-year interaction favouring dance participation. While the pattern of neurodegeneration observed in PD is known to disrupt sleep-related regions of the brain (Rothman & Mattson, 2012; X. Wang et al., 2022), daytime sleepiness remained stable in both groups across the six-year study period. One explanation may reflect the absence of coexisting sleep disturbances among our groups with mild-PD. For example, a 5-year longitudinal study found that insomnia and daytime sleepiness typically overlap as PD progresses to the advanced stages of the disease (Xu et al., 2021). However, additional research reported a significant association between insomnia and daytime sleepiness among males with mild PD (Shafazand et al., 2017), suggesting the stability of insomnia in the Dance group, compared with worsening in the Reference group, may reflect the protective role of dance against nocturnal motor disturbances through the preservation of motor symptoms (Bearss & DeSouza, 2021). Similarly, preliminary findings reported by Krampe et al.

(2014) in a feasibility study on the use of passive bed sensors also found reduced nighttime restlessness in older adults following a 6-week dance intervention compared to a no-dance group. While insomnia was not explicitly analyzed (Krampe et al., 2014), brain areas involved in sleep regulation, such as the hypothalamus and limbic regions (Duan et al., 2025), may become engaged through dance. In addition, research has demonstrated the association between sustained dance and improved depressive symptoms in PwPD (Bearss et al., 2024). Consistent with this finding, poorer sleep quality was associated with worse depressive symptoms among dancers (Junge et al., 2024), potentially suggesting the link between enhanced emotional regulation and dance in improving sleep quality.

The existing research surrounding the association between sleep and cognitive dysfunction in PD is inconclusive across the literature (Goldman et al., 2014; Kim et al., 2014). In the present study, we found no relationship between sleep disturbances and cognition in either group, however, Zhong et al. (2024) similarly reported greater longitudinal decline in global cognition on the MoCA among newly diagnosed and untreated PwPD with insomnia, and no association between MoCA scores and daytime sleepiness. In the present study, the Dance group showed improved or preserved cognitive functioning and stability in insomnia and daytime sleepiness compared to the Reference group, suggesting that the absence of associations may reflect the physical and cognitive benefits of exercise (Shafiq et al., 2024; Still et al., 2024). Consistent with this interpretation, a recent 5-year longitudinal study demonstrated that higher physical activity scores on the PASE were associated with slower deterioration in motor and non-motor symptoms, whereas lower scores predicted faster cognitive and functional decline, including sleep quality, among PwPD (Ng et al., 2025). In a separate analysis of individual non-motor symptom burden, the Reference group demonstrated significant worsening of constipation

as well. Interestingly, a recent study by Doi et al. (2023) investigating the relationship between constipation and nighttime sleep quality among PwPD found that constipation severity was significantly associated with poor sleep in PD. The presence of constipation has been further linked to worse non-motor symptom burden (Guan et al., 2018), with physical inactivity suggested to exacerbate the severity of such non-motor symptoms (Nimwegen et al., 2011), which evidently aligns with our findings demonstrating worse overall non-motor symptom burden in the Reference group.

Strengths and Limitations

To our understanding, the present study is the first to collectively investigate the influence of community dance engagement on sleep disturbances and overall non-motor symptom severity, alongside their relationship with global cognition, among PwPD across six-years. Specifically, we aimed to analyze insomnia and daytime sleepiness, as well as overall non-motor symptom burden, with global cognition as a functional outcome in a Dance group compared to a sedentary Reference group of PwPD across the same study period. Incorporating a community-based intervention within an observational design spanning six-years provided an opportunity to capture real-world trajectories of cognitive and non-motor symptom progression among PwPD. In contrast to our previous analysis which largely focused on global cognition within the same study sample (Rooprai et al., 2025), our current findings extend beyond cognition and demonstrate the population-level patterns of non-motor symptomatology in association with long-term dance engagement and physical inactivity, enhancing generalizability to the broader PD community. Although no cognitive change was observed in the Reference group in our previous analysis using the same study sample (Rooprai et al., 2025), the present

baseline-adjusted models may have revealed a time-related decline in cognition, even in the absence of a sleep-cognitive association, potentially strengthening the sensitivity and robustness of our findings.

Despite these strengths, the present study shares several methodological limitations with our previous analysis of global cognition within the same study sample (Rooprai et al., 2025). Firstly, the study design was observational, and both the Dance and Reference groups were non-randomized. Although both groups were matched on key demographic and disease-related variables, unmeasurable confounding variables, such as disease duration, may have played a role. PwPD in the Dance group were not referred or recruited, but voluntarily joined the study and were not consistently tested at each time point as well. This variability in the dataset could have reduced statistical power at certain timepoints, preventing subgroup analyses. We did not track volunteer attendance or attrition, therefore, those who discontinued participation may have received reduced benefits compared to individuals who maintained participation, resulting in potential attrition bias. However, a single data point may not reflect the true number of dance classes attended as volunteers may have continued to participate in between the data collection timepoints.

Similar to our previous analysis, the lack of consistency between the cognitive tools administered (i.e., MMSE in the Dance group and MoCA in the Reference group) may have introduced differences in measurement sensitivity. Although raw cognitive scores were standardized into z-scores, which is a commonly used approach to facilitate objective comparisons between outcomes across different assessment tools (Andrade, 2021; Caldwell et al., 2019; Mejía Arango et al., 2015), the difference in sensitivity and scoring structures between the MMSE and MoCA could have influenced findings. As such, these methodological limitations

should be considered when interpreting the global cognitive outcomes of both groups. While the MMSE is known to exhibit ceiling effects and may lack the ability to detect subtle changes in cognitive functioning (Franco-Marina et al., 2010; Trzepacz et al., 2015), the significant improvement observed in the Dance group suggests that global cognitive gains were sufficiently pronounced to be captured by this assessment tool. Despite the lack of data available on volunteer attendance, the repeated exposure to dance through the longitudinal nature of the intervention may help to support the observed improvements in global cognition. Interestingly, global cognition was assessed using the MoCA in the Reference group where a significant decline was observed, possibly suggesting the improvement in the Dance group may reflect meaningful cognitive change.

Non-motor symptoms, including sleep disturbances, were assessed using the Patient Questionnaire subsection of the UPDRS Part 1. While item 1.7, labelled sleep problems, has been used in previous literature to analyze the severity of insomnia (Horváth et al., 2014; Xu et al., 2021), item 1.8, labelled excessive daytime sleepiness, may not capture the full complexity of this symptom. EDS is a multifaceted symptom that can manifest at various times during waking periods, including while driving or during a conversation (Höglund et al., 2019; Horváth et al., 2014), thus a single-item measure may not be suitable for the range of situations in which EDS may be present. As such, future studies should administer comprehensive and descriptive measures, such as the 8-item Epworth Sleepiness Scale, to grasp the functional impact of EDS. Because the Epworth Sleepiness Scale is a subjective and self-reported questionnaire, future studies may also benefit from employing additional measures, including the Multiple Sleep Latency Test and the Maintenance of Wakefulness Test, to objectively monitor and analyze EDS among PwPD (Höglund et al., 2019; Suzuki et al., 2025). Lastly, the first half of the UPDRS Part

I was not collected in the Dance group, limiting our ability to comprehensively assess the full range of non-motor symptoms in both groups, thus potentially reducing the sensitivity of our non-motor analyses.

Conclusion

Taken together, our findings further support dance as a valuable non-pharmacological approach, alongside usual care, to help alleviate non-motor symptom burden, including sleep and cognitive dysfunction, among PwPD. Despite the acknowledged limitations, the present study provides preliminary findings on the longitudinal effects of dance on sleep disturbance, select non-motor symptoms, and their associated with global cognition. As further research is warranted, our findings may help inform future long-term investigations incorporating more rigorous protocols and comprehensive measures to strengthen alternative models of care, while contributing further to the literature surrounding the benefits of dance for PwPD.

CHAPTER 5

5. GENERAL DISCUSSION

5.1 Chapter Overview

This chapter provides an integrative overview of the findings presented across the thesis which consisted of a scoping review on dance-based interventions for PwPD, followed by two longitudinal investigations of cognitive and non-motor outcomes following six-years of community dance engagement.

5.2 Synthesis of Main Findings

The scoping review (Chapter 2) revealed that dance-based interventions for PD have predominantly focused on motor outcomes, which were consistently evaluated across the literature and most frequently associated with improvements. In contrast, non-motor and cognitive outcomes gained more recognition following 2015 and findings across these domains were more variable. The review identified a disparity in outcome prioritizing, emphasizing the need for a more balanced focus on cognitive and non-motor symptomatology in future dance-based PD research. The variability in outcomes further demonstrated the necessity for refined dance protocols, including longer durations and larger sample sizes. To address this critical gap in the literature, we conducted two secondary analyses (Chapter 3 and 4) focusing on cognitive and non-motor outcomes following a six-year dance intervention among 43 PwPD.

The first empirical analysis (Chapter 3) showed that cognitive performance of PwPD who took part in weekly dance classes for six years had improved significantly, whereas a relative decline was demonstrated by a PD-Reference group who did not engage in any physical activity. Building on these findings, we aimed to examine the influence of dance on domain-specific cognitive outcomes and non-motor symptoms, particularly sleep-related disturbances, within the same study population (Chapter 4). The initial analysis focused on cognitive domains that are most susceptible to impairments in PD, those being memory, attention/working memory, and visuospatial function. Across the six-year study period, attention/working memory improved both significantly and consistently. While improvements in memory and visuospatial domains were variable, the Dance group demonstrated patterns of stability across these outcomes. In contrast, the inactive Reference showed no changes in attention/working memory and visuospatial ability, and a declining trend in memory. Regarding non-motor and sleep-related disturbances, the Reference group demonstrated significant worsening of insomnia and overall non-motor symptom severity, whereas the Dance group remained stable. Scores of daytime sleepiness remained stable in both the Dance and Reference groups, suggesting the lack of co-existing sleep disturbances during the mild to moderate stages of the disease. Interestingly, the Reference group showed significant worsening in constipation as well.

While in our analysis of global cognitive outcomes (Chapter 3), we had found that the Reference group exhibited relatively no change across the six-year study period from 2014 to 2019, the baseline-adjusted GEE employed in the second study (Chapter 4) revealed a significant mid-period decline in global cognition when exploring the association between global cognition and sleep burden. To further support these findings, an LMM sensitivity analysis (Chapter 4) found significant declines across the mid-and late periods in global cognitive performance

among PwPD in the Reference group. Drawing on the gaps revealed in the scoping review (Chapter 2), the majority of interventions across studies evaluating cognitive and non-motor outcomes were typically short-term and approximately half reported no significant findings. In our analyses of cognitive and non-motor trajectories following a longitudinal dance intervention (Chapter 3 and 4), the preservation and improvements were observed over several years, highlighting the potential value of sustained dance engagement for PwPD.

5.3 Limitations

Following the JBI framework for scoping reviews, a risk of bias was not included in Chapter 2. In addition, the search was limited to English-language publications from 2000-onwards and excluded qualitative studies. Across the two longitudinal empirical studies presented in Chapters 3 and 4, several limitations overlapped. For example, the study design was observational and therefore, it did not include a control group. Instead, a non-randomized Reference group was selected from the PPMI database. While efforts were made to ensure both the Dance and Reference groups were comparable, all findings should be interpreted with caution. In addition, we did not match groups on disease duration as this may have reduced the sample size in the Reference group. While groups were matched on age, gender, and disease severity, we did not include these variables again as covariates given the relatively small sample sizes across both groups. As the study was observational, it should be further acknowledged that the Dance group was not consistently tested across the study period, similar to the Reference group, and dance class attendance was not collected. Another limitation concerns the different cognitive assessments administered in both groups. While the standardization of raw MMSE (Dance) and MoCA (Reference) scores allowed for between-group analyses, the notable

differences between these cognitive tools may have influenced findings. Similarly, the within-group analyses of individual cognitive domains (Chapter 4) should be interpreted carefully as the MoCA and MMSE are not equivalent and individual items may not be robust in analyzing domain-specific changes. Furthermore, statistically significant findings were based on p-values and do not reflect clinical significance. Another limitation is the use of item 1.8 from Part I of the UPDRS (Patient Questionnaire), which is a general question concerning daytime sleepiness and, thus, may not be sufficient in capturing the full extent of this symptom. Finally, the analyses presented in Chapters 3 and 4 relied on quantitative findings as qualitative data were not collected. This may have limited potential insights into the lived experiences of PwPD, which may be especially relevant for a better understanding of non-motor health and quality of life.

5.4 Future Directions

Collectively, the findings of the present work, along with the noted limitations, may provide several directions for future research. Future work and protocols should aim to incorporate well-matched and randomized control groups, with consistent testing intervals, as well as systematic tracking of intervention adherence. In addition, future research should utilize validated and comprehensive tools that are sensitive to changes in cognitive and non-motor symptoms, and the potential inclusion of neuroimaging tools to assess whether behavioural outcomes are accompanied by neuronal resilience. Longer intervention durations, including frequency of individual sessions, are further necessary to ensure sufficient engagement to produce meaningful changes. In doing so, refined protocols may provide a better understanding of how dance influences symptom trajectories, beyond motor manifestations, among PwPD.

In collaboration with Baycrest, the findings of the present thesis have directly informed the development of a feasibility trial aimed at investigating the influence of dance on visuospatial working memory among participants with PD and MCI. This feasibility study will incorporate an active control group that is matched on key demographic and disease variables with an experimental dance group. The study design further addresses several methodological inconsistencies addressed in the present thesis. While the research is currently underway, this study represents an important step towards refining dance-based protocols and measurement strategies for future research.

5.5 Conclusion

From a broader perspective, the present thesis drew attention to the importance of moving beyond a predominantly motor-focused emphasis within PD research. Dance represents a multidimensional and community-based intervention that simultaneously engages physical, cognitive, and psychosocial efforts. Future research should continue to examine how non-pharmacological approaches to care, particularly community-based dance, can be refined and integrated as part of usual care. The broad spectrum of impairments associated with the disease, encompassing motor, non-motor and cognitive deficits, coupled with current treatment limitations, further signifies the need for alternative forms of care for PwPD. In this context, real-world implementation of community-based interventions may offer better support for PwPD and contribute to enhanced quality of life within this population.

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APPENDICES

APPENDIX A: Search Terms for Scoping Review

1. **PubMed** (MEDLINE)

("Parkinson Disease"[MeSH] OR "Parkinson's disease" OR Parkinsons) AND ("Dance"[MeSH] OR "Dance therapy"[MeSH] OR dance OR "dance-based" OR "dance intervention" OR tango OR ballet) AND ("Motor Symptoms"[MeSH] OR "motor function" OR "motor symptoms" OR "motor impairment" OR "Cognition"[MeSH] OR cognition OR "cognitive function" OR "cognitive impairment" OR "cognitive decline" OR "Sleep Wake Disorders"[MeSH] OR "sleep disturbances" OR insomnia OR "excessive daytime sleepiness" OR mood OR depression OR anxiety OR apathy OR fatigue)

2. **PsycINFO** (via ProQuest)

AB ("Parkinson's disease" OR Parkinsons) AND AB (dance OR "dance-based" OR "dance therapy" OR "dance intervention" OR tango OR ballet) AND AB ("motor function" OR "motor symptoms" OR "motor impairment" OR cognition OR "cognitive function" OR "cognitive impairment" OR "cognitive decline" OR "sleep disturbances" OR insomnia OR "excessive daytime sleepiness" OR mood OR depression OR anxiety OR apathy OR fatigue)

3. **Web of Science**

Topic/Subject (TS)=("Parkinson's disease" OR Parkinsons) AND TS=(dance OR "dance-based" OR "dance therapy" OR "dance intervention" OR tango OR ballet) AND TS=("motor function" OR "motor symptoms" OR "motor impairment" OR cognition OR "cognitive function" OR "cognitive impairment" OR "cognitive decline" OR "sleep disturbances" OR insomnia OR "excessive daytime sleepiness" OR mood OR depression OR anxiety OR apathy OR fatigue)

APPENDIX B: Characteristics of Included Studies and Intervention Details

Author(s), Year	Country	Study Design	Population (I/C)	Comparator	Dance Style & Intervention Details
Abraham et al. 2024	USA	Exploratory case series	Intervention Size: 6 Sex (F/M): 3/3 Mean (SD) Age: 69.5 Mean (SD) H&Y: 3	No control	Adapted Tango (clinical setting) 12 weeks; 90 min
Duarte et al. 2023	Brazil	Longitudinal Pre/Post	Intervention Size: 13 Sex (F/M): 8/5 Mean (SD) Age: 65.9 (6.5) Mean (SD) H&Y: 2.2 (0.7)	No control	Baila Parkinson (clinical setting) 6 months; 2x/week; 50 min
Haputhanthirige et al. 2023	Australia	Quasi-experimental parallel group pre/post (Pseudo-randomized)	Intervention Size: 17 Sex (F/M): 14/3 Mean (SD) Age: 65.8 (11.7) Mean (SD) H&Y: 1.65 (0.79) Control Size: 16 Sex (F/M): 6/10 Mean (SD) Age: 67 (7.7) Mean (SD) H&Y: 1.56 (0.81)	Usual care	DfPD (clinical setting) 12 weeks; 2x/week; 60 min
Valverde-Guijarro et al. 2022	Spain	Uncontrolled Withdraw-Reversal (A-B-A)	Intervention Size: 27 Sex (F/M): 9/18 Mean (SD) Age: 67.3 (6.14) Mean (SD) H&Y: 2-3	No control	Contemporary dance – adjunct to physiotherapy (community setting) A (Physio): 4 weeks; 2x/week/ 45 min B (Physio + Dance): 8 weeks; 2x/week; 60 min A (Physio): 4 weeks; 2x/week; 45 min
Krotinger & Loui (2021)	USA	Pre/Post Uncontrolled	Intervention Size: 30 Sex (F/M): 23/7	Usual care	Mixed dance styles, e.g., African, contemporary, modern, Latin dances

			Mean (SD) Age: NR Mean (SD) H&Y: NR Control Size: 19 Sex (F/M): 11/8 Mean (SD) Age: NR Mean (SD) H&Y: NR		(community setting) 4 months; 1x week; 75 min
Fontanesi & DeSouza (2021)	USA	Repeated-measures within-subjects (controlled)	Intervention Size: Sex (F/M): Mean (SD) Age: 71.4 (6.7) Mean (SD) H&Y: 1.6 (0.5)	No control	DfPD (community setting) Unknown duration; 1x week; 75 min
Kalyani et al. 2019	Australia	Quasi-experimental Parallel Group Pre/Post	Intervention Size: 17 Sex (F/M): 14/3 Mean (SD) Age: 65.24 (11.88) Mean (SD) H&Y: 1.65 (0.79) Control Size: 16 Sex (F/M): 6/10 Mean (SD) Age: 66.5 (7.7) Mean (SD) H&Y: 1.56 (0.81)	Usual care	DfPD (community setting) 12 weeks; 2x week; 1 hour
Prewitt et al. 2017	USA	Uncontrolled Pre-Post	Intervention Size: 6 Sex (F/M): 3/3 Age Range: 62-87 years H&Y Range: Stages 1-3	No control	Mixed dance styles, eg., ballroom, foxtrot, samba, tango, line dance, others (community setting) 8 weeks; 2x week; 1 hour
de Natale et al. 2016	Italy	Controlled Trial (Non-Randomized)	Intervention (A) Size: 9 Sex (F/M): 2/7 Mean (SD) Age: 66 (9.15) Mean (SD) H&Y: 2.5 (0.7) Intervention (B) Size: 7 Sex (F/M): 3/4 Mean (SD) Age: 67 (7.7) Mean (SD) H&Y: 2.6 (0.6)	No control	A (Dance Therapy): Argentine Tango (clinical setting) B: Traditional Rehabilitation (clinical setting) Both: 10 weeks; 2x/week; 60 min

Westheimer et al. 2015	USA	Uncontrolled Pre-Post Mixed Methods	Intervention Size: 12 Sex (F/M): 6/6 Mean (SD) Age: 66.2 (7.3) Mean (SD) H&Y: 2.3 (0.8)	No control	DfPD (community setting) 8 weeks; 2x week; 75 min
Hackney & McKee (2013)	USA	Non-Randomized Controlled Trial	Intervention Size: 24 Sex (F/M): 12/12 Mean (SD) Age: 68.4 (7.5) Mean H&Y: 2.3 Control Size: 9 Sex (F/M): 1/8 Mean (SD) Age: 74.4 (6.5) Mean H&Y: 2	Interactive education seminars on well-being (active control; same duration as dance)	Adapted Argentine Tango (community setting) 12 weeks; 90 min (20 sessions total)
Heiberger et al. 2011	Germany	Uncontrolled Pre-Post	Intervention Size: 11 Sex (F/M): 6/5 Mean (SD) Age: 71.3 (8.4) Mean (SD) H&Y: NR	No control	Mixed dance styles, following DfPD method; ballet, jazz, contemporary, others (community setting) 8 months; 1x week; 75 min
Romenets et al. 2015	Canada	RCT	Intervention Size: 18 Sex (F/M): 6/12 Mean (SD) Age: 63.2 (9.9) Mean (SD) H&Y: 1.7 (0.6) Control Size: 15 Sex (F/M): 8/7 Mean (SD) Age: 64.3 (8.1) Mean (SD) H&Y: 2.0 (0.5)	Usual care	Partnered Argentine Tango (clinical setting) 12 weeks; 2x week; 1 hour
Hackney & Earhart (2010)	USA	RCT with Active Control	Intervention (A) Size: 19 Sex (F/M): 6/13 Mean (SD) Age: 69.6 (8.5) Mean H&Y: 2.5 Intervention (B) Size: 20 Sex (F/M): 5/15 Mean (SD) Age: 69.6 (9.5)	No control	A: Partnered Argentine Tango (community setting) B: Un-partnered Argentine Tango (community setting) 10 weeks; 2x week; 1 hour

			Mean H&Y: 2		
Moratelli et al. 2022	Brazil	RCT with active control	Intervention (A) Size: 18 Sex (F/M): NR Mean (SD) Age: 68.3 (8.6) Mean (SD) H&Y: NR Intervention (B) Size: 13 Sex (F/M): NR Mean (SD) Age: 64.3 (14.8) Mean (SD) H&Y: NR	No control	A: Binary Rhythm Dance (clinical setting) B: Quaternary Rhythm Dance (clinical setting) 12 weeks; 2x week; 45 min
Moratelli et al. 2023	Brazil	Clinical trial (non-randomized)	Intervention (A) Size: 23 Sex (F/M): 11/12 Mean (SD) Age: 67 (9.2) Mean (SD) H&Y: NR Intervention (B) Size: 23 Sex (F/M): 18/5 Mean (SD) Age: 72.7 (8.5) Mean (SD) H&Y: NR Control Size: 23 Sex (F/M): 6/17 Mean (SD) Age: 69.4 (9.6) Mean (SD) H&Y: NR	Usual care	A: Forro (clinical setting) B: Samba (clinical setting) 22 weeks; 2x week; 1 hour
Hashimoto et al. 2015	Japan	Quasi-randomized controlled clinical trial	Intervention Size: 15 Sex (F/M): 12/3 Mean (SD) Age: 67.9 (7.0) Mean (SD) H&Y: NR Control Size: 14 Sex (F/M): 7/7 Mean (SD) Age: 69.7 (4.0) Mean (SD) H&Y: NR	Usual care	Mixed dance styles, e.g., aerobic, tango, jazz, ballet, etc (community setting) 12 weeks; 1x week; 60 min
Haas et al. 2024	Brazil	Randomized clinical trial (uncontrolled)	Intervention Size: 31 Sex (F/M): 21/10	No control	Brazilian dance (clinical setting)

			Mean (SD) Age: 71.61 (8.89) Mean (SD) H&Y: 2.16 (0.88)		12 weeks; 2x week; 60 min
Hackney & Earhart (2009)	USA	Randomized between-subjects repeated measures	Intervention (A) Size: 17 Sex (F/M): 6/11 Mean (SD) Age: 66.8 (2.4) Mean (SD) H&Y: 2 (0.2) Intervention (B) Size: 14 Sex (F/M): 3/11 Mean (SD) Age: 68.2 (1.4) Mean (SD) H&Y: 2.1 (0.1) Control Size: 17 Sex (F/M): 5/12 Mean (SD) Age: 66.5 (2.8) Mean (SD) H&Y: 2.2 (0.2)	Usual care	A: Waltz/Foxtrot (community setting) B: Tango (community setting) 13 weeks; 2x week; 60 min
Kang et al. 2022	Korea	Single-centre, single-arm study	Intervention Size: 9 Sex (F/M): 4/5 Mean (SD) Age: 69.1 (4.3) Mean (SD) H&Y: NR	No control	Dance based on Feldenkrais method (community setting) 6 months; 1x week; 1 hour
Carapellotti et al. 2022	UK	Quasi-randomized controlled trial	Intervention Size: 7 Sex (F/M): 1/6 Age Range: 53-72 H&Y Range: 1-2.5	No control	DfPD (community setting) 12 weeks; 2x week; 1 hour
Bearss et al. 2017	Canada	Observational study	Intervention Size: 9 Sex (F/M): 5/4 Mean (SD) Age: 67.78 (6.14) Mean (SD) H&Y: 0.8 (NR)	No control	Dancing with Parkinson's (community setting) 12 weeks; 1x week; 75 min
Harrison et al. 2020	USA	Pilot study	Intervention Size: 11 Sex (F/M): 4/7 Mean (SD) Age: 69 (8) H&Y Range: 2-3	No control	Contemporary dance (clinical setting) 6 weeks; 2x week; 1 hour
Sistarelli et al. 2023	USA, UK,	Repeated measures	Intervention Size: 33	No control	Popping for Parkinson's (community

	Italy	design	Sex (F/M): 19/14 Mean (SD) Age: 67.5 (10.3) Mean (SD) H&Y: 1.8 (1.6)		setting) 1 dance class only
Bearss & DeSouza (2021)	Canada	Preliminary longitudinal investigation	Intervention Size: 16 Sex (F/M): 6/11 Mean (SD) Age: 68.7 (8.4) Mean (SD) H&Y: 1.3 (0.9) Control Size: 16 Sex (F/M): 6/11 Mean (SD) Age: 69.8 (4.9) Mean (SD) H&Y: 1.6 (0.5)	Usual care	DfPD (community setting) 3 years; 1x week; 1.25 hours
Volpe et al. 2025	Italy	Feasibility, pilot, single-blind, parallel-group, RCT	Intervention Size: 12 Sex (F/M): 6/6 Mean (SD) Age: NR Mean (SD) H&Y: NR Control Size: 12 Sex (F/M): 6/6 Mean (SD) Age: NR Mean (SD) H&Y: NR	Conventional physiotherapy (active control; same duration as dance)	Dance Well Parkinson's Program (community setting) 4 weeks; 2x week; 1 hour
Jola et al. 2022	UK	Within-subjects repeated measures mixed-methods	Intervention Size: 26 Sex (F/M): 15/11 Mean (SD) Age: 71.31 (8.39) Mean H&Y: males, 3; females, 1.5 (provided separately)	No control	Dance program for Parkinson's (community setting) 1x week; 40 classes total
McNeely et al. 2015	USA	Quasi-experimental (two matched groups)	Intervention (A) Size: 8 Sex (F/M): 4/4 Mean (SD) Age: 68.25 (10.90) Mean (SD) H&Y: 2.25 (0.27) Intervention (B) Size: 8 Sex (F/M): 4/4 Mean (SD) Age: 67.66 (8.62)	No control	Two groups: DfPD vs. Tango (community setting) Both: 12 weeks; 2x week; 1 hour

			Mean (SD) H&Y: 2.13 (0.58)		
Tillmann et al. 2020	Brazil	Non-randomized clinical trial with control group	Intervention Size: 23 Sex (F/M): NR Mean (SD) Age: 67 (9.2) Mean (SD) H&Y: 1.8 (0.7) Control Size: 24 Sex (F/M): NR Mean (SD) Age: 69.6 (9.5) Mean (SD) H&Y: 1.8 (0.7)	Usual care	Brazilian dance: Samba (clinical setting) 12 weeks; 2x week; 60 min
Mehta et al. 2024	India	Accessor-blind, randomized three-arm, parallel group, single-centre, pilot study	Intervention Size: 20 Sex (F/M): 8/12 Mean (SD) Age: 59.45 (9.37) Mean (SD) H&Y: NR Control Size: 15 Sex (F/M): 6/9 Mean (SD) Age: 62.13 (8.21) Mean (SD) H&Y: NR	Usual care	Garba Indian Dance (clinical setting) 12 weeks; 5x week; 1 hour
Carapelloti et al. 2025	UK	Cross over study	Intervention Size: 19 Sex (F/M): 7/12 Mean (SD) Age: 67.84 (6.24) Mean (SD) H&Y: 2.03 (0.90)	No control	Followed DfPD Protocol (clinical setting) 60 minutes per session (unknown length or frequency of intervention)
Dahmen-Zimmer & Jansen (2017)	Germany	Feasibility study	Intervention Size: 9 Sex (F/M): 3/6 Mean (SD) Age: 72.33 (6.69) H&Y Range: 1-3 Control Size: 12 Sex (F/M): 4/8 Mean (SD) Age: 70.42 (10.07) H&Y Range: 1-3	Usual care	Mixed dance styles, e.g., rumba, waltz (clinical setting) 30 weeks; 1x week; 1 hour
Delabary et al. 2020	Brazil	Non-randomized clinical trial	Intervention Size: 12 Sex (F/M): 9/3	Walking (active	Brazilian dances: Samba and Forro (clinical setting)

			Mean (SD) Age: 68.6 (6.7) Mean (SD) H&Y: 1.5 (0.2) Control Size: 6 Sex (F/M): 2/4 Mean (SD) Age: 64.2 (4.9) Mean (SD) H&Y: 2.5 (0.3)	control; same duration as dance)	12 weeks; 2x week; 1 hour
Kalyani et al. 2020	Australia	Quasi-experimental controlled efficacy study with 2 parallel groups	Intervention Size: 17 Sex (F/M): 14/3 Mean (SD) Age: 65.8 (11.7) Mean (SD) H&Y: 1.6 (0.7) Control Size: 16 Sex (F/M): 6/10 Mean (SD) Age: 67.0 (7.7 Mean (SD) H&Y: 1.5 (0.8)	Usual care	DfPD (community setting) 12 weeks; 2x week; 1 hour
Bouquiaux et al. 2021	Belgium	Controlled open-label study	Intervention Size: 10 Sex (F/M): 4/6 Mean (SD) Age: 65 (NR) Mean (SD) H&Y: NR Control Size: 6 Sex (F/M): 2/4 Mean (SD) Age: 68 (NR) Mean (SD) H&Y: NR	Usual care	General dance (unclear setting) 4 months; 16 sessions total; 60 min
Elpidoforou et al. 2021	Greece	Prospective, non-randomized, uncontrolled, open-label, pilot study	Intervention Size: 16 Sex (F/M): 8/8 Mean (SD) Age: 56 (12) Mean (SD) H&Y: NR	No control	DfPD (community setting) 8 weeks; 2x week; 60 min
Jehu et al. 2025	USA	Exploratory analysis of RCT	Total Intervention Size: 38 Sex (F/M): NR Mean (SD) Age: 69.24 (7.73) Mean (SD) H&Y: 2.28 (0.58)	No control	Low support tango vs. high support tango (clinical setting) 12-13 weeks; 20 sessions total, 90 min
Duncan et al. 2011	USA	RCT	Intervention Size: 32	Usual care	Tango (community setting)

			Sex (F/M): 11/15 Mean (SD) Age: 69.3 (1.9) Mean (SD) H&Y: 2.6 (0.1) Control Size: 30 Sex (F/M): 11/15 Mean (SD) Age: 69.0 (1.5) Mean (SD) H&Y: 2.5 (0.1)		12 months; 2x week; 1 hour

APPENDIX C: Outcomes, Measures and Key Findings of Included Studies

Note. (1) Superscript letters following the author name(s) and year denote outcome domains assessed: [A] motor; [B] non-motor; [C] cognitive. Multiple letters indicate studies assessing more than one domain. (2) ↑ Improvement; ↓ Deterioration. (3) Abbreviations of measures not previously included in the List of Abbreviations are defined at the end of the table.

Author(s), Year	Domain(s) Assessed & Measures	Key Findings
Abraham et al. 2024[ABC]	Motor: FOG-Q, MDS-UPDRS, TUG, DGI, gait speed, FSST, FAB, CPF Non-motor: PDQ-39, ABC, QoLS, SF-12, BDI-II Cognitive: TMT, BSM, D-KEFS, CWIT, Reverse Corsi Blocks, Serial 3's task, MoCA	1. Gait speed (Externally Guided group) ↑ 2. DGI (EG group) ↑ 3. FAB (EG group) ↑ 4. FOG-Q (EG group) ↑ 5. BDI-II ↑ 6. ABC ↑ 7. QoLS ↑
Duarte et al. 2023[ABC]	Motor: POMA, MDS-UPDRS III Non-motor: PDQ-39, MADRS Cognitive: FAB	1. Balance and gait (POMA) ↑ 2. Depression (MADRS) ↑ 3. PDQ-39 ↑ 4. Executive functioning, conceptualization, inhibitory control (FAB) ↑
Haputhanthirige et al. 2023[AC]	Motor: MDS-UPDRS III, Spatiotemporal gait variables (velocity, cadence, step/stride length, stride time, etc) Cognitive: ACE, verbal fluency, serial subtraction	All spatiotemporal gait variables ↑ (even walking conditions only; uneven was mixed)
Valverde-Guijarro et al. 2022[AB]	Motor: BBS, TUG, SOT, MCT, RWS Non-motor: Satisfaction Questionnaire	1. BBS ↑ 2. TUG ↑ 3. Composite equilibrium, vestibular ratio, strategy (SOT) ↑ 4. Medio-lateral velocity, antero-posterial velocity (RWS) ↑ 5. High adherence/satisfaction (satisfaction questionnaire) ↑

Krotinger & Loui (2021)[AC]	Motor: UPDRS III Cognitive: BAT, Tapping task	All measures ↑
Fontanesi & DeSouza (2021)[AB]	Motor: G-WALK, UPDRS III, TUG dual task Non-motor: PANAS-X, BSE	Gait symmetry (GWALK) ↑ PANAS-X (trend) ↑ BSE ↑
Kalyani et al. 2019[BC]	Non-motor: UPDRS I, HADS, PDQ-39 Cognitive: NIH Cognition Battery, ACE, TMT A&B	1. Depression and anxiety (UPDRS I) ↑ 2. Activities of daily living, emotional well-being, cognition (PDQ-39) ↑ 3. Auditory verbal learning test (NIH) ↑ 4. TMT B ↑
Prewitt et al. 2017[BC]	Non-motor: GSE, GDI, Schwab and England ADL Cognitive: SCOPA-COG, parts of the MoCA (visuospatial, fluency, verbal recall, executive functioning, attention, quantitative reasoning)	1. Schwab and England ADL ↑ 2. Executive functioning of SCOPA-COG (at one time-point only) ↑
de Natale et al. 2016[AC]	Motor: UPDRS III, BBS, GDI, TUG, 4SST, 6MWT Cognitive: FAB, Stroop TMT A&B	1. TUG ↑ 2. 6MWT ↑ 3. TMT A&B ↑
Westheimer et al. 2015[AB]	Motor: UPDRS III, BBS Non-motor: PDQ-39, BDI	UPDRS III ↑
Hackney & McKee (2013)[ABC]	Motor: UPDRS III, FAB scale, TUG-B/C/M, 4SST, FOG-Q Non-motor: SF-12 Physical and Mental, PDQ-39 Cognitive: Brooks Spatial Task, MoCA, Corsi Block	1. UPDRS III ↑ 2. FAB scale ↑ 3. BST ↑
Heiberger et al. 2011[AB]	Motor: UPDRS III, TUG, Semitandem Test Non-motor: QoLS, General Questionnaire	1. UPDRS III ↑ 2. TUG (trend) ↑ 3. QoLS ↑

Romenets et al. 2015[ABC]	Motor: UPDRS III, Mini-BESTest, TUG + dual task, FOG-Q, CCHS Falls Questionnaire, Purdue Pegboard test Non-motor: Krupp Fatigue Scale, PDQ-39, CGI-C, Apathy Scale, BDI Cognitive: MoCA	1. Mini-BESTest ↑ 2. TUG + dual task ↑ 3. Krupp Fatigue Scale ↑
Hackney & Earhart (2010)[AB]	Motor: UPDRS III, BBS, Tandem Stance, One-Leg Stance, GAITRite, 6MWT, TUG Non-motor: Exit Questionnaire	1. BBS ↑ 2. Tandem stance ↑ 3. one leg stance ↑ 4. Enjoyment, physical well-being, willingness to continue (exit questionnaire) ↑
Moratelli et al. 2022[A]	Motor: UPDRS III, Mini-BESTest, FOG-Q, TUG	1. UPDRS III ↑ 2. FOG-Q ↑ (binary dance group) 3. Mini-BESTest ↑
Moratelli et al. 2023[AB]	Motor: UPDRS Non-motor: PDQ-39	1. UPDRS III ↑ (Samba group) 2. UPDRS III ↑ (Forro-Samba group; trend) 3. Mobility subsection of PDQ-39 ↑ (trend) 4. QoL discomfort (PDQ-39) ↑ (FSG group) 5. Communication (PDQ-39) ↑ (SG; trend)
Hashimoto et al. 2015[ABC]	Motor: UPDRS, TUG, BBS Non-motor: Apathy Scale, SDS Cognitive: FAB, MRT	1. UPDRS ↑ (trend only) 2. All other measures ↑
Haas et al. 2024[ABC]	Motor: UPDRS III, TUG, 6MWT, Sit-to-Stand, Handgrip test Non-motor: FES, PDQ-39 Cognitive: MoCA	1. Sit-to-stand ↑ 2. Handgrip test ↑
Hackney & Earhart (2009)[A]	Motor: UPDRS III, BBS, TUG, 6MWT, GAITRite, FOG-Q	1. BBS ↑ 2. 6MWT ↑

		3. backward stride length (GAITRite) ↑
Kang et al. 2022[AB]	Motor: UPDRS, Tinetti scale, gait analysis Non-motor: NMSS, MADRS, PDQ-39	All measures ↑
Carapellotti et al. 2022[ABC]	Motor: UPDRS III, TUG + dual task, FOG-Q, FES-I, SOT Non-motor: PDQ-39, PHQ-9 Cognitive: MoCA, Trail A&B, DSST, DS	1. TUG ↑ 2. PHQ-9 ↑ 3. bodily discomfort (PDQ-39) ↑
Bearss et al. 2017[AB]	Motor: BBS, TUG Non-motor: QoLS, post-dance class questionnaire of wellbeing	1. BBS ↑ 2. TUG ↑ 3. relationship/learning (QoLS) ↑
Harrison et al. 2020[AB]	Motor: GAITRite, UPDRS III, new-FOG-Q, fall history questionnaire Non-motor: Life space questionnaire, GDS, PDQ-39	GAITRite (velocity, cadence, stride length, single support time variability measures) ↑
Sistarelli et al. 2023[B]	Non-motor: POMS	POMS ↑ (following dance class, however, back to baseline within 24 hours)
Bearss & DeSouza (2021)[AB]	Motor: UPDRS III & IV Non-motor: UPDRS I & II	No decline in UPDRS II, III, IV; decline (worsening) in Reference (non-dance) group
Volpe et al. 2025[ABC]	Motor: UPDRS III, BBS, 6MWT, TUG, FES Non-motor: BDI, STAI-I, AES Cognitive: CSST, TMT A&B	All measures ↑
Jola et al. 2022[A]	Motor: TUG	TUG ↑
McNeely et al. 2015[ABC]	Motor: UPDRS III, Mini-BESTest, 6MWT, Sit-to-Stand, four square step test, GAITRite, dual task walking, TUG, DT-TUG	1. UPDRS III ↑ 2. Mini-BESTest ↑ 3. TUG ↑ (tango group; worsened in DfPD)

	Non-motor: PDQ-39 Cognitive: MMSE	4. Sit-to-stand ↑ 5. Four square step test ↑ 6. 6MWT ↑
Tillmann et al. 2020[B]	Non-motor: PDQ-39, PDSS, BDI, FSS Fatigue severity scale, magnitude of perceived changes, UPDRS I	All measures ↑
Mehta et al. 2024[ABC]	Motor: UPDRS, FOG-Q, Mini-BESTest Non-motor: NMSS, FSS, Schwab & England ADL, GDS, PDSS Cognitive: SCOPA-COG	1. UPDRS ↑ 2. FOG-Q ↑ 3. mood (GDS) ↑ 4. Sleep (PDSS) ↑
Carapelloti et al. 2025[ABC]	Motor: 10MWT, 360 degree turn test, TUG Non-motor: VAS Cognitive: TMT A&B, FEP, DT-TUG, BPST	1. 360 degree turn test ↑ 2. TUG ↑ 3. anxiety (VAS) ↑ 4. TMT A&B ↑ 5. BPST ↑ 6. FEP ↑ (trend)
Dahmen-Zimmer & Jansen (2017)[ABC]	Motor: one-leg stand Non-motor: multidimensional mood questionnaire, HADS, CEDS depression scale, short scale of general self-efficacy, 12-item SFHS short form health survey Cognitive: PANDA, Number Connection test	1. One-leg-stand ↑ 2. subjective well-being (multidimensional mood questionnaire) ↓ (trend) 3. all cognitive measures ↑
Delabary et al. 2020[A]	Motor: TUG, gait kinematic analysis (spatio-temporal gait parameters)	1. TUG at SSS and FS ↑ 2. Spatio-temporal at SSS ↑ 3. Swing time at FS ↑
Kalyani et al. 2020[AB]	Motor: UPDRS, TUG, TAT, BBS, Mini-BESTest, ABC-S, GFQ, FOG-Q, Purdue Pegboard Non-motor: UPDRS	All measures ↑
Bouquiaux et al. 2021[ABC]	Motor: Tinetti test, 10MWT, 6MWT, fingertip-to-floor test Non-motor: VAS	10MWT ↑

	Cognitive: MoCA	
Elpidoforou et al. 2021[ABC]	Motor: BBS Non-motor: PDQ-8, BDI-II, PFS-16 Cognitive: MoCA	1. BBS ↑ 2. BDI-II ↑ 3. PDQ-8 ↑ 4. MoCA ↑
Jehu et al. 2025[AB]	Motor: TUG, 360 degree turn test, forward/backward/fast gait speed across 6.1 metre, 6MWT, chair stand test, tandem test Non-motor: MSPSS	Tandem stance with left foot forward ↑ (trend)
Duncan et al. 2011[AB]	Motor: UPDRS III, Mini-BESTest, FOG-Q, 6MWT, 4.87 GAITRite, 9HPT Non-motor: UPDRS I & II	1. UPDRS III ↑ 2. FOG-Q/6MWT/9HPT/ Mini-BESTest/GAITRite ↑ (trend)

Abbreviations Used:

a) **Motor**
10MWT – 10-Metre Walk Test; 4SST/FSST – Four Square Step Test; 9HPT – Nine-Hole Peg Test; CCHS – Canadian Community Health Survey; CPF – Composite Physical Function; DGI – Dynamic Gait Index; DT-TUG – Dual-Task Timed Up and Go; FAB Scale – Functional Ambulation Battery; FOG-Q/new FOG-Q – Freezing of Gait Questionnaire; GAITRite – GAITRite Electronic Walkway System; GDI – Gait Deviation Index; G-WALK – G-WALK Wearable Gait Analysis System; GFQ – Gait and Falls Questionnaire; MCT – Motor Control Test;
POMA – Performance-Oriented Mobility Assessment (Tinetti Test); RWS – Rhythmic Weight Shift; SOT – Sensory Organization Test; TAT – Timed Agility Test; TUG-B/C/M – Timed Up and Go (Backward/Cognitive/Manual)

b) **Non-Motor**
AES – Apathy Evaluation Scale; BDI-II – Beck Depression Inventory-II; BSE – Body Self-Esteem Scale; CEDS – Centre for Epidemiologic Depression Scale; CGI-C – Clinical Global Impression-Change; FES/FES-I – Falls Efficacy Scale (International); FSS – Fatigue Severity Scale; GDS – Geriatric Depression Scale; GDI (non-motor) – General Distress Index; GSE – General Self-Efficacy Scale; HADS – Hospital Anxiety and Depression Scale; MSPSS – Multidimensional Scale of Perceived Social Support; NMSS – Non-Motor Symptoms Scale; PANAS-X – Positive and Negative Affect Schedule (Expanded Form); PDQ-8 – Parkinson's Disease Questionnaire-8; PDSS – Parkinson's Disease Sleep Scale; PFS-16 – Parkinson's Fatigue Scale-16; PHQ-9 – Patient Health Questionnaire-9; POMS – Profile of Mood States; QoLS – Quality of Life Scale; SDS – Self-Rating Depression Scale; SF-12 – 12-item Short Form Health Survey; STAI-I – State-Trait Anxiety Inventory; VAS – Visual Analog Scale

c) **Cognitive**
ACE – Addenbrooke's Cognitive Examination; BAT – Brief Attention Test; BPST – Brief Parkinson's Cognitive Screening Tool; BSM – Brief Spatial

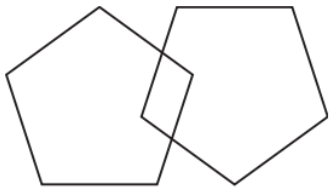
Memory Test; CSST – Choice Stepping Reaction Time Test; CWIT – Colour-Word Interference Test; D-KEFS – Delis-Kaplan Executive Function System; DS – Digit Span; DSST – Digit Symbol Substitution Test; FEP – Frontal Executive Performance Test; MRT – Mental Rotation Test; NIH Cognitive Battery – National Institutes of Health Cognitive Toolbox; PANDA – Parkinson Neuropsychometric Dementia Assessment; SCOPA-COG – Scales for Outcomes in Parkinson's Disease-Cognition; Serial 3's Task – Serial Subtraction by Three's Task

APPENDIX D: MMSE

The Mini-Mental State Exam

Patient_____ Examiner _____ Date_____

Maximum	Score	
		Orientation
5	( )	What is the (year) (season) (date) (day) (month)?
5	( )	Where are we (state) (country) (town) (hospital) (floor)?
		Registration
3	( )	Name 3 objects: 1 second to say each. Then ask the patient all 3 after you have said them. Give 1 point for each correct answer. Then repeat them until he/she learns all 3. Count trials and record. Trials _____
		Attention and Calculation
5	( )	Serial 7's. 1 point for each correct answer. Stop after 5 answers. Alternatively spell "world" backward.
		Recall
3	( )	Ask for the 3 objects repeated above. Give 1 point for each correct answer.
		Language
2	( )	Name a pencil and watch.
1	( )	Repeat the following "No ifs, ands, or buts"
3	( )	Follow a 3-stage command: "Take a paper in your hand, fold it in half, and put it on the floor."
1	( )	Read and obey the following: CLOSE YOUR EYES
1	( )	Write a sentence.
1	( )	Copy the design shown.



_____ Total Score

ASSESS level of consciousness along a continuum _____

Alert Drowsy Stupor Coma

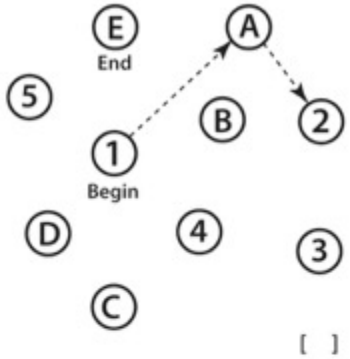
"MINI-MENTAL STATE." A PRACTICAL METHOD FOR GRADING THE COGNITIVE STATE OF PATIENTS FOR THE CLINICIAN. *Journal of Psychiatric Research*, 12(3): 189-198, 1975. Used by permission.

APPENDIX E: MoCA

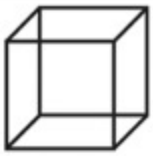
MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS



Copy cube



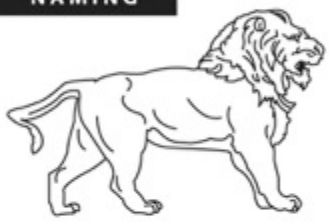
[ ] [ ]

Draw CLOCK (Ten past eleven)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

__/5

NAMING



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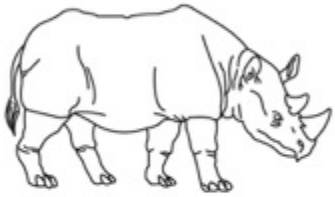

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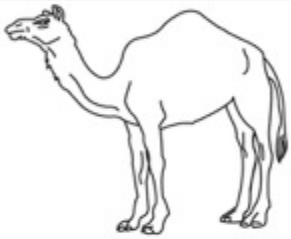

[ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2

__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

__/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ]

__/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words)

__/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler

__/2

DELAYED RECALL

	Has to recall words **WITH NO CUE**	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

__/6

© Z.Nasreddine MD **www.mocatest.org** Normal ≥ 26 / 30

TOTAL __/30

Add 1 point if ≤ 12 yr edu

Administered by: _____

APPENDIX F: Supplemental Domain-Specific Cognitive Analyses

Note. Domain-specific cognitive analyses are provided as supplementary material and not included in the primary study outcomes (Chapter 4) due to the methodological limitations associated with comparing domain scores from different cognitive screening tools (MMSE and MoCA).

1. Cognitive Performance – Dance Group (MMSE Domains)

Baseline-adjusted GEE models showed that memory scores improved significantly in 2016 (β = 0.3622, 95% CI [0.160, 0.564], p = .000) and again in 2017 (β = 0.3466, 95% CI [0.118, 0.576], p = .003), when compared to baseline (2014). Attention and working memory scores showed significant differences in 2016 (β = 0.3947, 95% CI [0.016, 0.773], p = 0.041), 2017 (β = 0.5341, 95% CI [0.146, 0.922], p = 0.007), 2018 (β = 0.5671, 95% CI [0.223, 0.912], p = 0.001), and 2019 (β = 0.5174, 95% CI [0.079, 0.956], p = 0.021), when compared to baseline (2014). A temporary significant improvement was observed in 2018 across the visuospatial domain (β = 2.9157, 95% CI [0.417, 5.414], p = 0.022), however, this difference was not sustained in 2019 (see Figure 4.1).

Sensitivity analyses were conducted to evaluate the robustness of the primary baseline-adjusted GEE results. For memory, the OLS model indicated a significant improvement during the Mid period (p = .001), consistent with the GEE model, while the Late period (p = .933) was not significant. For attention/working memory, both the Mid (p = .014) and Late (p = .002) periods remained significant, aligning with the GEE results. For visuospatial performance, no significant time effects were detected, although baseline visuospatial ability strongly predicted later performance (p < .001).

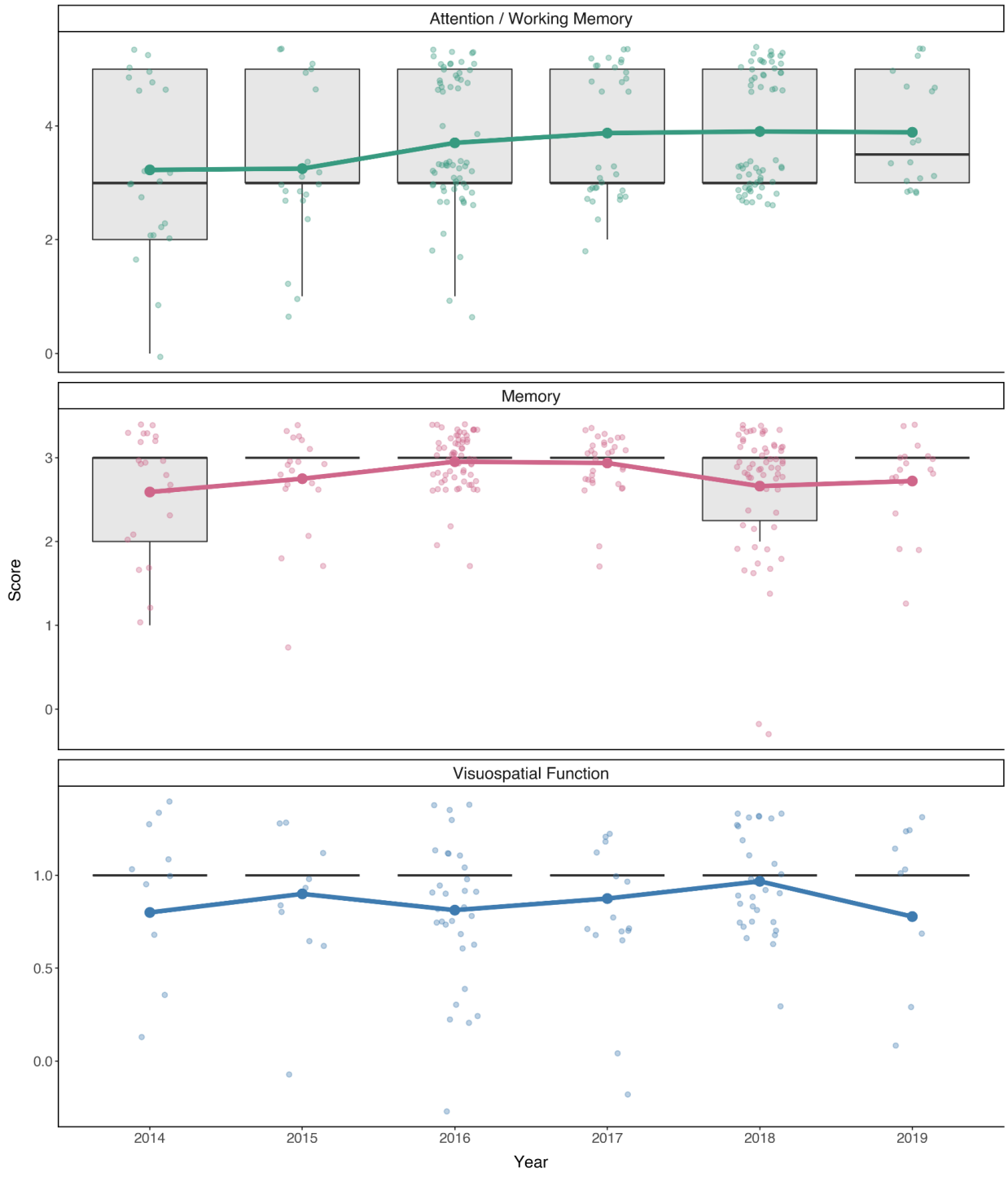

Figure 4.1. Domain-specific cognitive scores across six years among volunteers in the Dance group. Scatterplots and boxplots illustrate yearly distributions of scores for attention/working memory (green), memory (memory), and visuospatial (blue) function from 2014-2019. Solid

coloured lines represent mean trajectories within each domain. Boxplots display variability within each year, highlighting both within-year fluctuations and overall trends across the study period.

2. Cognitive Performance – Reference Group (MoCA Domains)

Baseline-adjusted GEE models showed that attention and working memory scores remained stable across the study period, with no statistically significant differences observed from 2015 to 2019 (all $p > 0.05$). Memory performance showed a declining trend during the middle and late periods of the study, however, these decreases were non-significant (all $p > 0.05$). Visuospatial ability fluctuated across the six-year period, but all differences relative to baseline were non-significant as well (all $p > 0.05$). The trajectory of domain-specific cognitive scores of the Reference group are illustrated in Figure 4.2.

Sensitivity analyses were conducted to confirm the robustness of the primary baseline-adjusted GEE findings within the Reference group. LMMs were first attempted for all continuous domains. The memory model converged successfully, showing moderate between-participant variability (random intercept variance = 0.50). No significant effects of time were observed ($p > .30$), while baseline memory remained a strong positive predictor ($p < .001$), consistent with the GEE results. For attention/working memory, the LMM failed to converge due to negligible random effects. Instead, OLS models were fitted and refitted with cluster-robust standard errors. No significant effects of time or baseline performance were detected (all $p > .16$), confirming the null findings from the GEE analyses. Finally, a GLMM with binomial distribution was used for visuospatial ability. No significant effects of time were observed ($p > .17$), while baseline visuospatial performance strongly predicted later success ($p < .001$).

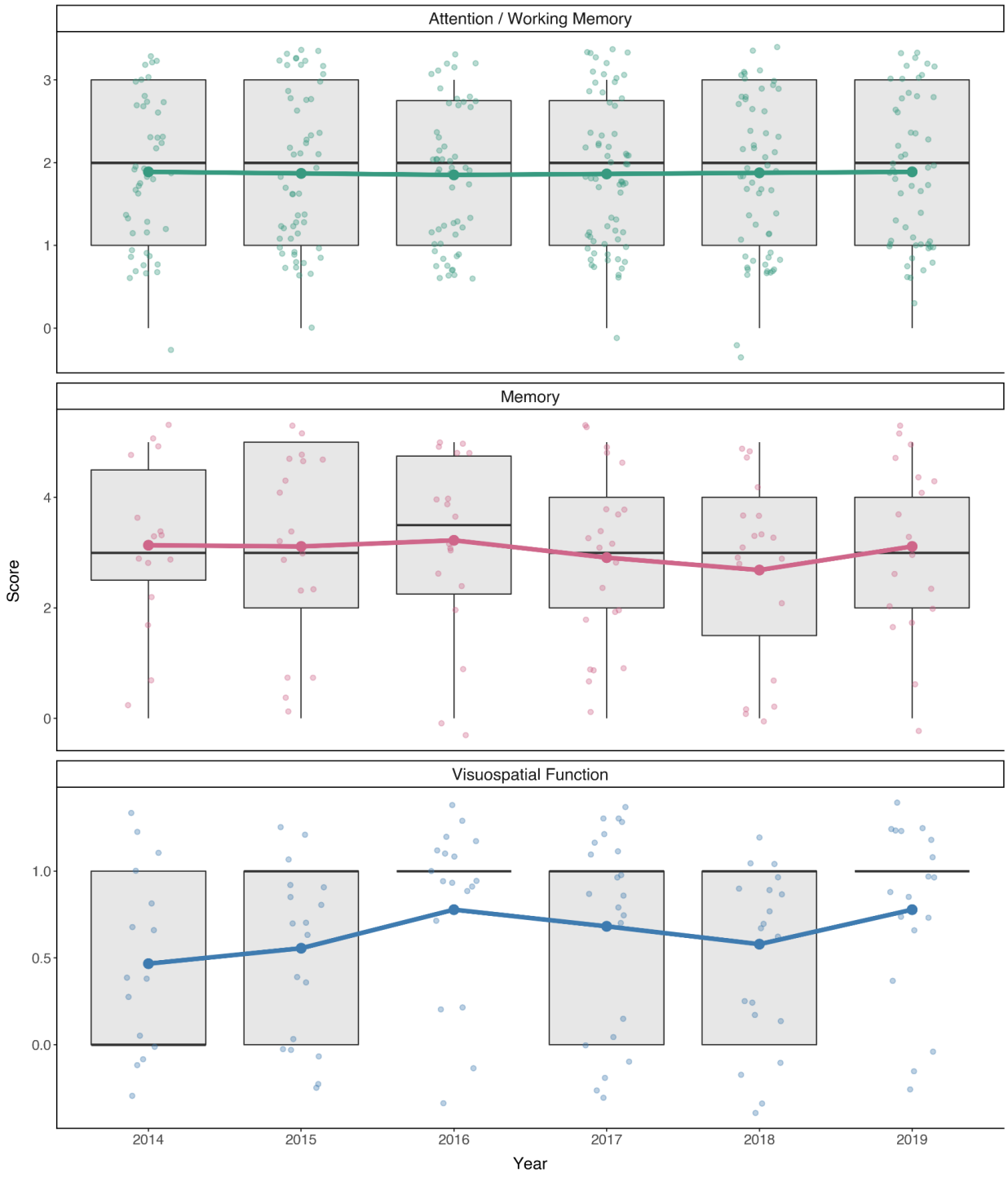

Figure 4.2. Domain-specific cognitive scores across six years among participants in the Reference group. Scatterplots and boxplots depict annual distributions of attention/working memory (green), memory (pink), and visuospatial (blue) scores from 2014 to 2019. Solid

coloured lines indicate yearly mean trajectories for each domain. Boxplots illustrate within-year variability and overall trajectories across the six-year period.

3. Cognitive Domains and Sleep Burden (Within Groups)

Dance group. Significant improvements were observed across all three cognitive domains relative to the early period in baseline-adjusted GEE models. Memory increased during the Mid (β = 2.757, 95% CI [0.627, 4.886], p = .011) and Late (β = 2.025, 95% CI [0.658, 3.393], p = .004) periods. Attention/working memory also improved in the Mid (β = 3.404, 95% CI [0.551, 6.257], p = .019) and Late (β = 3.7, 95% CI [1.599, 5.801], p = .001) periods of the study. Visuospatial scores showed gains at the Mid (β = 0.374, 95% CI [0.000, 0.747], p = .05) and Late (β = 0.54, 95% CI [0.195, 0.885], p = .002) periods as well. Sleep burden was not significantly associated with any cognitive outcome (all $p > 0.23$). The LMM results found no significant longitudinal changes in sleep burden across the study period (all $p > .52$). Sleep burden was unrelated to memory, attention/working memory, and visuospatial ability, indicating no associations between cognitive domains and sleep burden. Overall, findings of the sensitivity analysis confirmed the results of the primary GEE analysis by demonstrating stability in sleep burden across all periods of the study within the Dance group.

Reference group. No significant changes in cognitive domains were observed across the study period (all $p > 0.09$) in the baseline-adjusted GEE models. Baseline cognitive domain performance was a strong predictor of subsequent scores (all $p < 0.001$), however, sleep burden was not associated with memory (β = -0.0387, 95% CI [-0.549, 0.472], p = .882), attention/working memory (β = 0.0083, 95% CI [-0.274, 0.291], p = .954), and visuospatial ability (β = -0.0078, 95% CI [-0.071, 0.055], p = .808). Findings of the LMM results

demonstrated significantly higher scores of sleep burden during the Late period compared to the Early period. Mid-period changes were not significant. Across all domains, cognitive performance was not associated with sleep burden, with non-significant effects for memory, attention/working memory, and visuospatial ability, which was consistent with the primary GEE results.

APPENDIX G: MDS-UPDRS Certificate

International Parkinson and
Movement Disorder Society

States that

Simran Rooprai

has passed the

MDS-UPDRS Training Program & Certificate Exercise

on 1 December 2023

Pablo Martinez-Martin, MD
Co-Chair
MDS Rating Scales Program
International Parkinson and Movement
Disorder Society

Glenn Stebbins, PhD
Co-Chair
MDS Rating Scales Program
International Parkinson and Movement
Disorder Society

Exam ID: 52170