Wrist-Worn Accelerometer Measures of Activity by People with Parkinson's Attending Dance Classes

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Abstract

There has been increasing interest from researchers, dance artists and health professionals regarding the physical and psychological benefits of dance for people with Parkinson’s, particularly as a possible adjunct therapeutic intervention to medication. Studies examining the effect of dance on health outcomes such as parameters of movement have typically used brief, snap-shot assessments that limit understanding of movement to the timeframe in which the test or self-report measure is administered. Furthermore, such measures may be influenced by mood and cognitive capabilities. Accelerometry has been used to study the effect of various health interventions on the physical activity levels of people with Parkinson’s, but the types of activities studied have not yet included dance.

The present thesis aimed to investigate the application of wrist-worn accelerometers as an objective measure of movement to dance for Parkinson’s research. Specifically, this work intended to advance current knowledge regarding the uses of accelerometers with people with Parkinson’s by exploring i) the feasibility of using wrist-worn devices to measure movement parameters during and after participation in a dance class, ii) participant adherence to a wrist-worn device , iii) the validity of wrist-placement in the assessment of movement, iv) the usefulness of volume of movement as a single summary metric of movement, and v) how values for the assessment of physical activity intensity derived from a wrist-worn accelerometer compare to previously published values obtained from other device placements.

A series of exploratory studies were undertaken to address these aims. The first study addressed the gap in the literature regarding the use of accelerometry in the measurement of the level and pattern of movement made by people with and without Parkinson’s during a dance class. Participant triads, consisting of one person with Parkinson’s, an age-matched control and a young adult attending the same class at the University of Hertfordshire, wore a GENEActiv accelerometer on their wrist for an hour dance session and the following hour rest session. The results showed that the accelerometers accurately tracked the movement of the participant triads and detected between-group differences across all triads, such that young adults were significantly more active over the two hours compared to the participants with Parkinson’s and age-matched controls. The second study examined whether an objective measure of movement, derived from the accelerometers, supported the anecdotal reports of people with Parkinson’s of maintained levels of movement during the hours and days

following attendance to a dance class. To this end, people with Parkinson's and age-matched dancers (PD-D and AM-D, respectively) were asked to wear an accelerometer on their wrist over six consecutive days following attendance to a class, a free-living setting, and on a week when they did not attend a class. Accelerometer-derived movement and sleep metrics were compared between these two groups and to a separate control group of people with Parkinson's who had never attended dance classes (PD-C). All participants were compliant with wearing the accelerometer over the consecutive days and very few removed the device. No significant differences were found between participant groups in terms of volume of movement and sleep quality. Though non-significant, PD-Ds and AM-Ds were 7% and 10% less physically active, respectively, on a Friday afternoon on a no-dance week compared to a dance week. No significant difference was found when movement was examined as a daily average, indicating that if there is an effect of dance on movement, it is likely to be short-lived. The final study focused on the development of values that can be used to interpret raw acceleration data derived from wrist-worn accelerometers in terms of physical activity intensity levels, specifically for use with people with Parkinson's. Volume of movement (derived from a wrist, hip and ankle-worn device) and physiological energy expenditure (derived from a spiroergometry device) were calculated for people with Parkinson's and age-matched controls as they undertook a variety of exercises and household activities in a sports laboratory. Corroborating the findings of previous research, the results showed that volume of movement derived from a wrist-worn device significantly predicted energy expenditure, but the addition of a second hip-worn accelerometer increased accuracy. Though no differences were found between the participant groups for volume of movement and energy expenditure, people with Parkinson's rated all activities as significantly more exerting. This finding indicates that physiological exertion was similar between the two groups and that the symptoms of Parkinson's may play a role in perceived exertion.

Taken together, these studies demonstrate that wrist-worn accelerometers are acceptable and sensitive devices that can be used to investigate the engagement of people with and without Parkinson's in activities such as dance. Volume of movement as an accelerometer-derived outcome is useful when physical activity is monitored under observable and predictable conditions, however future exploratory studies should consider incorporating a measure of physical activity intensity to further interpret acceleration data in light of government physical activity guidelines, particularly when monitoring movement in a free-living context.

Declarations

I declare that this thesis represents my own work and it has not previously been submitted successfully for an award.

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Though it has absolutely been challenging and I wondered if I would ever get to this final point, reflecting on the experience as a whole has made me realise just how much I’ve learnt and that I am capable of more than I thought. I owe this to all the people mentioned above.

Table of Contents

List of Tables

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

List of Figures

List of Appendices

1. Chapter 1

1.1 General introduction

"They say that exercise is the best drug at the moment for Parkinson's and I think it's true and it's the least harmful one."

(Hadley et al., in press)

Currently there is no cure for Parkinson's Disease, a chronic neurodegenerative condition affecting approximately 145,000 people in the United Kingdom (Parkinson's UK, n.d.). Consequently, symptoms, both motor and non-motor, are managed through medication and adjunct therapies. Complementary therapies include exercise and physical activity, with increasing research indicating physical health (Ferraz et al., 2018; Schenkman et al., 2012; van der Kolk et al., 2019) and psychological benefits (C. Lewis et al., 2016; Solla et al., 2019) associated with such interventions for people with Parkinson's. In particular, many of these proposed benefits map onto a list of research priorities identified by people with Parkinson's, caregivers and health professionals; these priorities include the need for research to address motor (e.g. balance) and non-motor (e.g. anxiety and depression) symptoms, in addition to the development of personalised interventions (Deane et al., 2014).

Accompanying the growing body of literature has been the development and provision of several types of exercise interventions specifically tailored to people with Parkinson's. Many of these complementary therapies have been included in the recent release of the Parkinson's UK exercise framework (Parkinson's UK, n.d.), a guide for health professionals to be used when referring people with Parkinson's to activities. The types of activities recommended in the framework comprise of boxing (i.e. Parkinson's Warrior, commercially titled PD Warrior), training of functional movements (i.e. Lee Silverman Voice Treatment BIG), seated exercise (i.e. yoga) and also includes dance classes (i.e. Dance for PD® programme). Dance classes in particular have been popular, with 19 separate classes on offer in London alone (People Dancing, n.d.), in addition to the English National Ballet offering classes regionally across the UK. The benefits of dance for people with Parkinson's has also been covered by mainstream media channels, including the BBC (i.e. Darcey Bussell: Dancing to Happiness documentary; Gordon, 2018), and articles in the Guardian (Pugh, 2018) and Telegraph (Potts, 2018).

This increasing focus on exercise, supported by health professionals, charitable organisations and researchers, has also been voiced by people with Parkinson's, many of whom are also strong advocates for the benefits of being active (Leavy et al., 2016; Rocha et al., 2017), as illustrated by the quote at the start of this chapter. However, despite the growing interest in and demand for Parkinson's specific dance classes, the results of literature exploring the benefits of dance for Parkinson's are inconsistent, such that it remains largely unclear what type of dance, frequency, intensity, duration and volume are required for beneficial effects. Determining the contributions of these factors to health-related outcomes in Parkinson's will allow people with the condition, and their health care providers, to make evidence-based decisions about appropriate adjunct therapies and to reasonably anticipate what outcomes to expect based on these factors.

Some of the mixed findings in the scientific literature regarding the effect of dance for people with Parkinson's on physical and psychological outcomes may be due to the measures/assessments implemented in studies. Typically, researchers have employed self-report measures to assess changes in specific outcomes following participation in dance, such as physical functioning (i.e. balance; Hackney et al., 2007; Hackney & Earhart, 2010a; Mcneely et al., 2015). However, the accuracy of such measures is likely to be impacted by factors such as memory impairment (Duncan et al., 2014) and participant expectations, since it is difficult to investigate effects of dance in 'blind' studies. Accelerometers have been shown to be a useful tool for the objective measurement of movement made by people with Parkinson's (Chastin et al., 2010; Dontje et al., 2013), and have been used to capture different parameters of movement during and after participation in exercise (Coe et al., 2018; Nero et al., 2019). The use of accelerometers may provide further insights as to which factors are important for people with Parkinson's to benefit from dance, such as frequency, intensity and/or volume of movement.

Hence, the overarching aim of this thesis is to shed light on how accelerometry (wearable technology) can be feasibly implemented in dance for Parkinson's research by outlining the uses and constraints of these devices informed by the results of several exploratory studies. Specifically, the usefulness of volume of movement as an accelerometer-derived measure of physical activity will be explored and a validated alternative measure of intensity developed to fill existing gaps in the literature. Firstly, Chapter 3 investigates whether a wrist-worn device can be used to measure the volume of movement made by people with Parkinson's during participation in a dance class, to shed light on the acceptability and accuracy of the device. Then, Chapter 4 explores the effect of participating in dance on movement-based metrics of people with Parkinson's in the hours and days following attendance to a class, to provide evidence for the possible benefits of dance on the volume of movement made and sleep characteristics. Lastly, Chapter 5 focuses on generating cut-point values specifically for use with people with Parkinson's, the first study, to the author's knowledge, that provides these values using a wrist-worn accelerometer.

1.2 Literature review

The following literature review is divided into five sub-sections. Section 1.2.1 provides an overview of Parkinson's, covering the epidemiology, neuropathology and symptoms of the condition. Following on from this, in sections 1.2.2-1.2.3 the current state of research on exercise for older adults is reviewed, with a particular focus on Parkinson's – a condition of older age (Evans et al., 2016). Then, section 1.2.4 provides a critical review of the dance for Parkinson's research, followed by an overview of the use of accelerometry in physical activity intervention studies with people with Parkinson's in section 1.2.5.

To be defined as exercise, engagement in an activity needs to be structured and for the purpose of maintaining or improving physical health, key aspects differentiating exercise from the term physical activity (World Health Organisation, 2020). Physical activity has been defined as "any bodily movement produced by skeletal muscles that requires energy expenditure" (Word Health Organisation, 2020, p. 9), therefore a range of activities could be included under this term, such as activities of daily living associated with an individual's occupation or recreational behaviours (Winter & Fowler, 2009). Both terms will be used throughout this review and chapters 3-5 to reflect their usage in specific studies. The term exercise will be specifically adopted when discussing particular activities that meet the definition outlined above. Given the broad scope of activities that are likely to be captured by an accelerometer, often in a free-living environment where the activity is undefined, the term physical activity will be used.

1.2.1. Overview of Parkinson’s Disease

1.2.1.1 Incidence and prevalence

Parkinson’s disease is the second most common neurodegenerative condition following Alzheimer’s disease (Savica et al., 2018) with an estimated worldwide prevalence rate of 315 per 100,000 persons (Jette & Pringsheim, 2013). North America, Europe and Australia have been shown to have the highest prevalence rates (Pringsheim et al., 2014). Sex and age are reported to be the strongest contributing risks in the development of Parkinson’s (Gillies & McArthur, 2010). The age-related incidence of Parkinson’s has been shown to increase from 0.9 persons per 100,000 between the ages of 30-39 to 79.7 persons per 100,000 for the 70-79 stratum for a community-based sample in the UK. Incidence peaks at around 80 years of age, with inconsistent evidence of further increases beyond this age (Evans et al., 2016). An ageing population and increased life expectancy have important implications for the incidence and prevalence rates of Parkinson’s in future years (Dorsey et al., 2007), in addition to health services. Gender differences are also well documented in the Parkinson’s literature with higher incidence and prevalence rates reported for men compared to women (Kaasinen et al., 2015).

1.2.1.2 Neuropathology

Parkinson’s disease* is a neurodegenerative condition hallmarked by the presence of motor features, such as resting tremor, muscular rigidity, bradykinesia (slowness of initiation of voluntary movement) and postural instability (Kalia & Lang, 2015). The depletion of dopaminergic neurons in the pars compacta of the substantia nigra (SNpc) is a key pathological marker of Parkinson’s, with the ventrolateral tier of the SNpc most profoundly affected by the neuronal loss (Benazzouz et al., 2014; Rodriguez-Oroz et al., 2009). It is the pattern of neuronal degeneration within the substantia nigra, the dopamine neurons in the ventral tegmental area mainly spared compared to the loss seen in the ventrolateral tier, that separates Parkinson’s from other Parkinsonian neurodegenerative conditions (Obeso et al., 2017). A 60-70% reduction in dopamine levels in the striatum (Rodriguez-Oroz et al., 2009) appear to coincide with the physical manifestation of motor symptoms indicating that the neuronal loss contributes to the motor deficits seen in people with Parkinson’s.

*note: when referring to the pathology of Parkinson’s the term disease will be used, however in line with the recommendations of several organisations, including Parkinson’s UK, the term ‘Parkinson’s’ will be used throughout the remainder of the thesis (Ramaswamy et al., 2018).

Dopamine facilitates the initiation and inhibition of voluntary movement via two different, the indirect and direct, pathways (Zheng et al., 2018). The axons of the dopaminergic neurons located in the SNpc project to the striatum, forming the nigrostriatal pathway. The dopamine neurons of the SNpc innervate a number of structures of the basal ganglia, including the striatum, and play an important role in physical functioning, see Figure 1.1. The thalamus is generally under inhibition by neurons projecting from the globus pallidus internal, such that the activity of the thalamus is being suppressed. Suppression of the thalamus reduces stimulation of neurons projecting to the motor cortex, thus inhibiting movement. The function of the direct pathway is to dis-inhibit the thalamus, thus allowing excitation of thalamocortical circuits and facilitate initiation of movement, in addition to action selection (Surmeier et al., 2014). The role of dopamine within this pathway is to bind to D1 receptors on the inhibitory neurons that project between the striatum and globus pallidus internal (GPi). This leads to greater inhibition of the GPi and allows the thalamus to become more active. This results in greater excitation of the motor cortex and increased muscle movement.

In contrast, the indirect pathway is often thought of as the movement suppression pathway. More inhibitory messages from the globus pallidus internal to the thalamus leads to reduced activity of the thalamus. The motor cortex has an excitatory effect on the striatum. Inhibitory neurons project from the striatum to the globus pallidus external (GPe), so excitation of the striatum leads to reduced activity of the GPe. Neurons project from the GPe to the subthalamic nucleus resulting in increased activity of the subthalamic nucleus. The subthalamic nucleus sends excitatory messages to the GPi resulting in greater inhibition of the thalamus and reduced excitatory output to the motor cortex. The role of dopamine within the indirect pathway is to fine tune movement (Surmeier et al., 2014). It does this by binding to D2 receptors on the synapses of neurons at the striatum thus reducing the excitatory effect that these neurons have on connecting inhibitory neurons that project to the GPe. This results in reduced inhibition of the GPe (therefore, increased activity of this structure), greater inhibition of the GPi and consequently greater activity of the thalamus (Obeso et al., 2017).

The loss of dopaminergic neurons in Parkinson's is thought to disrupt the processes outlined above. Research using animal models of Parkinsonian dopamine loss suggest that a lack of dopamine results in a hypoactive direct pathway and a hyperactive indirect pathway culminating in greater inhibition of the thalamus, reduced activation of the motor cortex and reduced motor output to the muscles (Cui et al., 2013; Freeze et al., 2013). However, several limitations of the hypo/hyperactive model have been highlighted. For example, the model does not account for the more recent discovery that both the direct and indirect pathways are concurrently active in one hemisphere before the initiation of contraversive movement (Cui et al., 2013). Furthermore, there has been an increasing focus on the role that long-term dopamine treatment may have in the emergence of involuntary movements (e.g. dyskinesia) in people with Parkinson’s (Barroso Chinea & Bezard, 2010); the hypo/hyperactive does not account for the neural adaptation that is likely to contribute to these undesirable movements (for a review see Surmeier et al., 2014). Therefore, the role of dopamine within striatal circuits may be more complex than originally proposed.

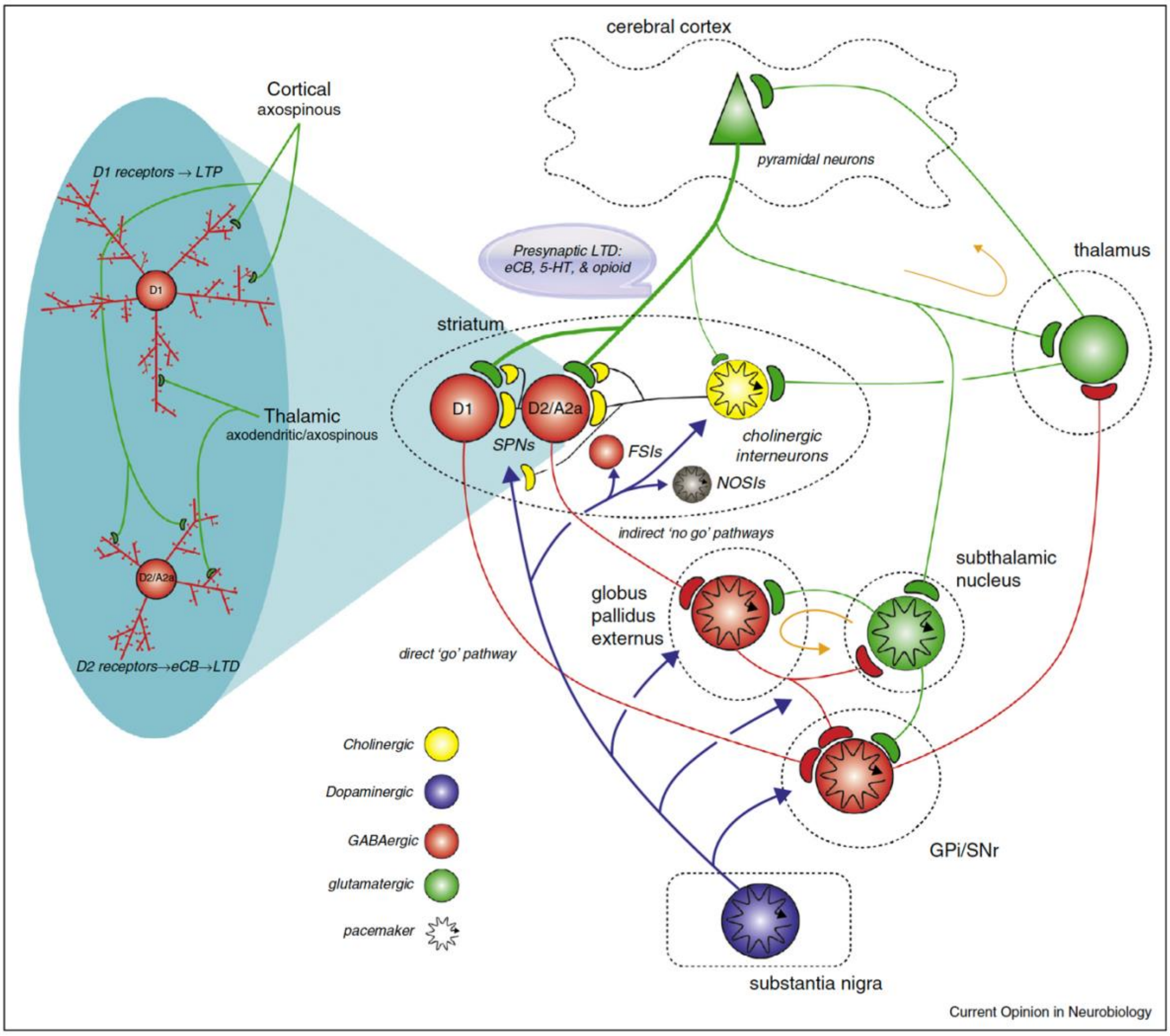


Figure 1.1 Diagram depicting the basal ganglia circuitry.
Figure sourced from Surmeier et al., (2014).

Symptom management of Parkinson’s is traditionally pharmacological and addresses the dopamine deficiency associated with the condition. Levodopa and dopamine agonists, such as Pramipexole and Ropinirole, are primarily used to control motor symptoms, though dopamine agonists may also be useful in the treatment of depression (for a review on the efficacy of pharmacological treatment for motor and non-motor symptoms of Parkinson's see Connolly & Lang, 2014).

In addition to the loss of dopaminergic neurons, the presence of misfolded proteins in Lewy bodies constitute another important pathological feature of idiopathic Parkinson’s (Obeso et al., 2017). There is an overlap in Lewy-body pathology found in Alzheimer’s Disease and Parkinson’s, though the type of protein and the pattern of distribution throughout the brain differ (Dickson et al., 2009; Kosaka et al., 1988). Parkinson’s is associated with the aggregation of mis-folded alpha-synuclein proteins within the cell body of neurons in the brain, in particular the brain stem (Kalia & Lang, 2015), whereas Alzheimer’s is characterised by amyloid plaques and neurofibrillary tangles (D’Andrea et al., 2001). In people with Parkinson’s higher levels of the alpha synuclein oligomer has been found in the cerebral spinal fluid compared to healthy age-matched controls (Hansson et al., 2014), and a Parkinson’s symptomatic group (Park et al., 2011). These synuclein aggregates are insoluble and are proposed to be the starting point from which amyloid fibrils develop, a component of Lewy bodies (Shahmoradian et al., 2019). The presence of Lewy bodies at post-mortem is used for definitive diagnosis of Parkinson’s. However, Lewy-body pathology has been identified in areas other than the brain for people with Parkinson’s including the spinal cord, vagus nerve, sympathetic ganglia and gastrointestinal system (Kalia & Lang, 2015), and is thought to be more widely distributed in Parkinson’s compared to other diseases with Lewy-body pathology (Beach et al., 2010). To account for the distribution of Lewy-body pathology identified in people with sporadic Parkinson’s Braak and colleagues (Braak et al., 2003) proposed a six stage model describing the temporal and spatial progression of alpha synuclein. Braak’s staging hypothesis suggests a specific pattern of spreading throughout the central nervous system, via the olfactory tract and vagus nerve (stage 1 and 2) towards the neocortex at the most affected stage (stage 5 and 6; Rietdijk et al., 2017), see Table 1.1 and Figure 1.2 for details. It has been suggested that stage 1 and 2 of Braak’s model represent the early stages of Parkinson’s and that the presence of synucleinopathy in the nondopaminergic lower brainstem is sufficient for the occurrence of Parkinson’s (Burke et al., 2008). The involvement of non-dopaminergic brain areas early on in Parkinson’s has been supported by clinical evidence of pre-diagnostic non-motor symptoms, such as rapid eye movement sleep, olfactory impairment and constipation (Ahlskog, 2007). In line with the hypothesis that the pathology of Parkinson's spreads in a prion-like manner, emerging evidence suggests Parkinson's pathology may start in the gut. Gastrointestinal symptoms, such as nausea and constipation, precede the onset of motor symptoms in Parkinson's and worsen with disease progression (Pfeiffer, 2016). Furthermore, accumulation of alpha-synuclein has been found in the enteric system in people with Parkinson's (Fasano et al., 2015) and may be found in enteric nerves before accumulations have progressed to the brain (Liddle, 2018). See Figure 1.3 for an overview of the distribution of synucleinopathy in the enteric system.

Several environmental and genetic factors have been identified as potential triggers for dopamine loss and the accumulation of misfolded proteins associated with Parkinson's. The role pesticides may play in the development of Parkinson's, potentially inducing oxidative stress and altering mitochondrial function (Irwin & Trojanowski, 2013), has been the focus of several studies (A.A. Li et al., 2005; Noyce et al., 2012; Priyadarshi et al., 2000). Specifically, since the discovery that the toxicant 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP) resulted in Parkinson's symptoms developing in a group of drug addict (T. P. Brown et al., 2006). Pesticides such as rotenone and paraquat, which have a molecular structure similar to MPTP, have been found to produce Parkinsonian motor and postural deficits in rats (Betarbet et al., 2000) and lead to alpha-synuclein aggregation in the brains of mice (Manning-Bog et al., 2002). Epidemiological evidence has also linked traumatic brain injury to the development of Parkinson's (alongside other neurodegenerative conditions such as Alzheimer's; D.H. Smith et al., 2013). Neuroinflammation as a result of head trauma is thought to be one of the mechanisms by which Parkinson's develops. Damage to the blood brain barrier, microglial activation, disruption to mitochondrial function and/ or excitotoxicity may result from head trauma and have all been linked to Parkinson's pathology (Jafari et al., 2013). In particular, accumulation of alpha synuclein, a pathological marker of Parkinson's, has been described for people with axonal injury (a type of traumatic brain injury; Uryu et al., 2007). Though an association between pesticides and head injury for risk of developing Parkinson's has been found, the exact etiology of Parkinson's still remains unclear with evidence of genetic mutations contributing to the development of the condition. Over 20 genetic loci are significantly positively or negatively associated with risk of developing Parkinson's (International Parkinson's Disease Genomics Consortium et al., 2014). Mutation in Leucine-rich repeat kinase 2 (*LRRK2*) and the *parkin* gene (*PRKN*, also known as *PARK2;*Arkinson & Walden, 2018) has been implicated in dominant and recessive inherited Parkinson's, respectively (Kalia & Lang, 2015), while mutation in *glucocerebrocidase* (*GBA1*) carries the highest risk for developing Parkinson's (for details regarding the frequency of *GBA1* mutations in Parkinson's see Sidransky et al., 2009). However, though genetic causes have been identified in some individuals, for the majority of people with Parkinson's the cause is unknown. It is likely that an interplay between environmental and genetic risk factors contribute to the development of Parkinson's (Kalia & Lang, 2015). Identification of the risk factors for Parkinson's has indicated possible targets for risk reduction, such as pesticide exposure, however studies investigating how to optimize preventative risk factors, such as anti-inflammatory statins and exercise, are still ongoing (Ascherio & Schwarzschild, 2016). In particular, the anti-inflammatory effect of exercise in protecting against chronic inflammatory diseases, such as coronary heart disease, type 2 diabetes and dementia, has been of recent interest (Gleeson et al., 2011). Exercise is known to modulate various systems, including the release of anti-inflammation factors to prevent the brain from pathological insults. Specifically, modulation of microglial activation has been linked to the development of neurodegenerative diseases, such as dementia and Parkinson's (Mee-inta et al., 2019), indicating the potential for exercise to attenuate disease progression (though there is no robust evidence for this yet in people with Parkinson's).

Table 1.1 Braak's staging of Lewy-body Pathology in Parkinson's (Braak et al., 2003; Kalia & Lang, 2015).

Braak stage	Pathology
Stage 1	Medulla predominantly affected, in particular the dorsal IX/X motor nucleus. The autonomic nervous system and anterior olfactory nucleus are also frequently affected.
Stage 2	The dorsal IX/X motor nucleus and the intermediate reticular zone are both more greatly affected, also accompanied by the observation of Lewy bodies in the neurons of the caudal raphe nuclei and the locus ceruleus.
Stage 3	The same pathology as stage 2 with the substantia nigra pars compacta, basal forebrain and limbic system additionally affected.
Stage 4	The same pathology as stage 3 with the addition of the thalamus and temporal mesocortex. No pathology identified in the neocortex.
Stage 5 and 6	Stage 5 is hallmarked by increased damage to mesocortical areas, severe affection of the olfactory nuclei and affection of sensory association areas of the neocortex. Stage 6 involves the affection of premotor areas and some minor pathological changes in primary motor areas.

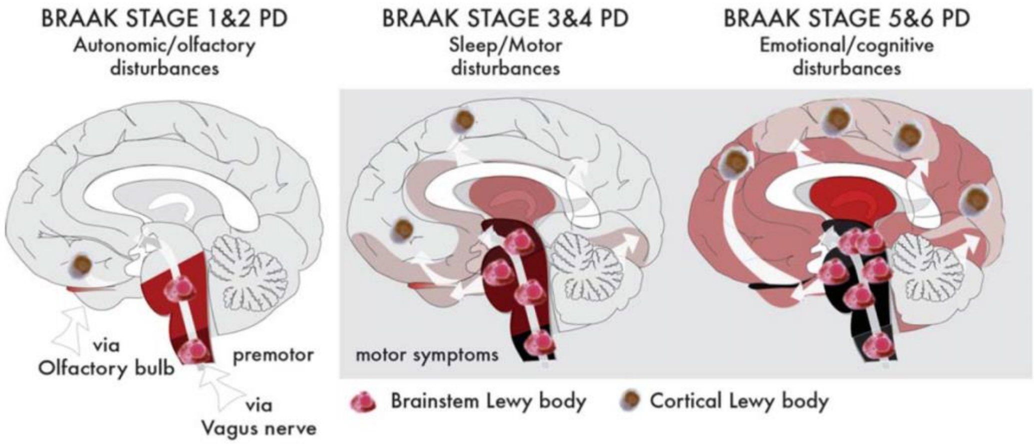


Figure 1.2 Braak's staging of Parkinson's disease indicating the progression of Lewy-body pathology and the co-occurring symptoms
Figure sourced from Halliday et al., (2011).

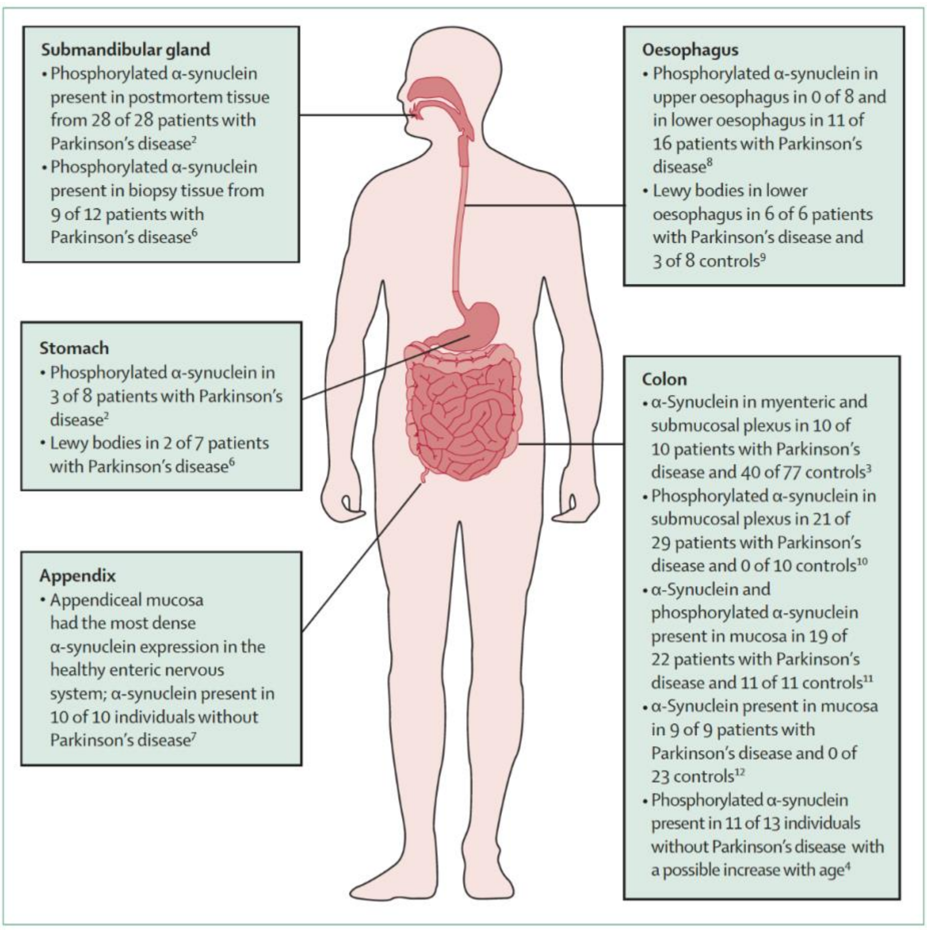


Figure 1.3 Distribution of synucleinopathy found in the enteric system of people with Parkinson's.
Figure sourced from Fasano et al. (2015).

1.2.1.3 Motor symptoms

1.2.1.3.1 Tremor

Involuntary movements that constitute tremor are a characteristic feature of Parkinson's and are reported to be one of the top five most troublesome symptoms in both the early and advanced stages of the condition (Politis et al., 2010). Tremor is reported to affect up to 75% of people with Parkinson's (Gironell et al., 2018), however the profile is highly variable between individuals. For example, rest tremor is the only sub-type of tremor that constitutes a diagnostic marker of Parkinson's, but many people with Parkinson's may alternatively have an action tremor or a mixture of both. The involuntary movement of a body part when supported against gravity (such as hands resting on the lap) distinguishes rest tremor from other forms of tremor (Hess & Pullman, 2012). Action tremor consists of two further subdivisions: postural and kinetic. These types of tremor occur with voluntary muscle contraction, unlike rest tremor and impact on approximately 60% of people with Parkinson's (Deuschl et al., 2001). Information regarding tremor frequency (in hertz) and the conditions under which it emerges (e.g. while resting vs while undertaking a goal directed movement) is used by clinicians to distinguish between the different types of tremor (Deuschl et al., 2001), though the heterogeneous nature of tremor presentation may make classification difficult. Tremor is a highly visible symptom that is not only noticeable to the individual with Parkinson's but to strangers, with the latter contributing to the negative psychosocial impact associated with tremor (Heusinkveld et al., 2018). Approximately 25% of 103 participants with Parkinson's reported negative feelings, embarrassment and depressed when completing a self-report measure of the impact of tremor on quality of life (QoL; Louis & Machado, 2015). Embarrassment regarding tremor may lead to an attempt to hide affected limbs, such as wearing clothing with pockets to hide hands or holding hands behind the back (Nijhof, 1995). The impact of tremor on functional activities has also been noted, with more than a third of the participants in the Louis and Machado (2015) study reporting that their tremor interfered with their ability to write, type and eat. The results of these studies demonstrate the detrimental effect tremor can have on activities of daily living and the self-esteem of people with Parkinson's. These psychosocial elements are likely to persist as the disease progresses with concern around tremor remaining prominent even when non-motor symptoms dominate.

1.2.1.3.2 Bradykinesia

The term bradykinesia refers to the slowness of voluntary movement (Bologna et al., 2016) and is a required feature for diagnosis of Parkinson's. The Parkinson's literature uses the terms hypokinesia and akinesia interchangeably with bradykinesia, though they are different movement complications. Specifically, hypokinesia includes decreased amplitude of movement, in addition to slowness. For example, the reduction in size of handwriting such that it becomes very small (micrographia) is associated with hypokinesia (Berardelli et al., 2001). Akinesia is described as a lack of spontaneous movement (e.g. facial expressions), but can also be associated with difficulties with initiating movement after being stationary, or during a movement itself, such as freezing of gait (FOG; the inability to step forward despite having the intention; Bluett et al., 2019) when walking (Caligiore et al., 2019). Reduced speed and amplitude of finger tapping of people with early stage Parkinson's has been found when compared to healthy controls indicating that motor complications are present early on in the condition (Bologna et al., 2016). The same impairments, but to a greater degree, were also found for those with advanced compared to early stage Parkinson's, therefore highlighting that bradykinesia and hypokinesia worsen as the condition progresses. Activities of daily living (ADL), walking and standing are likely to be compromised as the increasing severity of motor complications impact on movement patterns (Memar et al., 2018), thus reducing QoL.

The quantitative valuation of bradykinesia, alongside other motor symptoms, typically involves using the Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS; Goetz et al., 2008). The scale consists of four subsections, one of which is the 27-item motor part (part III). This subsection addresses the range of motor symptoms associated with Parkinson's, including bradykinesia, requiring an assessor to make visual observations of different movements (Memar et al., 2018). Scores on the MDS-UPDRS part III have been found to correlate significantly with a Parkinson's specific measure of QoL (Schrag et al., 2000), however several studies have indicated that it is the limitations on ADLs due to motor impairment that have the greatest impact on QoL, as opposed to the motor symptoms per se (Skorvanek et al., 2015, 2018). Specifically, motor activities such as dressing, doing hobbies and getting out of bed (as measured by part II of the MDS-UPDRS) were found to be independently predictive of poorer outcomes for health-related QoL (HR-QoL; Skorvanek et al., 2018). The reduced ability to undertake everyday activities has implications for the individual remaining independent and is likely to result in increased need for caregiver support (Rahman et al., 2008). Bradykinesia is reported to be the main contributor to gait and balance difficulties (Hallett, 2011), including FOG. Alongside dressing and hobbies, FOG was also found to be a significant determinant of HR-QoL in the Skorvanek et al. (2018) study. Therefore, the limited ability to undertake certain everyday activities as a consequence of motor impairments appears to have the greatest impact on QoL in Parkinson's. This fits with the understanding that as the duration of the condition progresses (including motor impairment) so does the prevalence of motor complications (Nicoletti et al., 2016) with greater disease severity reported to independently predict worse HR-QoL (Forsaa et al., 2008).

1.2.1.3.3 Postural instability

Postural instability, in addition to the motor symptoms abovementioned, is a characteristic and diagnostic feature of Parkinson's (Kalia & Lang, 2015) associated with increased risk of falls and worse QoL (Kimmell et al., 2015; Schoneburg et al., 2013). The function of postural control is to "[align] the body with respect to gravity, the support surface, and the visual environment and stabilizes the center of mass of the body relative to its base of support during daily activities" (Schoneburg et al., 2013, p. 1474). Impairments in postural control in Parkinson's may manifest as difficulty with trunk rotation, postural irregularity (e.g. stooped posture) and poor reactive balance adjustments (e.g. reduced ability to take corrective stepping movements; Palakurthi & Burugupally, 2019). Any one of these impairments may disrupt balance control and increase the probability of falls (Bekkers et al., 2018).

On average 60.5% of people with Parkinson's reported falling at least once and 39% experienced reoccurring falls according to a review of 22 studies (N. E. Allen et al., 2013). In addition to the physical implications associated with falling (such as hip fractures), there are psychological consequences, such as fear of another fall. Specifically, a study examining the relationship between fear of falling and postural control found that people with Parkinson's reported lower confidence in their ability to undertake ADLs whilst maintaining their balance and not falling compared to healthy controls (Adkin et al., 2003). People who experience either frequent or occasional falls report being less physically active compared to non-fallers (Bryant et al., 2015), which is likely to contribute to further psychological and physical health implication, such as increased social isolation and risk of developing osteoporosis; thus contributing to a negative cycle.

1.2.1.3.4 Other symptoms and motor complications

The variety of symptoms abovementioned may singularly, and combined, have a profound impact on an individual's ability to undertake everyday activities and lead the life they had before the onset of the condition. Recently, Parkinson's UK, a research and support charity, published a list of the top 10 research priorities for the management of Parkinson's from a nationwide survey undertaken by anyone with experience of the condition (e.g. people with Parkinson's, carers and family members; Deane et al., 2014). Among the symptoms identified the following were chosen as some of the most important: balance and falls, stress and anxiety, dementia and mild thinking problems. The majority of the top 10 priorities identified were non-motor symptoms thus corroborating the findings of other studies which suggest that non-motor impairments have a greater impact on QoL than motor symptoms (Chaudhuri, Antonini et al., 2019; Schrag, 2006).

Dyskinesias

Of the motor impairments that formed part of the top 10 uncontrollable movements experienced as a side effect of some medications (dyskinesias) was listed as the third most important priority. Rather than a symptom of Parkinson's per se, dyskinesia is a motor complication typically associated with long term symptom treatment with Levodopa (a dopamine replacement agent; Kalia & Lang, 2015). For example, dyskinesia may present as Chorea which is defined as:

"involuntary, rapid, irregular, purposeless, and unsustained movements that seem to flow from one body part to another. The severity of these movements can vary from occasional abnormal movements that are absent at rest and provoked only during active movement….to violent large amplitude flinging and flailing arm movements" (Thanvi et al., 2007, p.385).

A review of the incidence of dyskinesia found that after 5 years from initiation of treatment 40-50% of people with Parkinson's developed dyskinesia and after 10 years the incidence increased to 52-78% (Manson et al., 2012). Though dyskinesia is not a symptom of the condition, given that almost half of the people treated with Levodopa are likely to develop involuntary movements it is of relevance to consider the impact of dyskinesia on the wellbeing of people with Parkinson's. Frequent, large amplitude dyskinesias (referred to as troublesome dyskinesias) can be particularly disabling and may be hazardous therefore resulting in confinement to the home (Chaudhuri, Jenner, et al., 2019). Embarrassment regarding the uncontrollable movements may further contribute to social withdrawal (Manson et al., 2012). Constant involuntary movements may also lead to fatigue and exhaustion (Thanvi et al., 2007), which are also likely to reduce participation in ADLs. Despite reports of the negative impact of troublesome dyskinesias on physical and psychological wellbeing, the association between dyskinesias and QoL is less clear (Schrag & Quinn, 2000), suggesting that only a small percentage of people with Parkinson's experience troublesome dyskinesias.

Muscular rigidity

Though not part of the top 10 priorities for symptom management, muscular rigidity, a diagnostic feature of the condition, was ranked as the fifteenth most important symptom. Muscular rigidity is defined as the "abnormality of muscle tone" (Endo et al., 2009, p.2218). Specifically, the abnormality manifests as a constant resistance of a joint during passive stretching of a muscle (Berardelli et al., 1983). There has not been an extensive amount of research explicitly investigating the impact of rigidity on QoL. The results of studies that have examined this relationship have shown poor correlation between objectively (using a dynamometer) and subjectively (using the MDS-UPDRS part III) measured rigidity and QoL (as measured using the Parkinson's Disease Questionnaire- 39 item, PDQ-39; Cano-de-la-Cuerda et al., 2011; Schrag et al., 2000).

1.2.1.4 Non-motor symptoms

Over 90% of people with Parkinson's, across differing severities of the condition, experience some of the following non-motor symptoms: sensory, neuropsychiatric and gastrointestinal symptoms, fatigue, sleep disorders and autonomic dysfunction. The early appearance of non-motor symptoms, up to ten years before the onset of motor symptoms (Chaudhuri & Schapira, 2009), is in line with Braak's hypothesis; it indicates that the neuropathology of Parkinson's can affect other brain regions and the peripheral nervous system before reaching the substantia nigra. Even in the early stages of Parkinson's non-motor symptoms negatively impact on health-related QoL (G.W. Duncan et al., 2014). The non-motor symptoms that are documented to have the greatest impact on QoL and occur throughout the various stages of disease progression are considered below.

1.2.1.4.1 Anxiety and Depression

Anxiety and depression are commonly experienced in Parkinson's, with prevalence rates ranging from 25-40% and 13-22% respectively (Pfeiffer, 2016). General anxiety disorder, panic disorder and social phobias are most commonly experienced and may occur before the onset of motor symptoms, suggesting that the nigrostriatal pathway may not be involved in these symptoms (Schapira et al., 2017), thus lending support to Braak's stage hypothesis. Furthermore, a number of studies have suggested that anxiety might be a risk factor for the development of Parkinson's (Ishihara & Brayne, 2006; Prediger et al., 2012; Weisskopf et al., 2003). Though anxiety and depression are often present comorbidly, they may also occur independently and are often associated with motor fluctuations (Leentjens et al., 2012; Witjas et al., 2002). Recent research has indicated that for the majority of people with Parkinson's anxiety and depression, compared to other non-motor symptoms such as fatigue, are primarily experienced during periods when medication is wearing off and dopamine levels are lower (Storch et al., 2013), or during unpredictable fluctuations in the occurrence of Parkinson's symptoms which are often referred to as on/off periods. These on/off fluctuations in symptom severity tend to be associated with dopaminergic treatment (R. G. Brown & Fernie, 2015). The association between anxiety and motor fluctuations brought about by medication contrasts with the notion of anxiety being a risk factor for Parkinson's. Martens and Lewis, (2017) suggest that different mechanisms (dopaminergic and serotonin) may underlie these similar clinical features.

In addition to the neuropathology of Parkinson's, worry associated with the occurrence of certain symptoms has been identified as contributing to anxiety (Salazar et al., 2017). Specifically, experiencing and severity of FOG are associated with increased anxiety (Witt et al., 2019). Furthermore, exposure to an anxiety inducing virtual reality task (walking a plank low to the ground versus over a deep pit) has been found to increase the number of episodes and percentage of time per trial spent frozen for participants with a history of FOG (Martens et al., 2014). Perceived stigma regarding motor symptoms, such as tremor, may also reinforce feelings of worry and further exacerbate anxiety. Qualitative work exploring illness as experienced by people with Parkinson's has revealed that individuals were worried about being watched/judged when in public leading to an increased sense of isolation amongst participants (Stanley-Hermanns & Engebretson, 2010). Social withdrawal may also accompany the feelings of isolation and is likely to contribute to reduced independence and QoL (Salazar et al., 2017).

Depression is reported to be a significant source of disability in Parkinson's with the prevalence of clinically meaningful symptoms estimated at 35% (Reijnders et al., 2008). Depression in Parkinson's differs to major depressive disorder, such that it presents as a milder form characterised by sadness, dysphoria and the tendency to fantasise as opposed to attempting suicide (Fontoura et al., 2017). While depression has been recognised as one of the key determinants, alongside other non-motor symptoms such as sleep disturbance, of HR-QoL (Chaudhuri et al., 2011) it is not clear, however, what the cause of depression is in people with Parkinson's. The notion that depression could be a reaction to being diagnosed and/or living with a chronic condition in conjunction with evidence indicating that it might be prodromal has led some researchers to query whether depression associated with Parkinson's should be considered a specific sub-type of depression (Even & Weintraub, 2012). Furthermore, dopaminergic treatment ameliorates depression in a small subset of people with Parkinson's (Schapira et al., 2017), thus highlighting the complex association between Parkinson's pathophysiology and depression (Leentjens, 2019; Schapira et al., 2017).

The impact depression has on the wellbeing of people with Parkinson's is extensive and multifaceted; for example, it includes a reduction in ADLs, a negative association with psychological domains (such as purpose in life and self-acceptance; Nicoletti et al., 2017), independent prediction of mortality (Renfroe et al., 2016) and poorer HR-QoL (Schrag, 2006). Longitudinal research over a six year period has indicated that symptomatic depression is associated with greater disability (as measured by ADLs) compared to individuals with no depression or those who are in remission (Pontone et al., 2016). No baseline difference was found in self-reported ADLs between participants who were in remission and those who had never been depressed. Pontone et al. (2016) suggest that these findings indicate that the functional limitations associated with depression are not necessarily permanent providing that the symptoms of the depression are treated. However, over the course of the six years participants in remission declined in ADL function at the same rate as participants who were depressed, suggesting that besides depression disease progression may contribute to increasing disability, though this was not explicitly assessed in the study. The physical and psychological impairments that people with Parkinson's experience as part of the condition also limit their physical activity levels. Specifically, regression analysis has demonstrated that both anxiety and depression are associated with less daily physical activity and this may contribute to the higher amount of time people with Parkinson's spend sedentary compared to the general population (van Nimwegen et al., 2011).

1.2.1.4.2 Fatigue

Studies exploring the prevalence of fatigue in Parkinson's report percentages ranging from 33% to 58% (Friedman et al., 2007). Despite varying definitions and measures of fatigue, studies consistently demonstrate that people with Parkinson's report higher levels of fatigue compared to healthy controls (Karlsen et al., 1999; Lou et al., 2001; van Hilten et al., 1993) and similar levels compared to individuals with other neurological conditions, such as Multiple Sclerosis (Cochrane et al., 2015; Friedman & Friedman, 1993). Furthermore, fatigue was the most commonly reported (53%) non-motor symptom in a large-scale study including over 1,000 people with Parkinson's (Barone et al., 2009). Of all the symptoms experienced by people with Parkinson's fatigue is reported to be the most disabling (Friedman & Friedman, 1993) and is associated with the greatest reduction in physical HR-QoL (Müller et al., 2013; Nicoletti et al., 2017), including people in the early stage of the condition and not receiving treatment. This latter finding is consistent with research demonstrating fatigue is frequently reported during the early stages of Parkinson's before the presentation of motor symptoms (Schifitto et al., 2008). Therefore, fatigue is not necessarily exclusively associated with disease progression. Fatigue is known to restrict individuals' ability to participate in social activities, hobbies, sports (Kluger et al., 2016) and undertake work (Zesiewicz et al., 2007). Zesiewicz et al. (2007) found that fatigue was perceived as the greatest contributor to work disability in just under half (48%) of the 68 participants who took part in their survey regarding experience with disability insurance in the United States.

1.2.1.4.3 Autonomic symptoms

In addition to cardiovascular abnormalities the autonomic symptoms of Parkinson's encompass bladder, sweating and bowel dysfunction (Schapira et al., 2017). Though these symptoms may be present in the early stages of the condition it is recognised that they worsen alongside disease progression (Stanković et al., 2019). Specifically, individuals that report greater autonomic dysfunction have longer disease duration, higher disease stage and greater dosage of dopaminergic medication (Arnao et al., 2015). Worsening of autonomic symptoms is also independently associated with a reduction in ADLs and HR-QoL even when controlling for other factors, such as cognitive impairment (Merola et al., 2018). The detrimental impact of autonomic symptoms on QoL can be understood in terms of the how the symptoms manifest. For example, dysfunction of the urinary system can result in a greater urgency and frequency of urination, disruption to sleep due to increased frequency of urination (nocturia) and incontinence (Pfeiffer, 2016). The resulting behavioural elements associated with urinary dysfunction can increase the risk of sustaining an injury, such as a fall, due to the need to use the toilet at night when medication has worn off and symptoms are not controlled (M. Smith et al., 2016).

The full gastrointestinal tract can be affected in Parkinson's resulting in an array of symptoms ranging from excess salivation, constipation and intestinal bacterial growth (Fasano et al., 2015). The additional complications associated with gastroparesis, such as reaching satiety earlier, bloating, nausea, vomiting and gradual weight loss, are a source of additional distress in Parkinson's (Pfeiffer, 2016). Gastrointestinal symptoms are reported to be one of the most common reasons for hospital admission with complications such as malnutrition presenting in 15% of people with Parkinson's (Poirier et al., 2016). Weight loss in Parkinson's may contribute to a reduction of QoL (as measured by the PDQ-39). Specifically, Akbar et al., (2015) found that a reduction of 0.45kg per month was associated with an increase of 1.1% for the mobility and 1.5% for the ADL dimension of the PDQ-39. In the short term this may seem minor, however over an 18-month period the cumulative impact of consistent weight loss on QoL is likely to be much greater. In particular, experiencing embarrassment and lack of control over autonomic symptoms may result in withdrawal from employment (Perepezko et al., 2019), reduction in socialising (Thordardottir et al., 2014) and changes in intimacy with a partner/spouse (Fleming et al., 2004).

1.2.1.4.4 Cognitive impairment and dementia

As the severity of Parkinson's progresses, mild cognitive impairment (MCI) is likely, such that problems with executive functioning may arise (Chaudhuri & Schapira, 2009; Tanaka et al., 2009). It is reported that MCI will present in approximately 20-50% of people with Parkinson's (Goldman & Litvan, 2011). Individuals may display problems with planning and carrying out cognitive tasks, organising sequences of actions and problem solving (Majbour & El-Agnaf, 2017). Specifically, cognitive impairment in Parkinson's is characterised by deficits in visuospatial and executive functioning, therefore differing to the profile for Alzheimer's Disease that is hallmarked by greater memory impairment (Aarsland, 2016). Voluntary overt spatial orienting (remembered or delayed saccades to a location of interest) has found to be impaired in people with Parkinson's, whereas deficits are not found for visually guided saccades; thus indicating voluntary internal control of attention is compromised in Parkinson's (Briand et al., 2001). Executive functioning encompasses goal directed behaviour and adjusting to novel situations (Lange et al., 2018) and is typically tested using the Wisconsin Card Sorting Test (WCST), a rule based neuropsychological test. Significant impairments in the WCST have been found for non-cognitively impaired, non-depressed and unmedicated people with Parkinson's compared to healthy controls, according to a recent meta-analysis (Lange et al., 2018). Therefore, executive dysfunction may be present even in the earlier stages of Parkinson's. Collectively these aspects of cognitive impairment are known to have a detrimental impact on QoL for people with Parkinson's when compared to people with Parkinson's and no MCI (Baiano et al., 2019). Qualitative work indicates increased emotional distress as a result of a mismatch between self and social identity and physical and cognitive functioning in people with Parkinson's MCI (Lawson et al., 2018). However, Lawson et al. (2018) also found that some participants were not aware of their cognitive deficits thus did not perceive there to be any detrimental impact on daily life. The partners of these participants were very aware of the cognitive impairment and described a grieving process due to the cognitive and emotional absence of the person with Parkinson's. Therefore, MCI has probable negative implications for both people with Parkinson's and their partners (Carter et al., 2012).

Clinically significant mild cognitive impairment is thought to be a risk factor for future development of dementia, alongside age and motor symptom severity (Hoogland et al., 2017). Research suggests that 80% of Parkinson's patients in the late-stage of the disease are affected by dementia (Aarsland et al., 2003) and that self-reported impaired concentration and memory reduce QoL (G. W. Duncan et al., 2014). In Parkinson's the visual and verbal aspects of working memory, in addition to implicit procedural memory, are known to be impaired (R. G. Brown & Marsden, 1991; Fournet et al., 2000). In particular, impaired free recall of words has been demonstrated during a verbal and working memory test indicating impaired retrieval in some people with Parkinson's (Weintraub et al., 2004). Of the participants who performed poorly on the recall task, some demonstrated improved performance during a subsequent word recognition test, whereas a small number of participants did not show any improvement, thus indicating a possible deficit in encoding for a sub-group of participants. However, typically, recognition is reported to be preserved in people with Parkinson's (Hanagasi et al., 2017). It is well documented that neuropsychiatric symptoms (e.g. hallucinations of differing types, apathy and delusions) are associated with cognitive decline in Parkinson’s (Lenka et al., 2017). Specifically, Marinus et al., (2018) recently identified hallucinations as having the greatest associated risk for cognitive impairment and dementia. Furthermore, between 41-87% of people with Parkinson’s dementia (PD-D) experience hallucinations, compared to the lower prevalence rate of 7-15% for those without dementia (Chung et al., 2015). Cognitive decline combined with the presence of neuropsychiatric symptoms is associated with unfavourable health-related outcomes, such as increased distress and burden for the carer (Renouf et al., 2018), greater likelihood of nursing home placement and mortality for the person with Parkinson’s (Ffytche et al., 2017).

1.2.2 Exercise, older adults and Parkinson’s

While the population size across Europe is predicted to stabilise by 2050, it is estimated that the proportion of individuals aged over 60 years is likely to double. Worldwide, adults over 65 years will represent approximately 25% of the total population from 2025-2030 (Lutz et al., 1997; Oeppen & Vaupel, 2002). An association with greater reliance on health and social care services (Gondek et al., 2018) and economic burden (McPhail, 2016; Pinedo-Villanueva et al., 2019) means that much research has focussed on the relationship between ageing and health. Though increased life expectancy may be viewed positively in terms of scientific advancement, research suggests that ageing is not necessarily associated with good health. In particular, age is one of the strongest risk factors for several chronic conditions, including neurodegenerative conditions such as Parkinson’s, cancer and cardiovascular disease (Niccoli & Partridge, 2012). The development of age-related conditions is also likely to be associated with impairments of physical and cognitive functioning (Daley & Spinks, 2000). Specifically, physical impairments may include reductions in muscle strength, coordination of lower limbs, balance control and problems with gait (Thomas et al., 2019). These physical impairments, in particular gait, may contribute to an increased risk of falling (Van Abbema et al., 2015). Over half of the injuries that result in hospitalisation of older people are due to falls (Sherrington et al., 2008) and may result in loss of independence and poorer QoL (Merom et al., 2016). Therefore, maintaining the physical health of older adults is of interest and importance to not only the ageing individual, but associated health services. Engaging in exercise may be one way of supporting physical, and psychological health. Given that Parkinson’s is predominantly a condition of older age, this review will consider the effects of exercise in older people as well as in people with Parkinson’s.

According to a systematic review of studies undertaken across 10 different countries, adults aged over 60 years spend between 65-80% of their waking day being sedentary (Harvey et al., 2015). Similarly, objectively measured physical activity of healthy (no mobility impairment) older adults, aged over 60 years, has indicated that 63.4% of the day is spent sedentary (Manns et al., 2015). van Alphen et al., (2016) found that people with dementia residing in care homes spent 19% more time being sedentary compared to healthy older adults, whereas community-based dementia participants spent 8.9% more time being sedentary compared to the healthy older adults. Few studies have compared sedentary behaviour in Parkinson's to age-matched controls. The limited evidence suggests that the length of sedentary bouts is greater (Chastin et al., 2010) and the time spent being physically active is approximately 29% lower (van Nimwegen et al., 2011) for people with Parkinson's. However, Nimwegen et al. (2011) used a self-report assessment of physical activity for which the results may be biased due to inaccurate recollections of activity levels. Interestingly, Chastin et al. (2010) found that the percentage of total recorded time spent sedentary, measured over seven days using an accelerometer, was higher for people with Parkinson's compared to age-matched controls (76.7% and 71.5%, respectively). However, the difference was not significant; this may be due to the small sample size (*n* =17 for each group) such that the study was underpowered. The authors note that the additional time spent being sedentary (5%) for people with Parkinson's equates to approximately an hour per 24 hours, a finding that may have clinical importance. Of the studies that have used accelerometry to measure the physical activity of older adults with Parkinson's, but with no comparison control group, the percentage of the day spent being sedentary ranges from 75% (Wallen et al., 2015) to 98.3% (Dontje et al., 2013). The results of these studies highlight people with neurodegenerative conditions spend over half the day being sedentary and that the pattern of sedentary behaviour may differ to older adults.

There are a variety of studies evidencing that in older age increased time spent being sedentary may accelerate physical and psychological decline. Older women (aged 50-79) recording greater than 8 hours/day of sedentary time have been found to report lower physical functioning (such as strength and walking abilities) compared to women reporting less than 6-8 hours/day of sedentary time. Specifically, the association was found to be stronger for those who were older and more sedentary (Seguin et al., 2012). Furthermore, increased frequency of sedentary behaviours (such as sat a computer, playing cards or dinner with friends) has been associated with lower scores on tests of executive function, such as working memory and problem solving and reasoning, in adults aged over 65 years (Steinberg et al., 2015). Sedentary behaviour has also been linked to structural brain changes which is thought to underlie the cognitive changes associated with decreased physical activity (Colcombe et al., 2006). For example, a study by Arnardottir et al., (2016) investigated gray and white matter volume change between baseline and 5 year follow-up and the association between change and sedentary behaviour as measured at the 5 year follow-up in a group of older adults (mean age 79.1 years). The authors report that white matter loss at 5-year follow-up was associated with more time spent being sedentary as measured objectively using an accelerometer. The physical, cognitive and neuroplastic effects of sedentary behaviour as outlined above indicate the need to engage older adults, and in particular those with Parkinson's, in physical activity and reduce the time spent being sedentary.

To the best of the researcher's knowledge, no study to date explicitly examines the associated physical and psychological outcomes with sedentary behaviour in people with Parkinson's. Since people with Parkinson's may be more inactive (due to age and the condition) compared to healthy older adults, this sedentary behaviour may further contribute to symptoms of the condition. However, more research is needed to understand the effects of sedentary behaviour in Parkinson's and whether these can be disentangled from the effects of Parkinson's on physical and psychological outcomes. Instead, much of the focus has been on physical activity effects in Parkinson's, such as neuropathological changes (LaHue et al., 2016), disease burden (Lord et al., 2013), cognition (Amara et al., 2019; Lord et al., 2013) and mood (Amara et al., 2019). A recent longitudinal study by Amara et al., (2019) investigated changes in the self-reported physical activity of unmedicated (at baseline) people with early stage Parkinson's over a 3-year period compared with age-matched controls. The results of the study indicated that Parkinson's participants with higher activity levels at baseline had less disease progression over the 3 years. However, it is remains unclear whether a similar relationship exists between sedentary behaviour and disease progression.

Participation in exercise, such as resistance and aerobic training, has been shown to lead to cardiovascular, functional (e.g. strength, physical performance and fall risk), cognitive and metabolic improvements (Bouaziz et al., 2017) in older adults. Audio-visual perception, working memory and processing speed are some of the cognitive domains that have been found to improve (McSween et al., 2019). Several studies have also demonstrated the psychosocial benefits for older adults associated with exercise, including greater self-esteem

(Matson et al., 2019), reinforcement of social relationships (Gayman et al., 2017) and improved mood (Means et al., 2003). Furthermore, significant increases in cardio-respiratory fitness (CRF; measured as maximal oxygen consumption) have been found for older adults after participation in ergometer cycling (Lovell et al., 2010) and treadmill walking (Vaitkevicius et al., 2002). CRF represents the "functional capacity of an individual" (Ross et al., 2016, p.654), encompassing bodily functions such as pulmonary ventilation, the efficient transportation of oxygenated blood to the muscles and the capacity of the muscles to receive and use the oxygen. Increased CRF has important health implications for older adults, with evidence indicating that compared to other clinical variables, such as body mass index, CRF is a stronger predictor of mortality; higher CRF is associated with lower mortality in women over 60 years of age (Martinez-Gomez et al., 2015).The increasing evidence regarding the benefits of exercise has recently been incorporated into an updated version of the UK government guidelines to support physical activity recommendations for older adults (Department of Health and Social Care, 2019). Similarly, the American College of Sports Medicine published a position statement recommending older adults undertake 150 minutes of moderate to vigorous aerobic physical activity, in addition to resistance (e.g. weight training) and flexibility (e.g. static stretches) training two days a week at a moderate intensity (Chodzko-Zajko et al., 2009).

Functional improvements have been found for people with Parkinson's after participation in exercise programmes (aerobic; Ferraz et al., 2018; Miller Koop et al., 2019; Schenkman et al., 2012; van der Kolk et al., 2019, strength training; Cherup et al., 2019, and aquatic training; Carroll et al., 2017). Changes in the ability to undertake everyday activities has been considered indicative of functional improvement. These functional improvements are particularly important because they may allow individuals to remain independent for longer and reinforce QoL. Ferraz et al., (2018) compared the effects of functional training (including activities such as walking up and down stairs), an aerobic exercise programme using a stationary bike and an exergaming programme using the Xbox Kinect system (included activities using full body motion) on measures of walking capacity, gait speed, QoL, and lower limb strength and power of older adults with Parkinson's. Participants in all groups undertook 50-minute sessions of training three times per week for eight weeks. The authors found all three exercise modalities led to an improvement in walking capacity, perception of functional ability, and limb strength and power (as measured using the 6 minute walk test, The World Health Organisation Disability Assessment Schedule and sitting rising test, respectively), with no significant difference found between groups regarding the extent of improvement for these measures. These findings are in line with previous studies in older adults that have demonstrated a significant effect of exercise on the ability to undertake everyday activities, such as standing from sitting in a chair and reaching for an object when seated (Ozkaya et al., 2005). Ferraz et al., (2018) concluded that people with mild to moderate Parkinson's aged over 60 years may benefit from participating in any of the three exercise programmes used in their study. The authors also found that only two of the programmes led to significant improvements in QoL (functional training and exergaming), despite similar effects found across all three groups for functional tasks. These results suggest that enjoyment may be an important factor in participants perceptions of how functional changes translate to improved everyday functioning and that this is likely to be related to the type of activity undertaken.

While it is informative to investigate the effects of exercise on general functional abilities, Ferraz et al., (2018) limited their consideration of exercise effects on Parkinson's symptoms to measure of QoL. Change in overall disease severity and motor symptoms (both measured using the MDS-UPDRS at 4, 10 and 16 months) were included as secondary outcomes in a previous study by Schenkman et al., (2012) exploring the effects of two different supervised exercise programmes (flexibility balance function training and aerobic training) compared to an at- home exercise programme in older adults with Parkinson's (mean age > 60 years). Participants in the supervised groups exercised for 45-60 minutes three times a week for four months after which the sessions were tapered down to once a month. The home-based group were encouraged to perform their exercises five to seven days a week over a period of 16 months. The results indicated a significant group difference for disease severity at 4 months with a reduction for the aerobic group and a slight increase for the home exercise group, however no other group differences were found for severity at any other time point. The authors also note that no changes were found in motor severity between groups at any of the time points, therefore indicating that over the course of the study motor and total disease severity remained stable; whereas an annual increase of between 2.6 and 3.8 points (depending on age of onset) for the MDS-UPDRS motor score would generally be expected based on previous research (Alves et al., 2005). The findings suggest that all three types of exercise programme benefited participants and may even slow down disease progression. Furthermore, the results highlight that an at-home exercise programme is no less effective than supervised group activities in terms of stabilising the progression of Parkinsonian motor symptoms.

A more recent study by van der Kolk et al., (2019) focused on the implementation of an accessible aerobic exercise at-home programme for people with mild Parkinson's. Participants allocated to this group were required to exercise for 30-45 minutes three times a week for six months using a stationary bike that had been enhanced with virtual reality software to add a gamified element. A comparison active control group were recruited to undertake stretching and relaxation exercises for 30-minute sessions over the same time period as the aerobic group. Additional support was provided to both groups via a motivational tablet application and telephone/face to face coaching. van der Kolk et al., (2019) examined the effect of the aerobic and control interventions on disease severity (assessed using the MDS-UPDRS motor score off medication at baseline and 6 months) as the primary outcome. Secondary outcome measures included QoL, cognitive status, anxiety and depression (as measured by the PDQ-39, Montreal Cognitive Assessment, and the Hamilton Anxiety and Depression Scale, respectively). The authors report a significant between group difference in disease severity score at post intervention; specifically, the MDS-UPDRS motor score worsened for the control group (indicating an increase in motor severity) whereas, similar to Schenkman et al., (2012), the score for the aerobic group remained almost unchanged. This finding indicates that home-based aerobic exercise of moderate frequency attenuates Parkinsonian motor symptoms in the off-state and highlights the possibility of aerobic exercise having disease modifying effects.

In line with these findings studies that have used a mouse model of Parkinson's in which dopamine neurons have been destroyed by the neurotoxin MPTP (1-methyl-4-phenyl-1, 2, 4, 5-tetrahydropyridine) have demonstrated increased dopamine neurotransmission in intensively exercised mice. Specifically, Parkinson's type motor symptoms shown by the mice improved compared to non-exercised mice (for a review of the literature regarding exercise and neuroplasticity see Jakowec et al., 2016; Petzinger et al., 2015). Therefore, evidence from animal models predicts that exercise has the potential to slow disease progression in the brain. However, while some studies have found a beneficial effect of exercise on Parkinson's symptoms in humans (Altmann et al., 2016; Carroll et al., 2017; Schenkman et al., 2012; van der Kolk et al., 2019), there is no study to date which has demonstrated altered neuropathology in people with Parkinson's. In the van der Kolk et al.,

(2019) study it is also important to note that the significant difference found for the off-state did not extend to an on-medication state; this indicates that aerobic exercise does not have an effect on motor severity over and above medication. This finding also suggests that exercise effects may be due to enhanced endogenous dopamine release that are not apparent when L-dopa boosts dopamine production.

Van der Kolk et al., (2019) also found there were no between group differences for any of secondary measures, indicating no specific effect of aerobic activity on mood, cognitive status and QoL. Though significance is not reported, the change in scores (for both intervention groups) from pre to post-test suggest worsening of QoL and depression. Therefore, while an at-home exercise intervention may stall disease progression this does not necessarily translate to an increased QoL or improvement in mood, perhaps owing to the time commitment required to complete the intervention or the style of exercise itself. Alternative types of exercise that support physical and psychological wellbeing are needed, particularly programmes that are likely to be enjoyable, therefore facilitating longer term engagement.

1.2.3 Dance and older adults

For health professionals, finding an efficacious form of exercise that patients are likely to adhere to may be challenging. A systematic review by Farrance et al., (2016) reported a mean adherence rate of 69.1% for adults aged over 60 years attending community exercise programmes. Enjoyment and interest in an exercise intervention has been found to predict short and long-term adherence (Rhodes et al., 1999), in addition to level of exercise undertaken in a week (Hagberg et al., 2009). Attending dance classes is reported to be a more enjoyable and motivating activity compared to performing exercises at home (Clifford et al., 2019) and is associated with high adherence rates. For example, adherence rates of 84.3% and 92.5% have been found for contemporary (Britten et al., 2017) and salsa dancing (Granacher et al., 2012), respectively. It has been suggested that dance may be more enjoyable than other forms of exercise due to it being a social activity; most dance classes are a group based activity (Dhami et al., 2015) and certain styles, such as tango, are performed with a partner. Being able to attend a dance class with a partner has been reported as an important contributing factor in an individual's decision to participate. Furthermore, being able to learn a new skill with a partner has been identified as an enjoyable aspect of attending dance classes (Kunkel et al., 2018).

Dance has been suggested as an alternative to more traditional types of exercise (such as gym based aerobic activities) that may provide similar physical and psychological benefits for older adults (Hwang & Braun, 2015). Most styles of dancing involve the synchronisation of movements to rhythmic music which requires balance and motor coordination while also engaging cognitive functions (Franco et al., 2020). Several studies have examined the effect of dance on a variety of physical (predominantly) and psychological assessments including: balance (da Silva Borges et al., 2012; Krampe, 2013; Sofianidis et al., 2009), postural control (Ferrufino et al., 2011), cognitive flexibility (Coubard et al., 2011), gait (Granacher et al., 2012; Krampe, 2013) and proprioception in older adults (Marmeleira et al., 2009). These physical benefits have been explored across different dance styles, such as ballroom (da Silva Borges et al., 2012; Granacher et al., 2012), contemporary (Coubard et al., 2011; Ferrufino et al., 2011; Marmeleira et al., 2009), traditional Greek dance (Sofianidis et al., 2009) and jazz (Krampe, 2013). The results of these studies indicate that dance may be a socially interactive and conditioning form of exercise that older adults are likely to engage in on a regular basis.

1.2.4 Dance and Parkinson's

The therapeutic potential of dance has been explored for people with neurological conditions who may benefit physically and psychologically from a form of exercise that is socially engaging and motivating. Specifically, motor (e.g. postural instability) and non -motor (e.g. depression and fatigue) impairments which have been identified as modifiable with dance in older adults have been the focus of several studies with people with Parkinson's who also experience such impairments as part of their condition (Batson, 2010; da Silva et al., 2018; Hackney et al., 2007; Hackney & Earhart, 2009b, 2010a; Hashimoto et al., 2015; Kunkel et al., 2017; Loprinzi et al., 2018; McNeely et al., 2015). People with Parkinson's have been identified as a population who may particularly benefit from taking part in dance classes for reasons in addition to the impact dance may have on the symptoms. Higher time spent being sedentary compared to older adults (van Nimwegen et al., 2011), and a preference for solitary activities due to the unpredictable nature of symptoms, may compound social isolation and reduce QoL for people with Parkinson's (Perepezko et al., 2019). Therefore, dance, as a social activity that is generally undertaken as part of a group, is suggested to support the development of peer relationships and positively impact QoL for people with Parkinson's (Hackney & Earhart, 2009b). Furthermore, the use of music, in some styles of dance such as tango, combined with demonstrations by the dance teacher provide auditory and visual cues (respectively) that may help facilitate movement (Westheimer et al., 2015). Several studies indicate that auditory cuing using music with a steady rhythm (or a metronome embedded into the music) facilitates the synchronisation and regulation of features of gait to music in Parkinson's (Ghai et al., 2018; Rose et al., 2019). The use of action observation training (observing and then producing daily motor tasks; Buccino et al., 2011) has been found to increase the functional independence of people with Parkinson'; combining action observation with motor imagery has been shown to further enhance action imitation amplitude in Parkinson's (Bek et al., 2019). These studies provide an insight as to the potential mechanisms through which dance may provide physical and psychological benefits for people with Parkinson's.

The potential benefits of dance for people with Parkinson's has been studied across a variety of styles including: tango (Blandy et al., 2015; Di Biagio et al., 2014; Guettard et al., 2018; Hackney, Kantorovich, & Earhart, 2007; Hackney & Earhart, 2009a, 2010a; Koch et al., 2016; McNeely et al., 2015; Poier et al., 2019), ballet (Houston & McGill, 2013; Houston, 2015; McGill et al., 2019), contact improvisation (Marchant et al., 2010), Irish set dancing (Shanahan et al., 2015, 2017; Volpe et al., 2013), social dance (C. Lewis et al., 2016) and virtual reality (N. -Y. Lee et al., 2015). In addition to particular styles, Parkinson's specific dance training programmes, such as the Mark Morris Dance for PD® programme, have been the focus of several evaluative studies (Heiberger et al., 2011; Westheimer et al., 2015).

Of all the various dance styles and training programmes, Argentine tango, a music-based dance, has been the most widely studied and its effect on both motor and non-motor symptoms of Parkinson's investigated. It has been suggested that practising backwards stepping and walking, which are typically incorporated into tango routines, may be beneficial for addressing gait and balance irregularities in Parkinson's (R.P. Duncan & Earhart, 2012; Lötzke et al., 2015; Romenets et al., 2015) . People with Parkinson's demonstrate reduced velocity and stride length when walking backwards compared to controls (Hackney & Earhart, 2010b), in addition to smaller and delayed recovery steps when responding to external perturbations (Peterson & Horak, 2016). These gait impairments may also contribute to problems with balance and backwards falls (Horak et al., 2005; P.Y. Lee et al., 2013), therefore several studies have explored the effect of Argentine tango, as a therapeutic intervention, on parameters of gait, balance and falls in Parkinson's.

While the results of a meta-analysis specifically focused on tango indicated a significant effect of this dance style on balance and gait in Parkinson's (Lötzke et al., 2015), the results of individual studies are inconsistent. In particular, more recent studies that were not part of the meta-analysis have found differential effects of tango on gait and balance. For example, (McNeely et al., 2015) report an overall significant improvement in balance over time (as measured using the mini BESTest) when comparing a twice per week for 12 weeks tango intervention to the Dance for PD® programme. The study also did not find a significant effect of either dance intervention for forward and backward walking velocity (measured using the GAITrite pressure sensitive walkway), a finding that is partly consistent with other studies that report significantly greater gains for treadmill training when compared to tango (Di Biagio et al., 2014; Rawson et al., 2019). Therefore, while participating in dance may lead to an improvement balance, treadmill training may be a more useful intervention for people with Parkinson's who have gait impairment. However, differences in the measures used to assess gait (GAITrite; McNeely et al., 2015; Rawson et al., 2019, 10 minute walk test; Di Biagio et al., 2014), in addition to a focus on different parameters of gait, makes it difficult to compare studies based on their results. Furthermore, Rawson et al., (2019) tested participants off their medication to investigate whether the intervention had an impact on the underlying disease process (ordinarily obscured by the dopaminergic medication). It is also worth noting that Rawson et al., (2019) found no effect of time (pre vs post) or group (tango vs stretching vs treadmill) on balance. Therefore, while it could be concluded from McNeely et al., (2015) that dance more generally is beneficial for people with Parkinson's in respect to balance, the results of Rawson et al., (2019) found no effect of any type of exercise, including dance.

The interpretation of the findings from some of the initial studies investigating the effect of tango on gait and balance for Parkinson's are limited by minimal reporting of statistical tests (Hackney et al., 2007; Hackney & Earhart, 2009a). Hackney et al., (2007) investigated the impact of twice weekly tango classes over 13 weeks on measures of dynamic balance (functional reach test and one leg stance), balance confidence, falls efficacy and walking velocity (using motion capture) for people with Parkinson's and age-matched controls compared to a traditional strength/flexibility exercise class. The authors report small improvements for both balance measures for the tango group (an increase of 0.6 inches and 0.4 seconds for the functional reach and one leg stance, respectively), and a similar improvement for the traditional exercise group (0.4-inch increase and 1.4 second increase, respectively). Therefore, any positive effects on balance were not necessarily specific to dance. However, the authors do not report any statistical tests to explore the effect of time (pre-and-post) and between group differences for the balance tests. Similarly, descriptive differences are suggested between the tango and exercise group for balance confidence and falls efficacy, though are not statistically tested. Minor increases were found for both outcomes for the tango group and a slight decrease found for the exercise group. The results suggest that though the exercise group experienced improvements in balance, this was not matched by an increase in confidence to undertake ADLs without worrying about falling or balance. Therefore, tango may differ to traditional exercise in that it may have specific psychological (e.g. confidence) and physical (e.g. functional balance) benefits for people with Parkinson's. For walking velocity, a very small increase of 0.02 meters/second was found for both groups, which the authors note as non-significant, in line with the findings of McNeely et al., (2015). Therefore, while these studies aid understanding of the potential benefit of dance for people with Parkinson's regarding balance, it still remains unclear how these changes compare (in terms of significance and magnitude) to other types of dance and exercise, in addition to inactive individuals. Furthermore, dance style is likely to be only one of several other contributing factors as to why some studies find or do not find physical or psychological benefits for people with Parkinson's. For example, the intensity and frequency of classes are likely to be relevant factors.

Rather than focussing on specific motor symptoms of Parkinson's, several studies have reported a positive effect of dance (Dance for PD®; Heiberger et al., 2011; Westheimer et al., 2015, tango and waltz/foxtrot; Hackney & Earhart, 2009a, tango vs Dance for PD®; McNeely et al., 2015) on overall motor severity of the condition, as measured using the MDS-UPDRS part III (MDS-UPDRS part III). The MDS-UPDRS part III involves a motor examination during to detect changes associated with Parkinson's progression and is currently considered the gold standard for assessing severity (Brooks et al., 2019). While Westheimer et al., (2015) found that a dance intervention of moderate frequency (1.25 hours twice a week for 8 weeks) resulted in a significant reduction (although small effect size of 0.32) in Parkinson's motor severity post intervention for the 14 individuals who participated, Heiberger et al., (2011) found similar changes for a low frequency dance intervention (1.15 hours once a week for 8 weeks). Furthermore, the reduction in motor severity score (pre= 23.7, post= 15.5) was shown to occur immediately after participation in a dance class at the end of the 8 weeks indicating a short-term effect of dance on motor control for people with

Parkinson's (Heiberger et al., 2011). Though not statistically analysed, the authors report similar changes for three de novo patients who participated in just one class, with the decrease in MDS-UPDRS part III score ranging from -9 to -11, which is indicative of a moderate clinically important difference (CID; Shulman et al., 2010).

While CID is typically used for clinical drug trials, it may also be used to evaluate the efficacy of therapeutic interventions, such as dance, from a patient centered approach. The CID is defined as the change on a measure that patients identify as meaningful/ are able to recognise (Shulman et al., 2010). Few studies in the dance literature interpret their results in relation to clinically important difference (CID), however Westheimer et al., (2015) is one such study to note that the 10.4% (3 point) reduction in motor severity compared to baseline is equivalent to a minimum CID. According to Schulman et al., (2011) a difference of 2.3 to 2.7 points, 4.5 to 6.7 points and 10.7 to 10.8 indicates a minimal, moderate and large (respectively) clinical difference on the MDS-UPDRS motor score. Therefore, the results of the Westheimer et al., (2015) study indicate that a dance class of moderate frequency may lead to a reduction in motor severity that is recognisable to the individuals participating. In contrast, the results of Heiberger et al., (2011) indicate that a dance intervention of low frequency (once a week) can lead to a moderate CID in motor severity (a reduction of 8.2 points from pre to post testing). Therefore, both studies demonstrate that the Dance for PD® programme leads to a meaningful reduction in motor severity, though this may differ depending on the dose of the dance class. Neither studies include a follow-up phase, therefore it is unclear whether the reduction in motor severity is maintained long-term and whether frequency of attendance to a dance class is associated with sustained benefits. To the best of the researcher's knowledge there are no studies to date that explicitly investigate the optimal dose of dance for people with Parkinson's for short and long-term physical and psychological benefits.

In addition to investigating change in global motor severity before and after dance, Westheimer et al., (2015) focused on individual items of the MDS-UPDRS motor sub-section, such as gait and tremor. Scores for the gait sub-section were found to significantly improve between baseline and post dance intervention, with a moderate effect size of -0.49. It is interesting to note that a measure requiring visual observation for scoring, which could be argued as fairly subjective, indicated improvement in gait for people with Parkinson's, but studies using an objective computerised assessment of gait (GAITrite; McNeely et al., 2015;

Rawson et al., 2019, motion capture; Hackney et al., 2007b) did not find a significant improvement in gait. While the disparity in findings could be due to differences in dance interventions (tango; Rawson et al., 2019, Dance for PD® programme; Westheimer et al., 2015), the assessment tool used to measure gait may also be a factor to consider. Few studies include a clinical and objective assessment for the same outcome; therefore, it is unclear how objective measures map onto clinical assessments (and vice versa). Furthermore, the application of objective assessments is typically limited to pre-and post-dance intervention testing, whereas some measures may be informative when used during a dance class, such as motion capture and accelerometers.

The effects of dance on depression (Blandy et al., 2015; Guettard et al., 2018; Hashimoto et al., 2015; Romenets et al., 2015) and other non-motor aspects of Parkinson's has also been investigated, though the results of quantitative studies are varied. One recent study demonstrated a significant 46.1% reduction in depression scores (as measured using the Beck Depression Inventory; BDI) for participants who took part in a Sardinian Folk Dance intervention twice per week for 12 weeks; a finding that is greater than the 17.5% reduction required for a minimal clinically important difference with the BDI (Button et al., 2015). In contrast, for the Parkinson's care-as-usual control group the BDI scores increased, non-significantly so, by 0.8%. The authors also report a large between-group effect size of 3.22 for the measure of depression (Solla et al., 2019). However, a study by Guettard et al., (2018) found no improvement in mood, as assessed using the Hospital Anxiety and Depression Scale (HADS), for people with Parkinson's who took part in a low frequency (once per week for 3 months) adapted tango intervention. Similarly, Romenets et al., (2015) did not find a significant change in mood, as measured using the BDI, for people with Parkinson's who took part in a moderate frequency tango intervention. Furthermore, no difference in mood was found between the tango group and control participants who were given exercises on a leaflet to complete at home. This study differed to Guettard et al., (2018) in that participants were required to attend dance classes twice per week for 12 weeks. The higher frequency of classes per week may have contributed to the reported protocol violations; specifically, 6 out of 18 participants did not attend at least 50% of the classes. Therefore, it is not clear whether the intervention may have led to improvement in mood if all of the participants had attended every dance session. However, Westheimer et al., (2015) did not find any significant change in depression, also measured using the BDI, between baseline and post intervention assessment. This was for a moderate frequency (twice per week for 8 weeks) Dance for PD®

programme where there was good attendance to sessions by participants (authors report an average of 10 out of 12 attendees per session) and a low attrition rate.

The results of the studies reviewed suggest that tango (Guettard et al., 2018; Romenets et al., 2015) and Dance for PD® (Westheimer et al., 2015) interventions of low and moderate frequency may not have a positive effect on depression for people with Parkinson's. In contrast, a traditional Sardinian folk dance class of moderate frequency may lead to a reduction in depression, however it is important to note that the baseline levels of depression differed across studies. In particular, Solla et al., (2019) report the highest baseline depression levels for both the dance and control group of all the studies reviewed above; for example, the folk dance and control group had a mean of 14.10 and 13.76 , respectively, compared to 7.9 and 7.7 for the tango and control group, respectively, in the Romenets et al., (2015) study. Furthermore, the baseline levels of depression reported by Romenets et al., (2015) are low, given that the maximum score possible on the BDI is 63 and a score of 0-9 is within the normal range indicating no depression (Sajatovic et al., 2015). Therefore, the low scores are likely to limit the potential to detect change, whereas the baseline depression scores for both participant groups (dance and control) reported in the Solla et al., (2019) study are within the range that would be considered mild depression (Edelstein et al., 2010). Therefore, measures of depression, such as the BDI or HADS, may not be sensitive enough for use in studies where the majority of participants are not clinically depressed. Furthermore, people with Parkinson's who have been diagnosed with depression (approximately 35% of the patient population have clinically significant depression; Schapira et al., 2017) are likely to be receiving drug and/or therapeutic treatment. Therefore, baseline levels of depression prior to engaging in a dance intervention may be low even if some participants have been diagnosed with depression.

Though the frequency of the dance classes were somewhat similar across the studies reviewed (once per week, Guettarrd et al., 2018; twice per week, Romenets et al., 2015; Solla et al., 2019; Westheimer et al., 2015), it is not clear what the intensity of the dance was for each intervention and to what extent those taking part in the dance classes were actively participating in all elements (for example, some participants may have had to sit out during some parts). The difference in outcomes reported across the studies could be due to several factors, including the amount of movement and intensity of the exercise undertaken. Previous research indicates that an increase in the amount of time spent in moderate and vigorous activity may lower the severity of depression experienced (Dunn et al., 2001; Mumba et al., 2020) and the results of a longitudinal study suggested that regular physical activity (self-reported on three occasions across 8 years) was associated with a decreased probability of reporting depression symptoms at follow-up (Da Silva et al., 2012). Therefore, the amount and intensity of movement are likely to be important considerations when investigating the effect of exercise on psychological outcomes, such as depression. It has also been suggested that the social aspect of dance, such as interaction with and support from others with Parkinson's and volunteer helpers, may contribute to depression changes (Shanahan et al., 2016). Therefore, factors such as the structure of the dance classes (individual, partnered, or group) and whether attendees stay behind after the class (i.e. for refreshments) should be a consideration when evaluating the effect of dance on depression. Lastly, the music used during the dance classes may also be a contributing factor to changes in depression in people with Parkinson's. Previous research with healthy adults indicates a link between the amygdala, the neural substrate of emotional processing, and pitch perception (X. Li et al., 2014). In particular, a larger gray matter volume of the amygdala was found to be correlated with greater accuracy on a pitch perception task, therefore suggesting that the amygdala may play a role in music processing.

While the abovementioned studies focused on measuring the intensity of and change in depression, in contrast, C. Lewis et al., (2016) explored the effect of a 10 week (50 minutes once per week) social dance classes on global mood disturbance. C. Lewis et al., (2016) used the Profile of Mood States (POMS) to assess mood across six different states: tension, depression, anger, vigor, fatigue, and confusion (Yeun & Shin-Park, 2006). The authors reported a significant reduction in total mood disturbance for older adults, which included a group of people with Parkinson's, indicating that dance has psychological benefits but that this is not specific to people with Parkinson's. The maximum possible score for Total Mood Disturbance (TMD) on the POMS is 200, therefore the reported mean scores for the Parkinson's (22.56) and control (18.8) participants for TMD were relatively low at baseline. However, baseline scores for TMD, and the tension, vigour and confusion sub-scales, of participants with Parkinson's were reported to be significantly higher than geriatric normative data, indicating higher mood disturbance prior to the intervention. This difference was not found for the control participants, indicating the mean TMD was closer to that of a comparative, in age, sample of older adults. Though the results of this study do not indicate specific benefit of a 10-week social dance intervention on mood disturbance for people with

Parkinson's, understanding whether the TMD scores reduced to a level similar to normative data would provide further insight as to the value of dance for these participants. The authors do not specify the post-intervention scores for TMD; therefore, it is not possible to determine whether the post intervention scores for the Parkinson's group compared to normative data. Though C. Lewis et al., (2016) did not find a reduction in mood specific to people with Parkinson's, the results of the study indicate that assessments of change in mood, such as the POMS, may be more sensitive than using a depression specific measure.

The study by C. Lewis et al., (2016) is one of the few quantitative studies to measure changes in mood following dance for Parkinson's, however several qualitative studies have reported positive outcomes as expressed by participants during follow up interviews and on feedback questionnaires (Batson et al., 2016; Heiberger et al., 2011; Kunkel et al., 2018; Westheimer et al., 2015). One such study is that of Westheimer et al., (2015) which used a mixed method approach and included a structured open-ended questionnaire with 12 participants with Parkinson's after the final Dance for PD® session to explore the participants' experience of the classes. The authors report that many of the participants perceived there to be social and emotional benefits from taking part in the classes; for example, most participants described a sense of enjoyment from taking part, while two participants referred to psychological benefits ("helps a lot physically and mentally"). In particular, many of the themes developed from the interviews with participants may map onto items of mood disorder assessments. For example, the BDI includes items developed to measure the somatic (e.g. fatigue, bodily discomfort; Cheng et al., 2018), cognitive and affective (e.g. feeling sad, loss of interest in people; Cheng et al., 2018) symptoms associated with depression (Smarr & Keefer, 2011). Westheimer et al., (2015) report that many participants made reference to the other people taking part in the classes in varying contexts, such as a sense of companionship, the communal experience, camaraderie and generally enjoying being with the people in the group. In terms of the affective benefits of dance, when asked whether they perceived any change in themselves two participants referenced being happier, whereas another participant expressed feeling less helpless. Somatic changes were also noted by many participants, in particular improvements in general health, feeling physically stronger, an increased awareness of health and how to use the body were all reported. The qualitative results indicate perceived improvements in QoL and wellbeing, but these were not mirrored by a significant change between the pre-post scores on the BDI. Similarly, no change was found for the PDQ-39. Westheimer et al., (2015) suggest that assessments such as the BDI and PDQ-39 might not be sensitive enough to capture the perceived changes verbally reported by participants.

In line with these findings, subjective reports of improved social and emotional wellbeing have been given by people with Parkinson’s when taking part in improvisational dance classes (Batson et al., 2016). In particular, open-ended written responses from participants included references to “increased mobility”, “camaraderie and community” and “body warming up”. This feedback is similar to that identified in the Westheimer et al., (2015) study, specifically the perceived benefits of social interaction. However, the authors highlight that the reports were collected from an initial pilot study (Batson et al., 2014) and then on an ad hoc basis from people attending an ongoing (at time of publication) class. The means by which data were collected and analysed, in addition to the demographics of the participants, are not specified in detail in the paper. Despite the lack of clarity in relation to the methodology, the feedback is complemented by some quantitative data. Participants were asked to complete a survey rating the extent to which they had experienced increased life satisfaction and empathy for class attendees on a 1 (“not at all”) to 5 (“very much”) scale. Batson et al., (2016) found that 64% of participants selected “very much” when asked about increased life satisfaction and 82% reported increased empathy (selecting a rating 4 or 5). Though the results of Westheimer et al., (2015) and Batson et al., (2016) suggest that participants perceive benefits of attending dance classes that may reflect changes in mood, methodological differences between studies make it challenging to draw robust conclusions regarding the effect of dance on mood. In particular, qualitative research by Kunkel et al., (2018) suggests that the relationship with a dance partner may be a contributing factor to the perceived enjoyment of dance classes. For example, a number of participants interviewed about their experience of a 10-week ballroom and Latin dance programme indicated that, prior to attending the classes, the notion of dancing with a stranger had been a source of some anxiety. Furthermore, a partner’s lack of dance experience was identified as a negative by some participants; Kunkel et al., (2018) quote a participant with Parkinson’s describing that his/her partner’s unfamiliarity with the dance routines limited their performance of the steps. Therefore, some participants may not be able to engage with and fully perform the dance routines (in terms of volume of movement and intensity) to the best of their ability, though this is difficult to measure objectively. The findings of the Kunkel et al., (2018) highlight that partnered dancing may pose certain unique barriers to enjoyment, and perhaps improvement in mood, that need to be considered, particularly when undertaking larger scale intervention studies with the aim of boosting mood. In addition to mood, the findings of Batson et al., (2016) and Westheimer et al., (2015) indicate that dance effects on general wellbeing and QoL may also be insightful constructs to study.

Most studies have focused on the tango dance style to explore the effect of dance on QoL of people with Parkinson's, (Blandy et al., 2015; Hackney & Earhart, 2010a; Koch et al., 2016; McNeely et al., 2015; Poier et al., 2019; Romenets et al., 2015), with mixed results. Hackney and Earhart (2010a) undertook one of the earliest and few studies focusing on a singular individual with severe Parkinson's who participated in a one-hour tango session twice a week for 10 weeks. While most studies have chosen to focus on the potential benefits of dance for people with mild to moderate Parkinson's it is not well understood what impact, if any, classes may have on people in the later stages of the condition, particularly those with limited mobility. The authors note that the participant in their study could walk short distances with an assistive device but generally spent most of his time in a wheelchair, therefore some of the dance movements were completed whilst sat down. Using the PDQ-39 to assess QoL the authors report a 14% reduction (lower scores equate to improved QoL) in the summary index score between pre and post intervention testing, in addition to the improvement being maintained at 4-week follow-up. The participant was also asked to complete an 8-item exit survey ranking on a scale of 1 (strongly agree) to 5 (strongly disagree) different physical and psychological aspects of their wellbeing in relation to the dance. In line with the results of the PDQ-39, the participant reported perceived improvements on all items, including balance, strength, coordination and mood. Together these results indicate that frequent tango classes may be psychologically beneficial for an individual with severe Parkinson's and that this effect may be maintained in the longer term. It is possible that due to the severity of the condition the individual may have had more to gain from the dance classes. For example, a higher baseline PDQ-39 score (55.7) compared to studies that have included those with mild to moderate Parkinson's (26.8 for a tango intervention; Romenets et al., 2015, 21.3 for mixed dance intervention; Kunkel et al., 2017) indicates that the individual with more severe Parkinson's had a lower QoL initially. It is also interesting to note that the participant demonstrated psychological and physical (such as balance and general mobility objectively measured by the Berg Balance and 6-minute walk test, respectively) improvements despite not being able to perform all the dance movements. From the literature to date it is not clear whether the volume of movement per se may be a contributing factor to the effects of dance, psychologically and physically. The results of Hackney & Earhart (2010a) indicate that reduced participation in dance, in terms of not being able to perform all the movements, can still lead to improvements. However, it is not understood whether the same outcomes would be found if people with mild to moderate Parkinson’s were to take part in the same dance programme and whether participation, such as volume of movement, would vary between participants of different Parkinson’s severity.

Supporting the findings of Hackney and Earhart., (2010a), a meta-analysis by Sharp & Hewitt., (2014) concluded that dance for people with mild to moderate Parkinson’s, when compared to exercise, favoured improvements in QoL as measured by the PDQ-39. The meta-analysis encompassed two studies to examine the effect of dance on QoL; Volpe et al., (2013) compared Irish set dancing to physiotherapy exercises and Hackney & Earhart, (2009a) compared the following three groups: tango, waltz/foxtrot and no intervention. However, since the publication of Sharp & Hewitt. (2014) there have been several studies that have included assessments of QoL and have found participant scores to be unchanged after undertaking a dance programme. One such study is that by McNeely et al., (2015) who compared the effect of tango to a Dance for PD® programme on QoL, in addition to other outcome measures. Participants with Parkinson’s, eight allocated to each group, took part in an hour session twice a week for 12 weeks and the PDQ-39 summary index was used to assess QoL before and after the interventions. While the PDQ-score increased for the Dance for PD® group between pre and post assessment (though this was non-significant), indicating lower QoL, a decrease was found for the tango group, therefore indicating improved QoL even though the change was non-significant. The authors report that the results of their study are comparable with those of Romenets et al., (2015) and Westheimer et al., (2015) who did not find any effect of tango and Dance for PD®, respectively, on QoL. While this finding may reflect a genuine lack of effect, it is important to note that McNeely et al., (2015) had a very small sample size and was most likely not sufficiently powered to find an effect. Differences between the dance interventions and design of the studies (i.e. some include a control group while others do not) make it difficult to compare findings. For example, as opposed to including a second dance programme, Romenets et al., (2015) included an active control group who were given a leaflet of exercises to complete at home and Westheimer et al., (2015) did not include a control group. Likewise, a study by Kunkel et al., (2017) investigating the effect of mixed dance styles (ballroom and Latin) on non-motor, including QoL, and motor symptoms of Parkinson’s included a care as usual control group. Though the active control group of Romenets et al., (2015) differed to that of Kunkel et al., (2017), the authors did not record whether the control group undertook any of the exercises given to them. Therefore, it is not known how active the control group were during the 12 weeks or whether some participants engaged with the exercises whilst others did not. Objective monitoring of participants volume of movement would provide a useful insight as to whether groups differed during the intervention period. Based on the findings of the studies reviewed above there is no clear evidence to suggest that participating in a tango or Dance for PD® programme is better than completing exercises at home or no exercise at all for improved QoL as measured using the PDQ-39.

Alternative assessments of HR-QoL that are not specific to Parkinson's have been used in some studies, for example Blandy et al., (2015) used the Euroqol-5D which measures HR-QoL across five dimensions (mobility, self-care, usual activities, pain/discomfort and anxiety/depression). In addition to questionnaire items, the Euroqol-5D includes a visual analogue scale which is used to assess the participant's self-rated health on a scale of 'Best imaginable health' to 'Worst imaginable health'. Blandy et al., (2015) did not find any significant change in HR-QoL after participation in a 4-week tango programme as measured by the questionnaire and the visual analogue scale. Similar to Kunkel et al., (2017) and Romenets et al., (2015), the baseline scores on both the Euroqol-5D questionnaire and analogue scale indicate a high perceived QoL prior to the dance intervention. The median baseline score for both the questionnaire and analogue scale (0.78 and 80, respectively) are comparable to population norms for the 55-64 age group (normative scores from a UK data set are 0.80 for the Euroqol-5D summary index score and 81.70 for the visual analogue scale; Janssen & Szende, 2014). Furthermore, with only six participants the study was likely underpowered to find any significant effects. A small sample size has been identified by authors as a limitation of studies investigating the effect of dance on motor and non-motor symptoms (Heiberger et al., 2011; McNeely et al., 2015; Westheimer et al., 2015), though overcoming this may be difficult as studies with a large number of participants at baseline still report high attrition rates; for example, Shanahan et al., (2017) started with 90 participants in total but note that participant attrition was greater than 40% for each group (Irish set dance vs usual care).

Though typically measured as a standalone construct, QoL is also included within the definition of wellbeing and is sometimes used interchangeably with the term (Kennedy-Behr & Hatchett, 2017). The definition of wellbeing, according to the World Health Organization, (2007), encompasses all life domains that are considered to contribute to a "good life", including physical, mental and social aspects. Therefore, being able to carry out ADLs, a dimension of the PDQ-39, may be a fundamental part of physical wellbeing for people with Parkinson's (Olsson & Nilsson, 2015). Likewise, depression and anxiety, as experienced by many people with Parkinson's (as detailed in section 1.2.1.4.1), may impact on overall wellbeing (Nicoletti et al., 2017). Given that there is evidence to suggest that dance may be psychologically beneficial for people with Parkinson's, though there are not sufficient investigations and findings are inconsistent as highlighted in this chapter, wellbeing has been an outcome of interest in a few quantitative studies exploring the effects of dance. One such study is that by Koch et al., (2016) who found a significant improvement in wellbeing (and a large effect size of 0.69), as measured by the Heidelburg State Inventory (HSI) assessment, after people with Parkinson's participated in a singular 90-minute tango workshop. Data was collected from three separate 90-minute sessions with different participants attending each one. The authors used a unipolar 24-item version of the HSI; the original bipolar 12-item inventory was developed for use with clinically depressed sample (Koch et al., 2007). The modified version measures tension, anxiety, coping, vitality, and positive and depressed affect on a scale of 1 ("does not apply at all") to 5 ("does apply"). The HSI is not frequently used in dance studies with people with Parkinson's and though the authors provide details regarding the internal consistency of the assessment it is not clear if it has been validated for use with a Parkinson's sample. Therefore, more research is warranted using the inventory, in particular larger scale studies that intend to improve wellbeing through dance-based interventions. A further critique of the study is that the authors describe the tango workshop as intensive, however it is not clear what element of the workshop (i.e. length of time or intensity of exercise) the authors are referring to and how intensity was determined. There is no objective assessment of exercise intensity, such as heart rate, included in the study; such an assessment would serve as a useful validation and allow future studies to compare the intensity of dance interventions to the workshop developed by Koch et al., (2016). Lastly, the validity of the findings should be interpreted with caution given that each workshop started with the researcher giving a 30- minute presentation regarding the effects of dance and music on Parkinson's, therefore potentially creating some bias prior to participants undertaking the intervention and completing post assessments. The research exploring the effect of dance on general wellbeing is limited, however there is some evidence to suggest that the mind-body connection component of dance may have an impact on perceptions of the body.

Taken together, the studies reviewed in this chapter indicate inconsistencies in the effects found for dance on the motor and non-motor symptoms of Parkinson's. As detailed above, differences between studies in terms of the choice of the use of control groups, reporting of statistical tests and long-term follow up makes it difficult to compare the findings. Changes in outcome measures such as gait (Di Biagio et al., 2014; McNeely et al., 2015; Rawson et al., 2019) and depression (Romenets et al., 2015; Solla et al., 2019; Westheimer et al., 2015) vary across the literature. Differences in the assessment or equipment used to measure an outcome may account for some of these variances. However, it may also be the choice of outcome that is inappropriate for use with the study sample, as may be the case with depression. The disparities in outcomes are further complicated by the differences in the testing of participants on and off medication. Testing participants off medication provides insight into the effect of dance on the underlying disease process, though the discomfort this is likely to cause participants and possible associated difficulties with recruitment may be some of the reasons researchers chose not to include off medication testing.

Currently there is no clear evidence to indicate which components of dance are required for positive effects on physical and psychological outcomes and whether some components are superior to others in facilitating maximum benefit, and for whom; the outcomes for people of differing severities of Parkinson's are not well understood and most studies focus on people with mild to moderate severity. Some researchers have studied the effect of social activities on mood (A. Hall, 2017) to try and separate out the effects of dance from the social component and others have investigated the impact of music, independent of dance, on motor and non-motor symptoms of Parkinson's (see Ghai et al., 2018 for a review). Yet, the contribution of the social and musical aspects of a dance class to physical and psychological outcomes compared with other components, such as dose, requires further investigation.

1.2.5 Accelerometry to measure movement by people with Parkinson's

There is a need for objective measures of activity to be implemented in studies investigating the benefits of exercise and dance for Parkinson's. While different parameters of engagement with exercise can be assessed using self-report measures (Physical Activity Scale of the Elderly to assess frequency, intensity, and duration of activity; Amara et al., 2019, LASA physical activity questionnaire to assess level of physical activity, LAPAQ; van Nimwegen et al., 2013), developments in wearable instruments (such as fitness trackers and accelerometers) means that the objective assessment of volume and intensity of movement over an extended period of time can be achieved using a singular body-worn device.

Wearable devices range from consumer-grade to research-grade instruments. Consumer-grade fitness trackers, such as those produced by Fitbit™, Polar™, Garmin™, Apple Watch Sport™, are widely available and have become increasingly popular; in 2015 Fitbit sold 21,355 devices (Bassett et al., 2017). Further, most smart phones, such as the iPhone, include an in-built tri-axial accelerometer that can be used to monitor general, and certain parameters of, physical activity (step count; Althoff et al., 2017; Douma et al., 2018, step time and step length; R.J.Ellis et al., 2015). A recent study identified 423 different models of wrist-worn fitness trackers and noted that in 2011 there were only 3 brands available and that this increased to 131 by 2017 (Henriksen et al., 2018). The in-built software and mobile phone application capability facilitates the measurement of a wide range physical activity parameters, including step count, energy expenditure, activity counts, sedentary and active bouts. Unlike many research-grade wearables, the cleaning and post-processing of the data is done via the software or application provided alongside the consumer device. Typically, consumer devices have an interactive interface that allows the wearer to see their personal health statistics, as recorded and calculated by the device, and easily track these over a specified period of time. The latter feature of long-term monitoring that these devices provide has been identified as motivating factor for the wearer in becoming more physically active (Jo et al., 2019; Kooiman et al., 2015; Tedesco et al., 2017). Consumer devices can be inexpensive and therefore are not only an appealing option for the general public but to academics wishing to monitor or track specific parameters of physical activity (Pradhan & Kelly, 2019). In fact, many studies have investigated the use of wearable devices as a motivational and self-monitoring tool for physical activity (Cadmus-Bertram et al., 2015; Z. H. Lewis et al., 2017; Robinson et al., 2019). For example, Cadmus-Bertram et al., (2015) used Fitbits with a sample of inactive participants as part of a 16-week behaviour change intervention to facilitate participant tracking of step count and physical activity levels. Similarly, Z.H. Lewis et al., (2017) compared the feasibility and acceptability of a pedometer to the Jawbone fitness tracker in the self-mentoring of physical activity in older primary care patients. The usefulness of fitness trackers has also been demonstrated in a study examining the relationship between post-operative ambulation and risk of readmission in cancer patients (Low et al., 2018). The general ease of use and interactive features of consumer-grade devices (Z. H. Lewis et al., 2017) makes them suitable for use in studies where participants are encouraged to actively engage with the device.

Colón-Semenza et al., (2018) used a fitness tracker (FitBit Zip) as part of an 8 week walking intervention to engage people with Parkinson's with their own exercise behaviours, in addition to measuring changes in parameters of movement (i.e. steps per day and active minutes per week) from baseline to the final week of the intervention. Ten participants with mild to moderate Parkinson's were paired with a physically active Parkinson's peer coach (5 dyads in total) with whom they regularly interacted with via the FitBit app as well as phone calls. Rather than reporting statistical differences, the authors detail the percentage change for each of the movement parameters as measured by the FitBit. The results indicated that 4 of the peer mentees demonstrated a 31% increase in mean steps per day, thus exceeding the minimal clinical important difference for people with a neurological condition (Colón-Semenza et al., 2018). An increase (42%) in mean minutes spent being fairly to very active was also found across all mentees. The authors further note an increase from approximately 3 of 7 days of achieving 30 minutes of fairly-very active minutes to 4 of 7 days at the end of the intervention. Therefore, the results suggest the intervention resulted in increased physical activity of people with Parkinson's, although it is not clear whether this was maintained once the intervention ended. Furthermore, the study demonstrates the utility of fitness trackers in the monitoring of parameters of movement for both the wearer and research purposes. A more recent study investigated the feasibility of implementing a fitness tracker as part of a 12-week intervention to increase wellbeing, physical activity self-efficacy and QoL of people with Parkinson's (Hermanns et al., 2019). Five physically active people with mild to moderate Parkinson's wore a FitBit Alta on their wrist over the duration of the intervention which involved following an exercise video 3 times per week and engaging in an online peer support group. A post-intervention evaluation revealed that 4 of 5 participants wore the fitness tracker over the course of the intervention (one participant had skin sensitivity) with participants indicating a greater awareness of their physical activity when wearing the trackers. Despite the reported increase in awareness, only one participant demonstrated increased physical activity levels between pre to post intervention. Some technological issues were reported; in particular, participants found it challenging to use the FitBit application which had to be accessed using an iPad. The small sample size limits the findings and consequently the conclusions that can be drawn. However, the majority of participants were able to tolerate wearing the device, though it is not clear how efficacious the fitness trackers were in encouraging physical activity self-efficacy.

Consumer-grade fitness trackers have also been used in the assessment of motor changes associated with dopaminergic medication (Cai et al., 2017), though such studies are limited. Twenty-one people with mild to severe Parkinson's who experienced specific motor symptoms (bradykinesia plus either rest tremor, muscle rigidity or postural balance disorder) and 20 healthy controls wore a fitness tracker on their wrist for 5 consecutive days while undertaking their normal everyday routine. The movement parameters extracted from the fitness trackers included total average daily calories, daily walking calories, average walking frequency, average daily sleep time and step count. The authors were particularly interested in these parameters for the hour following levodopa medication and for the hour before the participant's next dose to explore whether the fitness tracker detected changes in motor symptoms associated with wearing on and off medication periods. The results indicated a significant difference in several movement parameters between wearing on and off periods; namely the number of steps and walking distance were significantly higher in the hour after the levodopa dose compared to the hour before a dose. Significantly lower total daily calories, walking frequency and sleep time were reported for participants with Parkinson's compared to controls. These findings indicate that the activity pattern of people with Parkinson's differs from age-matched adults without Parkinson's and that it is feasible to use a fitness tracker to monitor movement over an extended period of time with these participant groups. The findings further highlight the novel ways in which activity monitors can be applied in the area of ambulation and Parkinson's, in addition to the variety of movement parameters that can be studied using the devices.

The functionality of consumer devices has contributed/encouraged wide scale application of the devices within research to different populations, such as older adults and those with a neurological condition (as discussed above). However, there is limited evidence of reliability and validity for the use of the devices with such populations. The studies that have examined the accuracy of consumer devices in estimating specified outcomes, such as step count, have tended to concentrate on healthy populations (Wendel et al., 2018). Though such studies have generally indicated good agreement between the selected physical activity outcome parameter and criterion measure (such as step counts versus visual observation, Floegel et al., 2017; Paul et al., 2015) there are still instances in which accuracy is compromised. Slowing of walking speed has been found to be associated with a decline in accuracy (Simpson et al., 2015). For example, Ehrler et al., (2016) compared the step count accuracy of three different wrist-worn pedometers. The authors found that at a walking speed of 0.8 meters per second (m/s) only one device exceeded 50% for mean relative errors (when comparing device step count vs observed count), whereas at the slower walking speed of 0.4 m/s the percentage of errors exceeded 50 for all three devices. This is particularly important to note given that fitness trackers have potential to encourage behaviour change regarding physical activity levels for populations that are known to spend a large amount of time being sedentary, in particular the elderly and people with chronic conditions (Preusse et al., 2017; Sullivan & Lachman, 2017). Both of these populations are also known to have impaired mobility, thus potentially reducing walking pace. Therefore, despite the advantages of consumer-grade devices, an alternative is perhaps necessary for more accurate tracking of movement in populations likely to move at slower speeds.

Research-grade accelerometers differ from consumer-grade trackers in that they measure and store raw acceleration data that can be translated into different movement parameters, such as intensity, frequency and duration of physical activity (Berlin et al., 2006). Examples of research grade accelerometers devices include GENEActiv (Activinsights Ltd.), ActiGraph GT3X+ (ActiGraph Ltd.), Axivity AX3 (Axivity Ltd.), and ActivPAL Micro4 (PAL technologies). Research-grade devices allow for greater flexibility in terms of body wear location. Using a belt or Velcro strap the accelerometer may be attached to the ankle, hip, back or wrist. Placement of the accelerometer will often depend on the movement parameter of interest (see Migueles et al., 2017 for a comprehensive review) and the wear-time protocol of the study. For example, in a sample of healthy adults a wrist-worn accelerometer was shown to be superior in predicting activities that involved arm movements, such as household activities (laundry, dusting and dish washing), whereas a hip-worn device was predictive of locomotive activities, such as walking and running (K. Ellis et al., 2014). However, a higher average predictive accuracy of physical activity behaviour (based on 8 different activities, including both household and locomotive) was found for the wrist compared to the hip (80.2% and 70.2%, respectively; K. Ellis et al., 2014). These findings highlight the usefulness of wrist placement when an individual’s movement includes the different types of activities (locomotive and household) undertaken in free-living environments.

Wrist-worn accelerometers may also be preferable for use in research where the participant is required to wear the device for an extended period of time. The ease of putting on and removing a wrist-worn device, in addition to the similarity with wearing a watch in terms of comfort, are likely to be factors that contribute to wear-time compliance (Tedesco et al., 2017). Huberty et al., (2015) compared the acceptability and wear-time compliance for different models of accelerometers (GENEActiv, ActiGraph and SenseWear) worn at different body locations (wrist, hip and upper arm, respectively). Participants, a sample of inactive women, were asked to wear each device for 24 hours/day for seven consecutive days. A satisfaction survey completed at the end of the study indicated that 95% of the participants felt the GENEActiv device was easy to wear and preferred the wrist placement to hip placement (for the ActiGraph). The authors also report high wear-time compliance for the GENEActive device, with all participants wearing the monitor for the full 7 days and 95% wearing the device for all 6 nights. A lower compliance rate was found over the 7 days for the SenseWear and Actigraph (75% and 62%, respectively). Higher daily wear-time for a wrist compared to a hip-worn device has also been reported in a study with children (McLellan et al., 2018). While there are several studies that have investigated the experiences of older adults using wearable devices, these have predominantly used consumer-grade devices (The Withings Activité Pop and Jawbone UP3; Ehn et al., 2018, Misfit Shine and Fitbit Charge HR; Farina & Lowry, 2017, Fitbit One; McMahon et al., 2016). Though there are some similarities between consumer and research grade devices, most consumer-grade devices provide real-time feedback on physical activity levels, whereas many of the research-grade devices do not. For example, the GENEActiv Original does not have an interactive user interface. Many of the studies exploring the acceptability of consumer-grade devices focus on the participants experience of the interactive features (Ehn et al., 2018; Farina & Lowry, 2017). Therefore, the findings of these studies are often not applicable to researchers that wish to implement research-grade devices into a study. However, a recent study investigated the experience and satisfaction of older adults with mild dementia in wearing the GENEActiv Original accelerometer on their wrist continuously for a month (Farina et al., 2019). For comparison purposes the carers of the participants with dementia were also asked to wear a device for the same time period. Satisfaction was measured using the Quebec User Evaluation of Satisfaction with Assistive Technology and via interview. The results indicated that 89% of the participants with dementia wore the device for the full month, compared to 86% of the carers. Participants were required to wear the device for a minimum of thirteen hours each day for the data to be classified as a valid day. The percentage of valid days was found to be similar between the two participant groups (98% for dementia and 100% for the carer), in addition to the average wear-time (23.1 hours/day for dementia group and 23.8 for the carer group). The results of this study suggest that people with a neurodegenerative condition are likely to comply with wearing an accelerometer on the wrist over an extended period of time and that the level of compliance may be as high as found for healthy adults.

The number of planes in which movement is measured can range from uniaxial to triaxial and varies between models of accelerometers. The GENEActiv Original, the device used throughout this thesis, is a triaxial accelerometer meaning that raw acceleration data is measured across three planes (X, Y and Z) by 3 internal accelerometers positioned at 90 degrees from one another (Berlin et al., 2006). Studies exploring physical activity in people with Parkinson's have tended to focus on translating the raw acceleration data using specified values (cut-points) to classify the data according to a chosen parameter. For example, using cut-points to categorise the intensity of a movement (Boucard et al., 2019; Ellingson et al., 2019; Porta, Pilloni, et al., 2018) and tracking the number of steps taken (Cavanaugh et al., 2015; Stack et al., 2018; Warlop et al., 2017). Therefore, the data obtained through research-grade devices allows for greater flexibility in terms of data analysis and offers researchers the possibility to develop population specific metrics, such as for those who move at a slower pace (e.g. populations with gait impairments, such as Parkinson's). However, cut-points are specific to the population from which they were developed, in addition to the wear location of the device (i.e. wrist) used to generate the values. Therefore, to increase the accuracy of intensity level classification, such as light or moderate activity, researchers often try to use cut-point values derived from a study that included the same population, brand of device and device wear location (i.e. a Parkinson's population and a GENEActiv waist-worn device). However, the availability of published cut-points for all possible wear locations for all brands of accelerometer is limited. Currently, there are no published cut-point values for the GENEActiv Original validated for the use with people with Parkinson's and device placement on the wrist (Porta, Pilloni, et al., 2018). As an alternative researchers have primarily used the following: implement cut-point values derived from the correct population but a different wear location to that being used in their study (i.e. Porta, Corona, et al., 2018), or use cut-points derived from a different population (often older adults) but from the same wear location (i.e. Coe et al., 2018; Loprinzi et al., 2018). There is some evidence to suggest that the cut-point values validated for people with Parkinson's for activities of different intensities are lower compared to older adults (Nero et al., 2015) and differ to other neurodegenerative conditions (Motl et al., 2009), however such research is limited. Therefore, the need for the development of cut-point values that are specific to a Parkinson's population derived from a wrist-worn accelerometer is addressed in Chapter 5 of the current thesis.

Rather than use cut-points, some studies have used the sum of vector magnitudes (svm), a metric that can be obtained from the raw acceleration data, as a measure of physical activity. Of the studies that have used magnitude counts as a proxy for physical activity, Wallen et al. (2015) used svm to calculate the volume of activity undertaken per minute and per day, alongside other parameters of movement, to explore the activity levels of people with Parkinson's over the course of a week. The results showed a non-significant trend towards higher vector magnitude counts per minute and per day at the weekend compared to during an average weekday, thus indicating greater activity levels during the weekend. The study did not include a control group, however the authors indicated that the levels of activity by the people with Parkinson's were similar to that of controls, albeit from other studies (Lord et al., 2013; van Nimwegen et al., 2011) rather than a direct comparison. However, one of these comparison studies used a self-reported assessment of physical activity (van Nimwegen et al., 2011) and the other study used an accelerometer to measure total time spent walking per day and classified this as volume (Lord et al., 2013). The advantage of flexibility to translate accelerometer-derived data into several movement parameters has consequential limitations on the ability to compare studies. Reviewing the current literature in the topic area has highlighted the discrepancy in the application of accelerometery, and in particular the selected movement parameters of interest. Though there is an increasing body of research implementing accelerometry, greater conformity between the methods and application of devices between studies is needed to help with interpretation of findings.

An alternative use of svm has been to explore the benefits of an intervention on physical activity. For example, Nero et al., (2019) investigated the effect of a 10-week balance training programme (60 minutes, 3 times per week) on the total physical activity levels of people with Parkinson's (n = 51) compared to a care as usual group (n = 49). Hip-worn accelerometers (Actigraph GT3X+) were used to measure the total vector magnitude counts (a proxy for total physical activity), in addition to the frequency and time spent walking and sedentary bouts. Participants wore the device for seven consecutive days before and after the programme, in addition to 6- and 12-month follow-up. The results indicated a significant reduction in total physical activity (baseline; 292475 and 280835, 12-months; 253270 and 270882, control and intervention, respectively) and increase in sedentary behaviour over time, however no significant interaction was found between group and time for either outcome measure. The authors also found a significant interaction of group and time for minutes of brisk walking when comparing baseline to post intervention and 6-month follow-up, in favour for the balance programme. However, this interaction effect was not found at 12-month follow-up, indicating a return to baseline activity levels for the balance group. These findings suggest that the balance training had a positive effect on the amount of brisk walking, but not on total physical activity, for up to 6 months after the intervention. Furthermore, the results demonstrate the efficacy of accelerometry in tracking long-term changes in physical activity of people with Parkinson's.

Many studies provide a transient insight into the movement parameters of people with Parkinson's. However, within the literature there is increasing use of accelerometers to measure the amount of movement made over a sustained period of time, such as Nero et al., (2019). Such studies have sought to gain a more comprehensive understanding of the pattern and level of physical activity of people with Parkinson's during and after participation in a health intervention (aerobic exercise; Coe et al., 2018, walking; T. Ellis et al., 2019, balance; Nero et al., 2019, physical therapy; van Nimwegen et al., 2013). The ParkFit study (van Nimwegen et al., 2013) is an example of the use of accelerometers to evaluate the effectiveness of a two-year behavioural change programme aimed at increasing physical activity in people with Parkinson's (*n* = 255). The intervention involved physical therapy and coaching sessions and was compared to a control physiotherapy programme. The primary outcome measure was seven-day recall of physical activity, assessed using the LAPAQ at baseline and then every six months over the two-year period. Physical activity (translated into kilocalories per day; kcal/day) was measured using an accelerometer over a 14-day period every 6 months as a secondary outcome. Physical fitness was assessed using the six-minute walk test. The results indicated there was no significant difference between the participant groups in terms of hours per week spent being physically active as assessed using the LAPAQ. However, the results of the accelerometer data showed a significant difference between the two participant groups in terms of mean change in kcals/day from baseline compared to 6-24 months, such that the participants receiving the ParkFit intervention showed an increase in physical activity levels, whilst controls showed a decrease. An increase in physical fitness, as measured by the six-minute walk test, was also found for the ParkFit group between 12 and 24 months. Though accelerometers were used as a secondary measure of physical activity, the results suggest that this outcome measure was more accurate at detecting changes in activity levels than the LAPAQ. Specifically, the LAPAQ relied on the participant being able to accurately recall his/her activities during the previous seven days. As previously mentioned, people with Parkinson's often report impaired concentration and memory as a non-motor symptom that significantly impacts on QoL (G.W. Duncan et al., 2014). Therefore, questionnaires and interviews may not be the most appropriate measures of physical activity with people with Parkinson's due to such impairments. Accelerometers are likely to provide a more accurate assessment of physical activity over a sustained period of time, thus their use as a primary outcome measure may be more valuable, particularly when used in conjunction with physical assessments of fitness.

Accelerometers have also been effectively implemented in the assessment of specific motor symptoms of Parkinson's, such as monitoring changes in tremor and bradykinesia (Salarian et al., 2007) and the detection of FOG (Rodríguez-Martín et al., 2017). Warlop et al., (2017) used an ankle-worn uniaxial accelerometer (Vitaport 3 ambulatory recorder) to assess differences in gait variability and spatiotemporal gait variables (i.e. gait speed, cadence and step length) of 14 people with Parkinson's and 10 age-matched controls during a normal and Nordic walking session. While wearing the accelerometer, participants undertook two bouts of 12-minute walking around an oval indoor track using Nordic poles for one of the sessions. The authors found significant differences for several of the parameters in favour of the Nordic walking session (greater magnitude of stride duration variability, increased step length and reduced gait cadence) when compared to the normal walking session, however there was no effect of group. These findings suggest that Nordic walking had a similar effect on the measured parameters of gait in both people with Parkinson's and healthy controls, thus both groups may benefit from such an intervention. Though the results demonstrate the feasibility and sensitivity of accelerometers to capture pre-post intervention changes in several parameters of gait, from these findings it is not known how the accuracy of the accelerometer-derived measures of gait compares to other clinical assessment tools (such as the GAITRite). Furthermore, it is not clear whether accelerometer-derived parameters of movement are sensitive to group differences.

One of the studies that has examined the efficacy of an accelerometer compared to a clinical assessment is by Weiss et al., (2010). Seventeen older adults with Parkinson's and 15 age-matched controls wore a tri-axial accelerometer (the Mobi8 system) on the lower back while performing two trials of the Timed UP and Go (TUG), a timed assessment that provides a brief snapshot of an individual's mobility and fall risk at the time of undertaking. The test starts with the individual seated in a chair with back support. The individual is instructed to rise from the chair (sit-to-stand), walk 3 meters, turn to walk back to the chair and finally return to a seated position (stand-to-sit); they are asked to do so in the quickest and safest way possible (Mohamed & Appling, 2020). Performance on the task is typically assessed as the time taken to complete the initial sit-to-stand and return back to the original seated position. In addition to the stopwatch-based performance measure, Weiss et al., (2010) used the recorded acceleration data from the anterior-posterior axis to examine the total duration of the task (time taken between sit-to-stand and then stand-to-sit). The accelerometer-derived TUG duration was found to be significantly higher for the Parkinson's participants compared age-matched controls (10.2 seconds and 8.2 seconds, respectively). Though there was a trend towards a higher stopwatch assessed TUG duration time for participants with Parkinson's (8.7 seconds), this was not found to be significantly different to controls (7 seconds). These findings indicate that accelerometers can be used to capture group differences in mobility, specifically the time taken to complete the TUG. Furthermore, using accelerometer-derived parameters may be more sensitive than standardised tools to such group differences. Several studies have also demonstrated the feasibility and acceptability of accelerometry as a tool to measure physical activity when examining the relationship between specific movement parameters and other variables of interest (self-reported walking difficulties; Leavy et al., 2018, cognitive function; Loprinzi et al., 2018, spatiotemporal and kinematic parameters of gait; Porta, Pilloni, et al., 2018). For example, Loprinzi et al., (2018) investigated the relationship between the time spent at different intensity levels of physical activity and the cognitive function of people with Parkinson's. The authors noted that the participants were adherent to wearing an accelerometer on the waist, with a reported average wear-time of 13.9 hours per day. The results indicated that participants with increased moderate to vigorous physical activity (MVPA) had higher cognitive function, even after controlling for the effect of age, gender, and Hoehn and Yahr score. Specifically, a 10 minute per day increase in MVPA was associated with a one unit increase in score on the Montreal Cognitive Assessment. The authors note the benefit of using accelerometry as an objective measure of activity, however they also highlight that a limitation of using the devices is that there is no context regarding the type of activity, the location and whether it was undertaken individually or part of group. The use of self-report activity diaries or other activity questionnaires, such as the LAPAQ as used by van Nimwegen et al., (2013), alongside accelerometers may be a more useful approach.

Questions regarding the optimal dose, intensity, volume of exercise and length of a dance intervention remain to be sufficiently addressed in the literature. Most studies reviewed in this chapter detail the frequency of classes and length of the intervention, however few make reference to or measure the intensity of the dance classes even though evidence suggests this is a contributing factor to positive outcomes on certain measures, such as depression (Dunn et al., 2001; Mumba et al., 2020). There is some evidence to indicate that people with Parkinson's may benefit from dance even if they cannot actively participate in all parts of the class (Hackney & Earhart, 2010a), however engagement in terms of the volume of movement performed in the classes is rarely accounted for in the literature reviewed. Therefore, it is difficult to draw any conclusions about whether the volume of movement is an important contributing factor to the benefits of dance. Understanding the contribution of volume of movement is particularly important given the physical decline associated with disease progression. Low outcome expectancy from exercise has been identified as a significant barrier to exercise in people with mild to severe Parkinson's (T. Ellis et al., 2013). Lastly, the outcome measures used in the studies focused on assessing changes in mobility only provide a snapshot of the participant's functional ability at the time the test is administered (e.g. McNeely et al., 2015; Rawson et al., 2019; Romenets et al., 2015). For the majority of studies reviewed the outcome measures were completed before and after the dance intervention. These measures are limited in that they provide no insight into the participants' mobility in the days and weeks directly following a dance class. The reviewed evidence indicates that accelerometers may be feasibly implemented to address some of the abovementioned limitations. Specifically, a wrist-worn device is likely to be acceptable to people with Parkinson's and can be used to objectively measure various parameters of movement over both a short and extended period of time.

1.3 Aims of the current thesis

Reviewing the literature has demonstrated that wearable technology is increasingly being applied to novel areas of Parkinson's research. There is evidence to indicate that both accelerometers and fitness trackers provide an objective, yet non-invasive, way of quantifying the volume of activity made by an individual (Eslinger et al., 2011) and may be feasibly applied to exercise interventions. However, as discussed in this chapter, there are several advantages to using research-grade accelerometers, such as the flexibility of wear location and data processing. This flexibility affords the researcher more options in terms of study design (i.e. using accelerometers to measure/track movement or to develop cut-point values) and greater choice regarding the movement parameters of interest. To this end, the current thesis uses the GENEActiv Original, a widely used research-grade device (pulmonary fibrosis; Atkins et al., 2018, older adults; M.J. Duncan et al., 2019; Lim et al., 2018, Parkinson's; Delextrat et al., 2016; Jaywant et al., 2016), to measure the movement of people with and without Parkinson’s. The device specifications are provided in section 2.1.4.1).

The use of the accelerometers has been predominantly limited to aerobic exercise interventions and tends not to include assessment of movement during the intervention itself. Therefore, there are few studies measuring the pattern and levels of activity of people with Parkinson’s while they participate in exercise classes, such as dance. In particular, it is not clear from the literature reviewed the extent to which people with Parkinson’s are able to engage with exercise sessions and whether this is an important factor for positive physical and psychological effects. Furthermore, few studies have considered how accelerometer-derived movement parameters, such as volume and intensity, compare between exercise interventions (i.e. yoga and dance) and the relationship these parameters may have with other health related outcomes. Before such comparisons can be made, the first step is to investigate whether it is feasible to use accelerometers to track the movement of people with Parkinson’s during a dance class and to explore how the pattern and volume of movement compares to those without Parkinson’s. Hence, Chapter 3 of this thesis aims to address this gap in the literature and uses a wrist-worn GENEActiv accelerometer to measure the volume of movement made by people with and without Parkinson’s during a dance class.

Accelerometers have been shown to be a useful tool for the long term, continuous assessment of movement, particularly over the hours and days following participation in an exercise intervention (Coe et al., 2018; T. Ellis et al., 2019; Nero et al., 2019). Thus, accelerometers have the potential to provide a more detailed insight into the volume and pattern of movement of people with Parkinson’s after taking part in dance than the pre-post measures used in the dance studies reviewed in section 1.2.4. However, accelerometry has yet to be implemented in such a way. People with Parkinson’s anecdotally report maintained movement following participation in a dance class, however there are no studies to date that have investigated whether using an objective measure of movement supports these reports.

Therefore, Chapter 4 of this thesis investigates the viability of using an accelerometer to measure the volume and pattern of movement over the week following participation in a dance class.

As discussed in section 1.2..5 above, the studies using accelerometers to measure movement and physical activity of people with Parkinson's have used devices that have not been calibrated for use with this population (Dontje et al., 2013; Wallen et al., 2015). When analysing the data, the authors used cut-points (values derived from the accelerometer output used to classify the intensity of a given activity, for example sedentary, light, moderate or vigorous) generated from a sample of healthy adults. There are certain motor features of Parkinson's that are unlikely to be represented in a sample of older adults, therefore cut-points generated from a Parkinson's population may differ to those from healthy older adults without motor impairments. However, to the best of the researcher's knowledge, there are no published studies to date that have investigated whether this is the case. Furthermore, the GENEActiv accelerometer has not been validated for use with people with Parkinson's on the wrist. Hence, Chapter 5 of this thesis focuses on the development of threshold values that can be used to interpret intensity of movement for people with Parkinson's using a GENEActiv wrist-worn accelerometer.

2. Chapter 2

2.1 General methods

This chapter details common methodological procedures used for each of the experimental studies presented later in this thesis. Methodologies relevant to specific studies are detailed in the associated chapter.

2.1.1 Participant recruitment

2.1.1.1 Recruitment strategy

People with Parkinson's were recruited via convenience sampling for Chapters 3-5. For chapter 4 two groups of participants with Parkinson's were recruited, a group that attended dance classes (PD-D) and another that did not attend classes (PD-C). Age-matched controls without a diagnosis of Parkinson's were recruited for Chapters 3-5 and young adults without a diagnosis of Parkinson's were recruited for Chapter 3.

A variety of recruitment methods were used. For chapters 3-5 people with Parkinson's and age-matched controls were recruited from the University of Hertfordshire Dance for Parkinson's classes (class details provided in section 2.1.3) and word of mouth. The researcher attended the dance classes most weeks to gain familiarity with the attendees and to talk to the class about the different research projects. The majority of participants were regular attendees, though no information was formally recorded about length of time spent attending the dance class. For chapters 4-5 the Parkinson's UK Research Support Network provided assistance with the recruitment of people with Parkinson's from Hertfordshire and surrounding counties, such as Bedfordshire, Cambridgeshire and Buckinghamshire. The Parkinson's UK Research Network advertised the research through several channels, including their dedicated website and social media. The researcher also distributed leaflets to aid recruitment of people with Parkinson's and age-matched controls for chapters 4-5. Previous participants who had agreed to be part of a research database at the University of Hertfordshire were also contacted about each study. For chapter 3 the young adults were opportunistically recruited from students studying at the University of Hertfordshire and class helpers at the Dance for Parkinson's sessions. Before research commenced, all participants provided written informed consent.

2.1.1.2 Inclusion and exclusion criteria

For chapter 3 participants with Parkinson's were required to have a diagnosis of idiopathic Parkinson's by a neurologist to be included and the exclusion criterion was a diagnosis of any other movement and/or neurological condition. The exclusion criterion for age-matched controls was a diagnosis of a movement and/or a neurological condition. The same exclusion criterion were applied for the recruitment of young adults as outlined above for the age-matched participants. All three groups of participants were required to attend an hour-long dance class at the University of Hertfordshire and the following refreshment session.

For chapter 4 inclusion criteria for the PD-D participants were a diagnosis of idiopathic Parkinson's by a neurologist and attendance to the Dance for Parkinson's classes at the university. The exclusion criterion was a diagnosis of any other movement and/or neurological condition. For the PD-C group an additional criterion was that they had no previous experience of participating in dance classes; though participants could have experience of and/or be actively participating in other types of activities such as yoga or swimming. The exclusion criterion for age-matched controls was a diagnosis of a movement and/or a neurological condition. The inclusion criterion was attendance to the dance class at the University of Hertfordshire.

For chapter 5 the inclusion criteria for participants with Parkinson's were a diagnosis of idiopathic Parkinson's by a neurologist and ability to walk continuously for 10 minutes without a walking frame or assistant. Exclusion criteria included a diagnosis of another movement disorder, a cardiac or lung condition and known breathing difficulties. For the age-matched control group the inclusion criterion was no diagnosis of a movement disorder. Exclusion criteria was identical to that outlined above for the Parkinson's group except for the movement disorder diagnosis.

<u>2.1.2 Ethical approval</u>

Ethical approval was obtained for each study from the University of Hertfordshire Health, Sciences, Engineering & Technology Ethics Committee with Delegated Authority prior to recruitment. Written informed consent was provided by all participants prior to taking part.

The protocol number for chapter 3 and 4 is: aLMS/PGR/UH/02222(3). The protocol number for chapter 5 is: aLMS/PGR/UH/02721(2).

2.1.3 Dance for Parkinson's classes

Reported here is the structure of a weekly hour-long dance class for people with Parkinson's that has been taking place Friday mornings on the de Havilland campus at the University of Hertfordshire for approximately 5 years. The dance classes include a range of dance styles over the course of a singular session, such as samba and waltz, performed to music. A qualified dance teacher with 20 years' experience of ballroom and Latin dance leads the sessions at the University of Hertfordshire, as well as teaching several other classes across neighbouring counties. The class has been developed based on the teacher's conversations with occupational and physiotherapists, in addition to learnings from attending conferences and workshops on movement therapies for Parkinson's. The teacher's methods include improvisation, the use of imagery, repetition and cognitive tasks, which are incorporated into the sessions to support functional abilities. For example, action observation and motor imagery are used to facilitate movement in the class. Recent research has demonstrated that combining the observation of an action and imagining the same action (in addition to sensations associated with making the movement) may lead to increased imitation of hand movements in people with Parkinson's (Bek et al., 2019).

During the dance classes at the university the dance teacher will ask the attendees to imagine holding a beach ball and throwing it to other members of the class. The teacher will also demonstrate these actions while the class are instructed to imagine holding their own beach ball. The teacher also includes activities that require improvisation to encourage creativity and divergent thinking. Sitting in pairs, the individuals are asked to take it in turns to perform a sequence of 4-6 hand movements which their partner must then copy. A mirroring exercise is also included in each class which is performed to Swan Lake by Tchaikovsky. One individual from the pair moves their arms in time with the music, spontaneously generating the movements, whilst the other person copies. After about a minute the individuals swap roles. Research has indicated that participation in ten sessions of improvisational dance may lead to improvements in divergent thinking (thinking that allows for multiple answers or new ideas when there is not a singular solution; Colzato et al., 2013), in addition to QoL (C. Lewis, 2012).

2.1.3.1 Class structure

Each dance class was an hour long and incorporates individual movements, as well as pair and group work. The class consists of six phases, starting with a warm-up and ending with a cool-down (see Table 2.1). The structure of the class is typically the same each week, however routines may vary between sessions. The dance teacher will often introduce a new routine at the start of a term by demonstrating some initial steps. The routine is then built upon over the following few weeks and repeated most weeks.

Following each dance class was an hour-long rest session where the class attendees sat and engaged in conversation with each other whilst the volunteers served refreshments. Once the refreshments had been served the volunteers sat with the class attendees. As with the dance session, having the volunteers present for refreshments gave the class attendees a chance to socialise with different people. In particular, it was a chance for the partners of the people with Parkinson's to spend time talking with others and take a break from any caring duties they may have.

Table 2.1 Structure of a dance for Parkinson's class.

Phase	Time	Movements
Warm-up	10-15 minutes	Initiated by 2-3 minutes of marching around the room accompanied by traditional march music (i.e. the Radetzky march). Group is then guided through several seated stretches (such as a hamstring stretch and spinal twist), in addition to sequences of finger movements, switching and dual tasking.
Dance steps. Performed alone or in pairs and seated or stood (depending on the individual's mobility and balance).	10-15 minutes	Different sets of steps are performed to music. E.g. a basic step from the style of salsa dancing is selected and paired with music. This movement is then repeated for a small duration of the music. The dance teacher typically selects 2-3 different routines which are performed back to back.
Paired seated activities	10 minutes	In pairs, facing each other, attendees take part in various clapping and mirroring routines. The routines are timed to music and involve copying movements dictated by the teacher, in addition to replicating the movements demonstrated by their partner.
Group activities. Performed seated or stood (depending on the routine and the individual's mobility and balance).	5-10 minutes	The group either stay seated or stand in a semi-circle facing the teacher to perform a couple of routines, such as the Hokey Cokey, Macarena or Hand Jive.

Learning and performing a dance routine. Generally performed stood, though some may stay seated.	5-10 minutes	The group perform several dance routines as demonstrated by the dance teacher. Each routine involves different movements and music. E.g. One routine uses movements inspired by Bollywood dance and these movements are paired to the soundtrack Jai Ho by A.R. Rahman and The Pussycat Dolls.
Seated cool down	5 minutes	The teacher leads the group through some gentle stretches.

2.1.4 Materials

2.1.4.1 Activinsights GENEActiv Original accelerometer

The GENEActiv Original is a commercially available, research-grade model of accelerometer manufactured and distributed by the company Activinsights. The accelerometer is a tri-axial waterproof device than can be worn on different locations on the body to continuously assess acceleration over a period ranging from 7 days at 100 Hz to 45 days at 10 Hz (measurement frequency). The device does not have a screen and all data is contained within the accelerometer such that it can only be accessed once connected to a USB port and downloaded to a computer with the GENEActiv software installed (see appendix 1 for device specifications). The accelerometer is provided with a wrist strap, but the configuration of the device can be altered to accommodate different bodily locations. Dependent on the location of the device the orientation of the accelerometer needs to be adjusted accordingly. When collecting data from the wrist the device is worn like a watch such that the serial numbers on the face of the accelerometer can be read by the wearer. The gold pins of the device will be orientated upwards or downwards depending on the wrist it is being worn, see Figure 2.1 and 2.2 .

2.1a

2.1b

2.1c

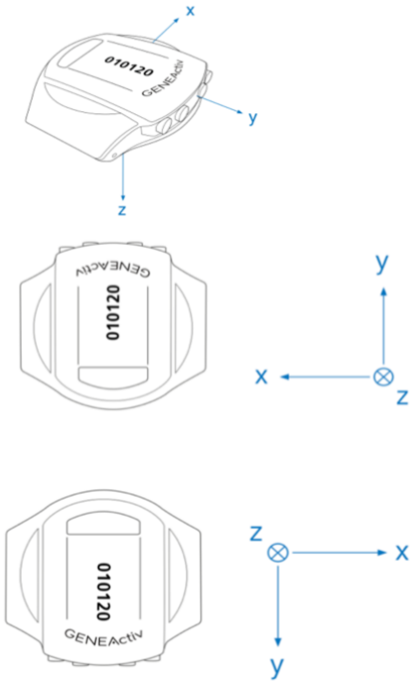


Figure 2.1 Diagram of the orientations of the accelerometer depending on wrist location.
2.1a. The orientation of the device as it would appear to the wearer, 2.1b The orientation of the device to an observer when on the right wrist of a participant, and 2.1c. The orientation of the device to an observer when on the left wrist of a participant. Sourced from Activinsights Ltd, (n.d.)

2.2a. 2.2b.

Figure 2.2 The GENEActiv Original is a small, watch-like device.
2.2a. The device comes with an artificial rubber strap designed for wear on the wrist, though this can be changed to a fabric strap for wear on different body locations. 2.2b. The device worn on the right wrist of a mock participant.

2.1.4.1.1 Programming the accelerometer

GENEActiv provide software that allows the user to pre-programme the accelerometer before recording data, such as selecting recording frequency, recording start time and enter the demographic details (e.g. body mass index, BMI; date of birth and gender) of the participant who will be wearing the device. A recording frequency of 100 Hz was used for chapters 3-5. Specifically, for chapter 4 this allowed for 7 days of data to be recorded before the maximum memory capacity was reached.

The user has the following various pre-programming options regarding recording start time: 1) select a defined recording time period, 2) set the device to record on disconnect from the software, or 3) set recording to start on a device button press. Setup of the device through the GENEActiv software included synchronising the internal clock of the accelerometer to the clock of the computer. Activinsights report the accuracy of the internal clock of the device to be +/- 1.7s per day.

2.1.4.1.2 Data extraction and analysis

Different movement metrics can be extracted from the accelerometer using the GENEActiv software. The metric of interest for Chapters 3-5 was the svm, also referred to as vector magnitude counts. The svm is the combination of acceleration across the three different axes of the accelerometer for a specified epoch, generally calculated per minute (Sehgal, 2019), and has been used as an indicator of the volume of activity for people with Parkinson's in a number of studies (Nero et al., 2019; Wallen et al., 2015). Bassett et al. (2015) argue that using svm is a useful approach to investigating the levels and patterns of physical activity because it accounts for the intensity, frequency and duration of movement in a singular metric. Bassett et al. (2015) also suggest that svm is a more accurate representation of body acceleration compared to more distinct metrics, such as step counts or intensity levels, which are derived from statistical methods which have several limitations (these are explored in detail in Chapter 5).

In order to extract the svm data from the accelerometer the device was placed in a cradle connected to the USB port of a computer. The GENEActiv data extraction function allows the user to select a file location and save the recorded data. The software default is to save the data as a compressed .bin which can only be opened using another software package, such as MATLAB. However, the user can programme the GENEActiv software to convert the .bin files to .csv files that can be opened in Excel. A large volume of data is contained within the .bin files (particularly if the device has been used for a seven-day recording protocol), therefore the GENEActiv software provides the option to convert the .csv files into an epoch compressed version (either 1, 5, 10, 15, 30 or 60 seconds). The output of the .bin and epoch compressed files contain the acceleration values for the X, Y and Z axes. The epoch compressed files also includes the values of gravity-subtracted sum of vector magnitudes, which the software calculates using the following equation:

SVMgs = $\sum | (x^2 + y^2 + z^2)1/2$ - 1g |

For Chapters 3-5 the data from the accelerometers were downloaded after each testing session. A separate CSV file was created for each participant containing the time stamped raw acceleration and svm data.

2.1.4.2 Demographic measures

For chapters 3-5, age, sex, handedness, and information regarding current health conditions, such as Parkinson's, were collected via questionnaire (see appendix 2). For those with Parkinson's, additional data was collected regarding age of diagnosis, presence of rest tremor, deep brain stimulation (DBS), symptom specifics and medication details. For chapter 5 information regarding average weekly exercise was also collected.

2.1.4.3 Anthropometric measures

For chapters 4 and 5, height was measured in centimetres using a stadiometer (Seca 217 Stadiometer, Seca, Hamburg, Germany) and weight in kilograms using electronic scales (Seca 799, Seca, UK), both with shoes removed. For chapter 5 measured height and weight were used in the GENEActiv software to calculate BMI (kg/m^2).

2.1.4.4 Modified Hoehn and Yahr Staging Scale (MH&Y, Goetz et al., 2004; Hoehn & Yahr, 1967)

For Chapters 3-5 the MH&Y, a Parkinson's specific measure, was to determine the degree of disability associated with a participant's symptoms of Parkinson's. Degree of disability is measured on a 7-point scale, ranging from stage 1 to 7. The stages progress from the lowest degree of impairment (unilateral presence of symptoms, stage 1), to bilateral presence of symptoms (stage 2), then moving to impaired postural stability (stage 3) to severely affected mobility (stage 4) to finally the highest degree of impairment as indicated by the diminishment of unaided mobility. The original scale developed by Hoehn and Yahr (1967) had 5 stages, but this number was increased in the 1990's to include two 0.5 increments (1.5 and 2.5). These additional stages were added to account for individuals with unilateral symptoms and some indications of postural imbalance that do not meet diagnostic relevance (see appendix 3).

3. Chapter 3

Wrist-worn accelerometer measures of movement by people with Parkinson’s during dance classes.

3.1 Introduction

Valid and reliable instruments to assess movement are key to understanding the impact of exercise on a variety of health outcomes and markers of disease progression in Parkinson’s. Accelerometers are increasingly being used to assess changes in the volume, pattern and level of movement of people with Parkinson’s after taking part in exercise interventions (Coe et al., 2018; T. Ellis et al., 2019; Nero et al., 2019). However, few studies have used devices to measure movement during exercise. Before undertaking such studies, it is necessary to understand the uses and constraints of accelerometers to ensure appropriate implementation. Therefore, the purpose of the current study was to explore the feasibility of using a wrist-worn accelerometer to track the movement of people with and without Parkinson’s during a dance class held at the University of Hertfordshire.

There is one study to date, to the best of the researcher’s knowledge, that has used accelerometry to establish the feasibility of six Zumba Gold® dance sessions for people with mild to moderate Parkinson’s. Delextrat et al. (2016) examined the effect of dance style and session number on the exercise intensity levels, as measured using a wrist-worn GENEActiv accelerometer during the classes. The classes included steps from dance styles including: pop, belly dance, salsa, reggae-ton, cumbia and merengue, all accompanied by music. Exercise intensity was calculated by applying cut-off values (taken from Esliger et al., 2011) to the accelerometer-derived svm data. The average of the total time across all six sessions was greatest for sedentary (77%) activity, followed by 32.6% of the time for light activity and 0.8% of the total time was spent engaging in moderate intensity activity. Participants also wore a heart rate monitor during the dance classes. The high proportion of time spent being sedentary, as measured by the accelerometer, was also reflected in the heart rate measure of exercise intensity which indicated 80.6% of the total time was spent in the very light to light heart rate zone. These findings suggest that using accelerometer-derived measures of exercise intensity are of similar accuracy to those obtained via a heart rate monitor.

Delextrat et al. (2016) also compared the svm for the different dance styles within the Zumba classes and findings indicated a significantly lower svm for the cumbia style compared to salsa. Excluding merengue and reggaeton, svm increased between the first and the last Zumba session for all dance styles. These findings suggest that wrist placement is a valid method for the assessment of body and limb acceleration during dance, in addition to svm being a sensitive metric to detect change between dance styles and progressive sessions.

The authors also concluded that the changes in svm between session indicated the participants learnt how to perform the steps over the 6 weeks. However, without a comparison group or any observational data from the sessions this suggestion is not well evidenced by just the accelerometer data alone. Furthermore, the lack of control group means it is not clear how the svm and time spent in certain activity intensity levels compare to people who do not have Parkinson’s.

To this end, the current exploratory study examined the feasibility of people with Parkinson's, and age-matched and young adults who did not have the condition, wearing an accelerometer on their wrist while taking part in a dance for Parkinson’s class at the University of Hertfordshire and during the following rest hour. The aims of the current study were to i) explore the volume and pattern of movement, measured as vector magnitude counts, made by people with Parkinson’s during a dance class and ii) to compare the volume and pattern of movement made by people with Parkinson’s with adults who do not have the condition.

An effect of session type (dance compared to rest) was predicted. It was expected that the volume of movement would be significantly higher for the dance class compared to the rest session. Given the increased sedentary behaviour of people with Parkinson’s during free-living contexts (Chastin et al., 2010), an effect of group on the total volume of movement was predicted. People with Parkinson’s were expected to have a significantly lower volume of movement across the dance and rest session compared to both age-matched controls and young adults. Young adults were predicted to have a significantly higher volume of movement compared to both people with Parkinson’s and age-matched controls.

3.2 Method

3.2.1 Participants

Twelve people with Parkinson’s (*n* = 9 females *n* = 3 males), 12 age-matched controls (*n* = 7 females and *n* = 5) and 12 young adults who did not have a diagnosis of Parkinson’s (*n* = 12 females) voluntarily participated in the current study. See Table 3.2 in section 3.3 for full demographics.

Three participants with Parkinson's reported having tremor (two on the right side and one on the left). Four participants wore the device on their dominant side, in relation to handedness, and three on their non-dominant side. One participant was ambidextrous and for four participants the wrist on which the device was worn was not recorded. Seven of the age-matched controls wore the accelerometer on their dominant side, four on their non-dominant side and for one participant wrist location was not recorded. Seven of the young adults wore the accelerometer on their dominant side, four on their non-dominant side and one participant reported being ambidextrous. Wrist location and handedness for all participants are presented in Table 3.1.

Table 3.1 Number of participants who wore the accelerometer displayed for wrist location and handedness for each group

		Participant group		
		Parkinson's (n = 12)	Age-matched (n = 12)	Young adult (n = 12)
Wrist location	Left	3	5	3
	Right	5	6	9
	Missing	4	1	-
Handedness	Left	2	-	1
	Right	9	11	10
	Ambidextrous	-	-	1
	Missing	4	1	-

3.2.2 Design

The study was a mixed factorial 3 (participant group: Parkinson's, age-matched and young adults; between subjects) x 2 (session type: dance versus rest; within subjects) design. The dependent variable was the volume of movement measured as the sum of vector magnitudes (svm, as calculated over a 45-minute period).

3.2.3 Materials

3.2.3.1 GENEActiv accelerometer

In the current study, before each testing session the accelerometers (multiple devices used per session) were set to record at 100Hz and to start recording on removal from the docking station. Further details about the accelerometer and device setup are provided in the general methods chapter (section 2.1.4.1).

3.2.3.2 MH&Y

For details about this measure please refer to the general methodology *section* 2.1.4.4.

3.2.3.3 Demographics questionnaire

For details about how participant demographics were collected please refer to the general methodology *section 2.1.4.2.* Demographic measures for each participant group are presented in Table 3.2.

3.2.4 Procedure

Please refer to the general methodology *section* 2.1.3 for specific details about the Dance for Parkinson's classes at the University of Hertfordshire. Due to variations in the routines and movements taught in the dance class from week to week, the participants were invited to participate in the study in triads. Each triad consisted of one person with Parkinson's, one age-matched control and one young adult. Each triad of participants took part in the same dance for Parkinson's class at the University of Hertfordshire, thus providing matched data balanced across the three groups for any variations in the dance routines on different weeks. Participants were fitted with the accelerometer a few minutes in advance of the dance class. Participants wore the device on the wrist of their choosing. The time at which the accelerometer was placed on the wrist, the start and end time of the dance class, were recorded in addition to the end time of the rest session and the time the device was removed. Each participant wore the device for the entirety of the hour-long dance class and the hour-long refreshment session that immediately followed the dance class. Other than wearing the device, participants were not required to do anything other than participate in the dance class.

Some of the routines practised in the dance class required attendees to partner up. Typically, participants with Parkinson's partnered with either their partner or carer, however not all the participants attended the class with someone. In these instances, a volunteer dance partner (usually a student or staff member from the university) would pair with the participant. Therefore, some of the data for the triads was collected from attendees who partnered with each other during the class, though not all individuals of a couple necessarily wore an accelerometer. After the dance class participants stayed for refreshments and continued to wear the accelerometer. Once the participant had finished socialising the accelerometer was removed from their wrist and the data downloaded later that day.

3.2.5 Data extraction and analysis

The .bin files were converted to 60 second epoch compressed files using the GENEActiv software. The volume of movement made by all three of the participants (measured as svm per 60 seconds) of a triad was plotted for the 45 minutes of the dance class. The rest session data were plotted in the same manner. In order to calculate the total volume of movement (measured as svm) for each participant vector magnitudes were summed across 45 minutes of the dance class (excluding the warmup period) and summed separately for the 45-minute refreshment period. Only 45 minutes of data were used for the dance class due to late arrival of some participants, resulting in missing data. The rest session following the dance class tended to be an hour long, however the time spent socialising is very much dependent on what the class attendees have planned later that day. Therefore, on some occasions, the rest session ended earlier as attendees filtered out. Forty-five minutes of data were used for the rest session, as to correspond with the dance class, however the last 15 minutes of the rest session were excluded from the analysis for the reasons outlined above.

Due to the small sample size for each participant group and non-normal distribution of ages, a non-parametric analysis was used to check for between group differences in age. Observation of histograms and Q-Q plots indicated non-normal distribution of the vector magnitude movement data for both the dance and rest session for each participant group. However, no outliers were detected therefore a parametric analysis, specifically a two-way mixed analysis of variance (ANOVA), was run in order to explore whether the volume of movement undertaken by participants differed between the participant groups and the session type. This type of analysis has been shown to be robust in detecting significant differences between means and minimising type 1 error (Blanca et al., 2017). A 3 (group: Parkinson's, Age-matched and Young adult; between subjects) x 2 (session: dance and rest; within subjects) mixed ANOVA was undertaken as. A non-parametric analysis was run to confirm the results of the parametric test.

3.3 Results

3.3.1 Demographics

A Mann-Whitney U test indicated there was no statistically significant difference between the ages of the Parkinson's participants (median =69.00, IQR =14.00) and age-matched controls (median =69.00, IQR =18.00), z =0.12, p =0.91. The ages of the Parkinson's participants were significantly higher (median =69.00; IQR =14) than the young adults (median = 24.00; IQR =6.50, z =-4.16, p =<.001, see Table 3.2 below).

Table 3.2 Demographic measures for each participant group.

Demographic measures		Participant Group		
		Parkinson's (n = 12)	Age-matched (n = 12)	Young adult (n = 12)
Age (years)		67.92 (10.87)	68.33 (10.11)	25.17 (5.10)
Age of diagnosis (years)		60.00 (3.50)	-	-
Years living with the condition		7.92 (6.43)	-	-
MH&Y	Stage 1	3	-	-
	Stage 1.5	3	-	-
	Stage 2	1	-	-
	Stage 2.5	1	-	-
	Stage 3	3	-	-
	Stage 4	1	-	-

All values are means and standard deviations, except for MH&Y scores which are presented as frequencies.

3.3.2 The main effect of session type and group on movement

The results of the two-way ANOVA indicated a significant main effect of session type, F (1, 33) =150.62, p <.001, as indicated in Figure 3.1. The volume of movement made by participants was significantly higher during the dance class (mean =36982.40; SD = 10021.36) compared to the rest session (mean = 14015.64; SD =5973.26; r =1.10). There was also a significant main effect of group, F (2, 33) =5.63, p =0.01, ηp^2 =0.26. Bonferroni corrected post-hoc comparisons indicated that the volume of movement made by the young adults (mean =29815.56; SD =13429.13) was significantly greater compared to both the participants with Parkinson's (mean = 22924.36; SD =16117.27; p =0.01) and the age-matched controls (mean = 23757.15; SD =12259.31; p =0.03). There was no significant difference in the volume of movement made by people with Parkinson and age-matched controls (p =1.00) and no significant interaction between session type and group (p =0.89).

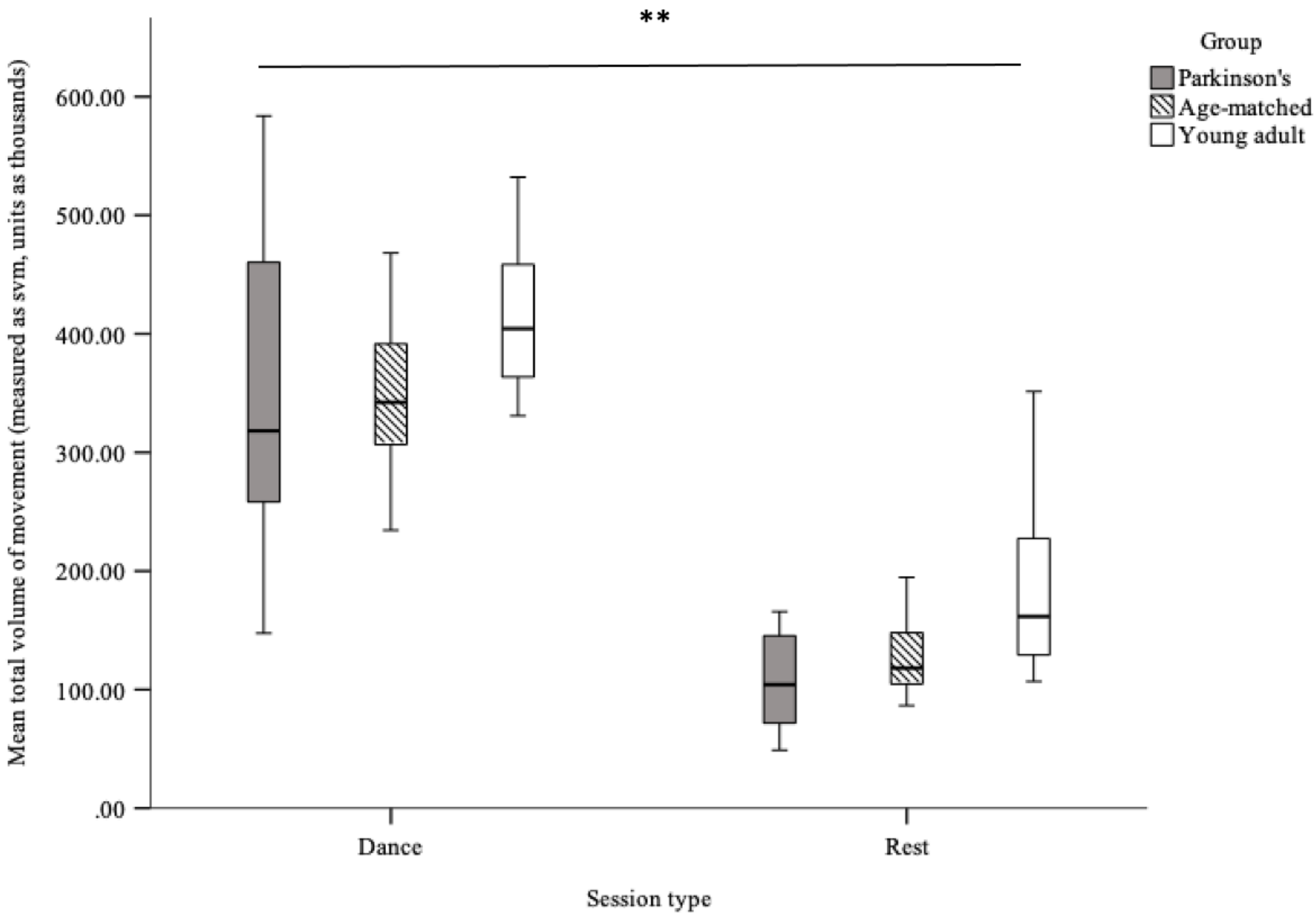


Figure 3.1 Mean values of total volume of movement for the Parkinson's, age-matched and young adult group*s* for the dance and rest session.
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR). The ** indicates p<0.001.

3.3.3 Tracking the movement of participant triads

3.3.3.1 Dance classes

To understand the pattern and volume of movement undertaken by each participant group the sum of vector magnitude data (used as a proxy for movement) was plotted as a line graph for each participant triad, with 12 figures produced in total. Two of these figures are presented below (see Figure 3.2a and 3.2b), the remaining figures are included in appendix 4. The line graphs allowed for the peaks and troughs of the data for each individual of a triad to be visualised and facilitate interpretation of the accuracy of the accelerometer tracking movement.

The approximately synchronous peaks and troughs in the vector magnitude data for each participant of a triad, as seen in both figure a and b, suggest that the participants made the same, or at least similar volume of movement, at the same time points during the class; even for individuals who differed in the severity of their condition (Fig 3.2a MH&Y stage 4; Fig 3.2b MH&Y stage 1). Therefore, inspection of the figures indicates the accelerometer tracked the movement of the participants as they took part in a dance class.

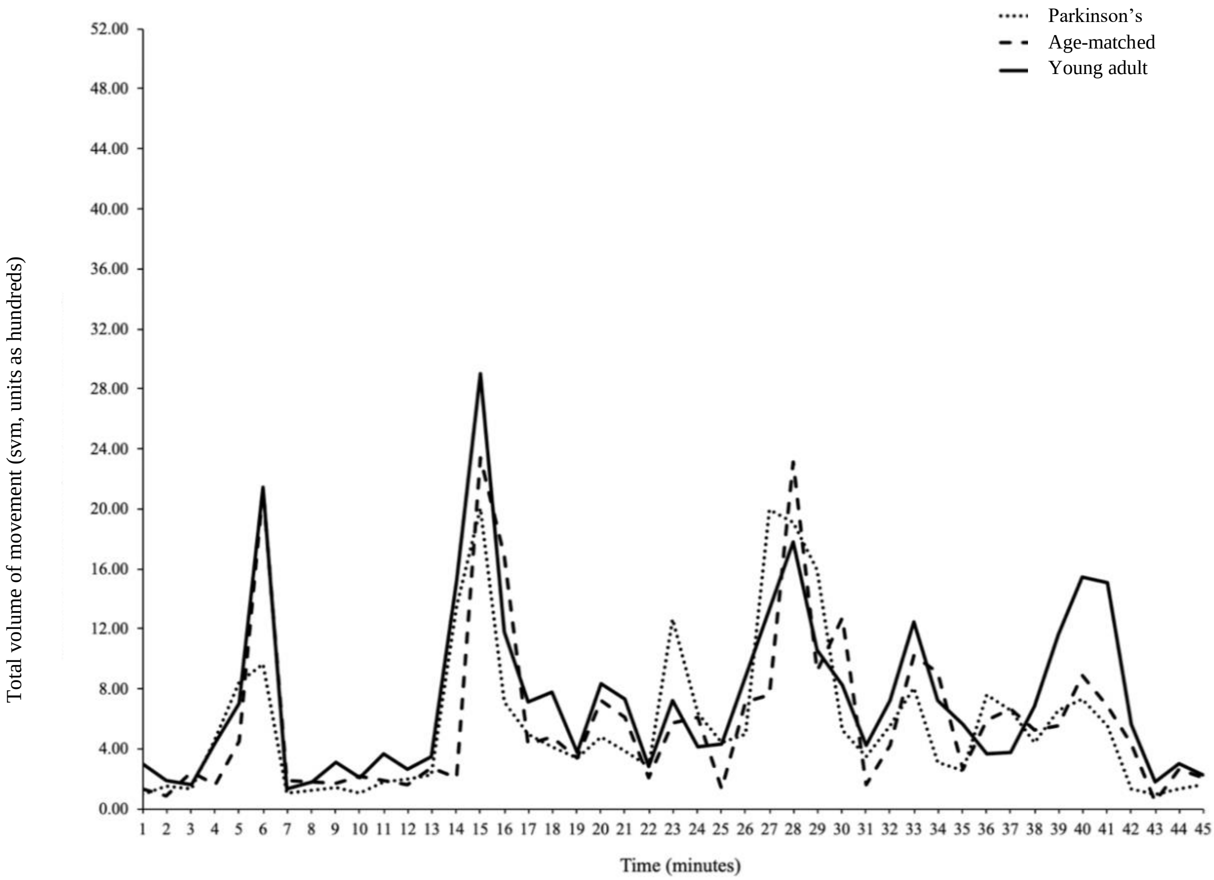


Figure 3.2a The total volume of movement made for each minute of a dance class for a participant triad.
Triad included one person with Parkinson's self-reported MH&Y stage 4, one age-matched control and one young adult without Parkinson's.

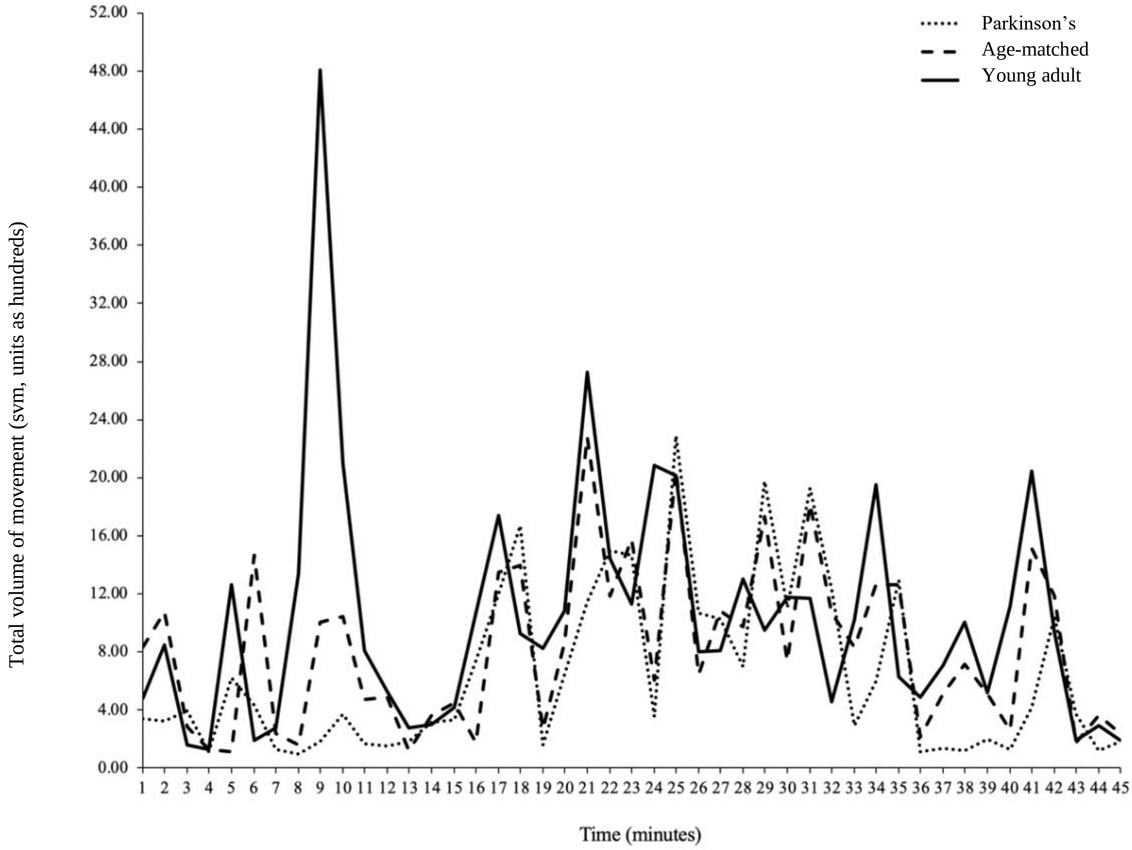


Figure 3.2b The total volume of movement made for each minute of a dance class for a participant triad.
Triad included one person with Parkinson's self-reported MH&Y stage 1, one age-match control and one young adult without Parkinson's.

3.3.3.2 Rest session

Inspection of Figures 3.2c and 3.2d indicate that the peaks and troughs do not occur at the same time points during the rest session for the participants of each triad. This is in line with the nature of the rest session which does not include guided movement, but instead participants may choose to spend their time as they wish. Therefore, the variability in movement patterns between the participants of the same triad is to be expected. The remaining figures are included in appendix 5.

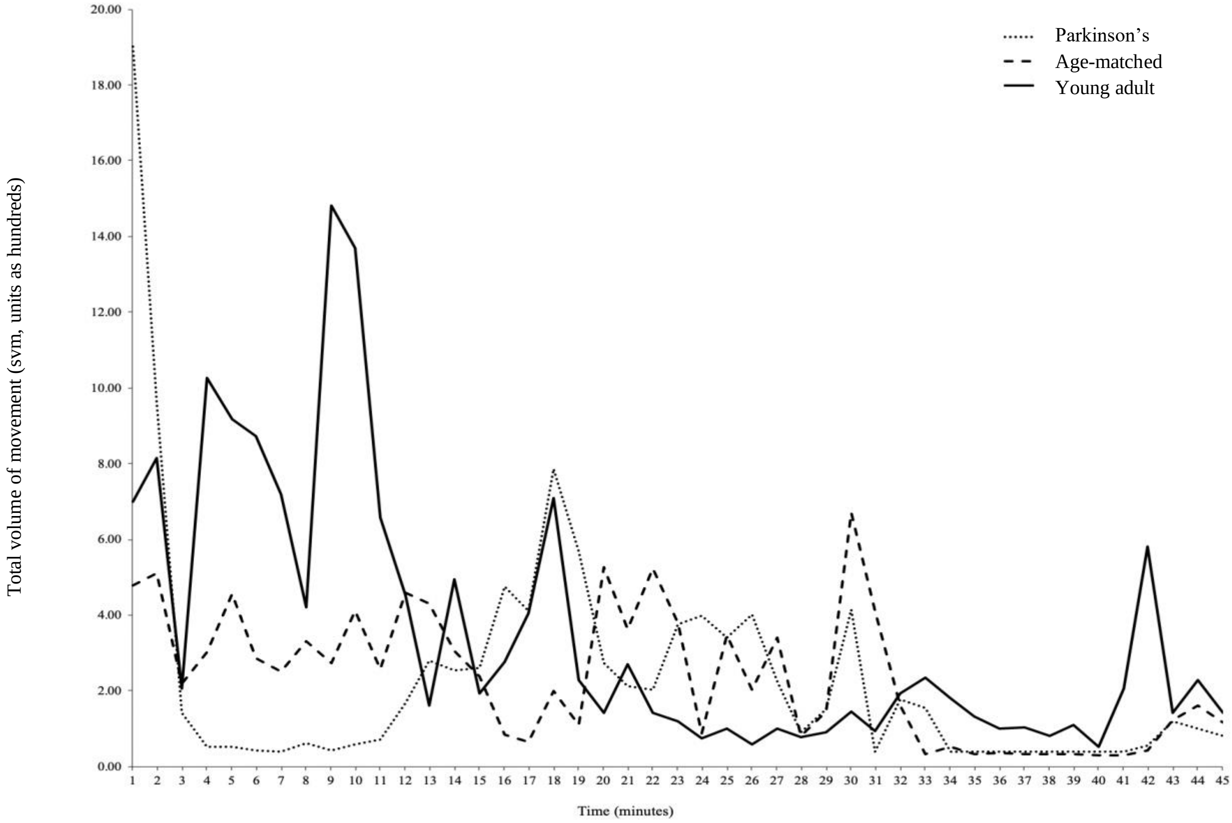


Figure 3.2c The total volume of movement made for each minute of a rest session for the same participant triad as fig 3.2a.
Triad included an individual with Parkinson's self-reported MH&Y stage 4.

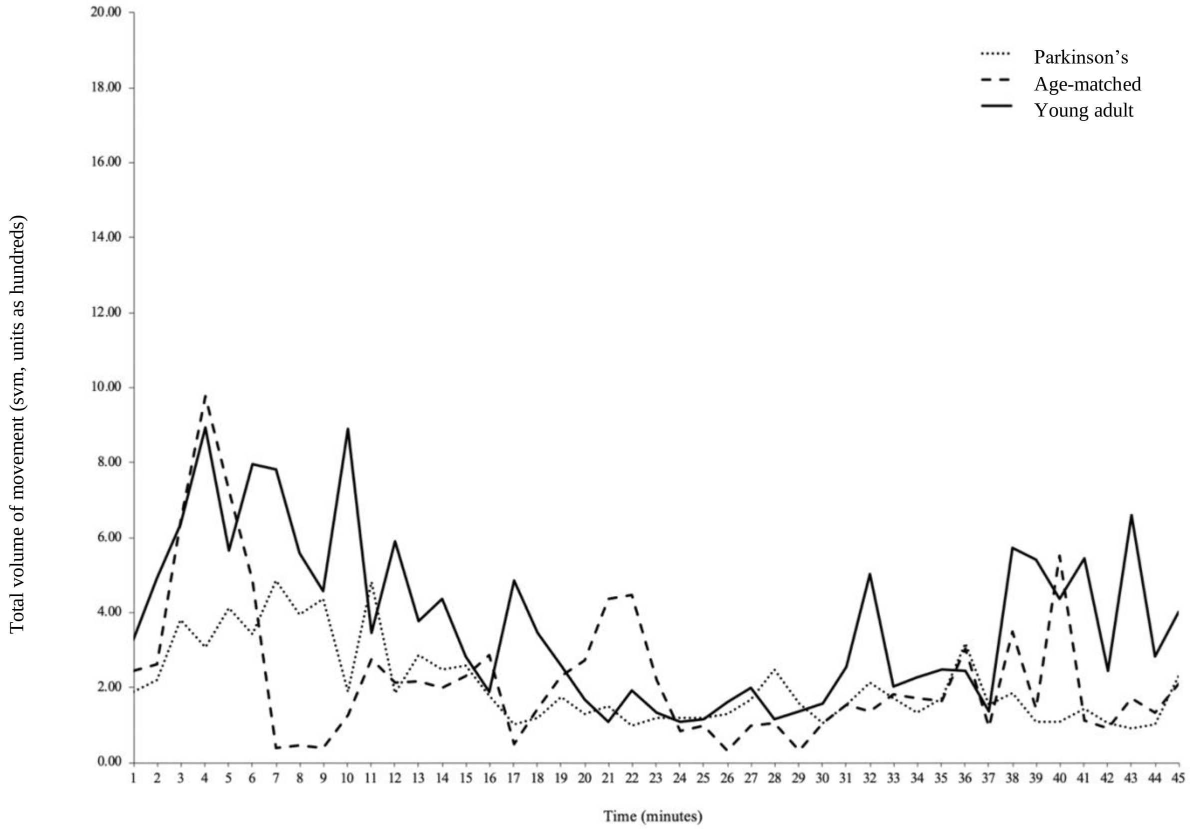


Figure 3.2d The total volume of movement made for each minute of a rest session for the same participant triad as fig 3.2b.
Included an individual with Parkinson's self-reported MH&Y stage 1.

<u>3.3.4 Exploring volume of movement for MH&Y stages</u>

To understand the variability in movement made by participants at different stages of Parkinson's, the sum of vector magnitude data for the dance and rest session was plotted according to MH&Y stage, see Figure 3.3 and 3.4 below. Data were combined for least severe (1 to 1.5), mild (2- 2.5) and moderate (3 and 4) stages of the MH&Y scale. Inspection of Figure 3.3 indicates that the median volume of movement made by individuals with a MH&Y score of 2- 2.5 was similar to those with a score of 3-4. These were both higher than the median for those in stages 1- 1.5 of the condition, thus indicating greater volume of movement made throughout the dance session by those rated as having more severe symptoms. However, as seen in Figure 3.3, a similar range in the volume of movement was found for those in the 1- 1.5 and 3-4 MH&Y stages, whereas this was much smaller for the MH&Y 2- 2.5 group. Figure 3.4 shows a different spread of the data for the rest session, with the smallest range in volume of movement found for the stage 3-4 group. The figure also indicates that the largest range in volume of movement was for the 1-1.5 group, which suggests greater variability in movement during the rest session.

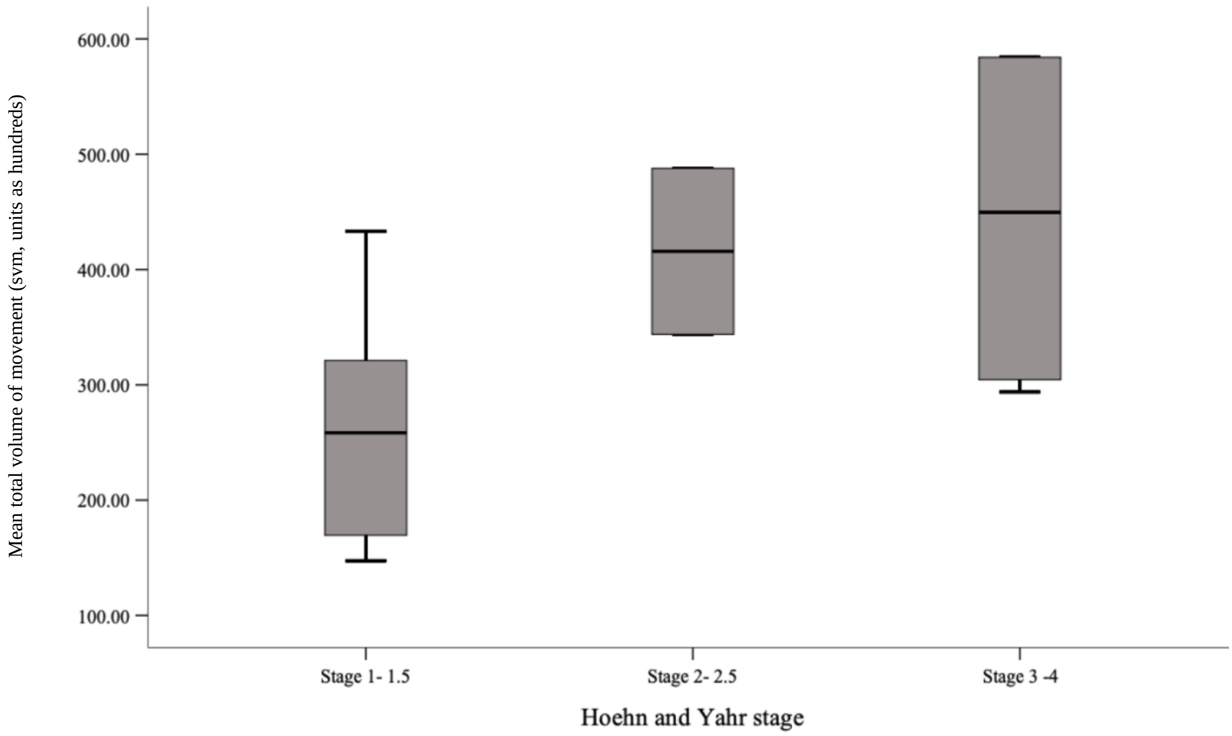


Figure 3.3 Mean values for total volume of movement made by people with Parkinson's during the dance session grouped by Hoehn and Yahr score (stage 1- 1.5, *n* = 4; stage 2-2.5, *n* = 2; stage 3-4, *n* = 4).
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

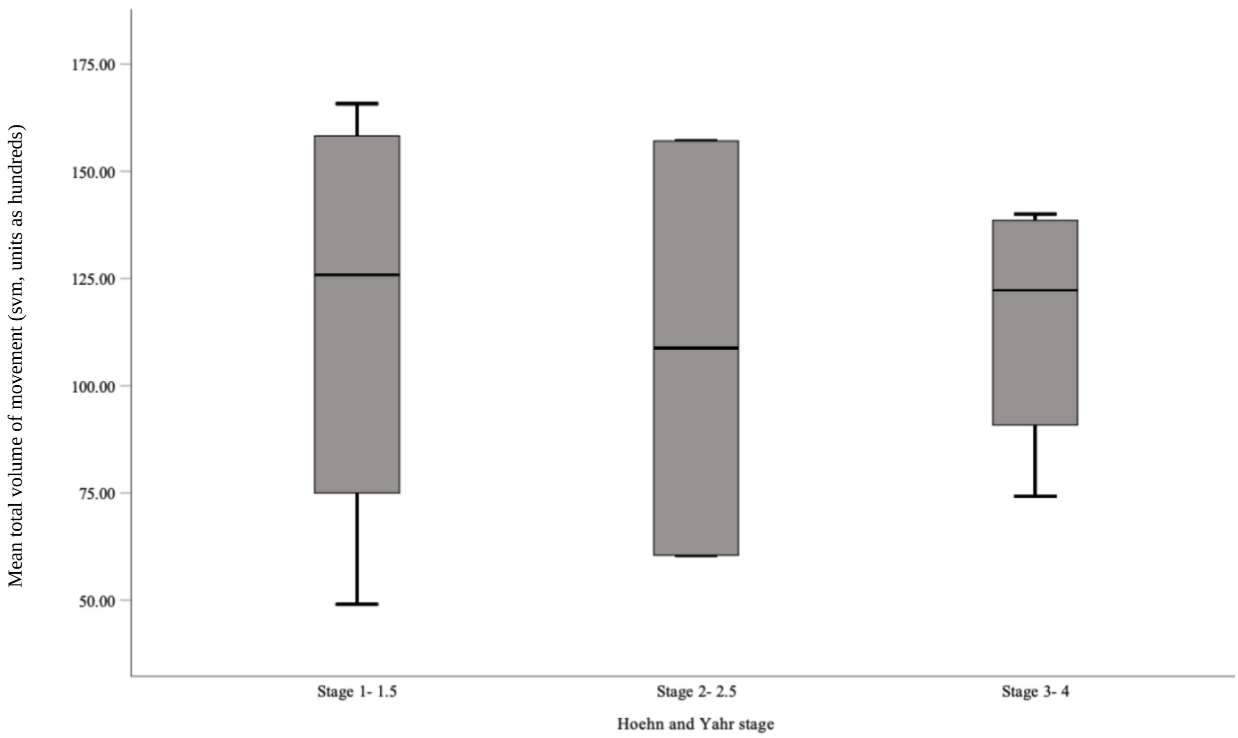


Figure 3.4 Mean values for total volume of movement made by people with Parkinson's during the rest session grouped by Hoehn and Yahr score (stage 1- 1.5, *n* = 4; stage 2- 2.5, *n* = 2; stage 3-4, *n* = 4).
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

3.4 Discussion

In line with the findings of previous studies that have used wrist-worn accelerometers (Delextrat et al., 2016; Farina et al., 2019; Huberty et al., 2015), the results of the current study demonstrate the feasibility and willingness of participants to wear the devices on their wrist throughout the duration of a dance class and rest session. All participants in the current study complied with the two-hour wear-time. Some studies have reported that participants experienced irritation when wearing a device on their wrist (Hermanns et al., 2019). The current study did not find this to be the case with the GENEActiv devices, thus indicating acceptability of the wear location and the feasibility of people with Parkinson's wearing the devices continuously for longer periods of time.

To the best of the researcher's knowledge, the current study is the first to implement the wearable devices to explore the total and pattern of movement made by people with Parkinson's during a dance class. The synchronous pattern of svm data across the dance class for most participant triads provides a good indication that the accelerometer captured the volume of movement made by all participant groups.

It has been argued that using the svm is a more useful approach as it includes several movement parameters, such as intensity and duration, without the need to be translated into another metric where accuracy may be compromised (Bassett et al., 2015). Though the current study demonstrates the usefulness of svm in tracking the pattern of movement over a dance class, there is still a need to express the data in a physiologically meaningful way. Given that the majority of research investigating the physical activity of people with Parkinson's (including exercise interventions and free-living contexts) focus on intensity levels, such as sedentary, light and moderate, it is important that comparisons between findings can be made. In particular, if there is to be an advancement in understanding of the dose-response relationship for exercise and health related outcomes then consistency across studies in the selected movement parameter of interest is needed. Therefore, intensity levels generated from wrist-worn accelerometers might be more insightful way of exploring the data in future studies, however the cut-point values need to be validated for use with people with Parkinson's (see Chapter 5).

In line with the hypothesis, the results indicated that the volume of movement was significantly higher for all participants, regardless of group, during the dance class in comparison to the rest session. Given that the rest session involves participants socialising while being seated, greater movement was to be expected for the dance class. These findings reflect the engagement in movement as visually observed during the dance and rest session, demonstrating that the accelerometers accurately tracked changes in movement across different sessions. The efficacy of using accelerometers to track changes in movement has been demonstrated in several previous studies (Nero et al., 2019; van Nimwegen et al., 2013; Wallen et al., 2015), however most of these illustrate the use of the devices when worn continuously for several days. The present study demonstrates the efficacy of using devices to capture change over a shorter period of time; this is a much needed requirement when applied to the measurement of movement during a specific class where movement levels and patterns are likely to change throughout the course of the session, as demonstrated by the results of the present study.

The second aim of the current study was to investigate whether active engagement (physical) during the classes differs between those with and without Parkinson's. Specifically, it was predicted that the volume of movement would be i) significantly lower for people with Parkinson's in comparison with age-matched controls and young adults irrespective of session type, and ii) significantly higher for young adults in comparison to both age-matched controls and people with Parkinson's, irrespective of session type. The hypotheses were partially supported, such that the results of statistical analysis indicated that young adults had a significantly higher volume of movement across the dance and rest session compared to both people with Parkinson's and age-matched controls. However, the volume of movement was similar for people with Parkinson's and age-matched controls. This similarity is also reflected in the tracking of movement for participant triads. The synchronous peaks and troughs in svm for the Parkinson's and age-matched participants of each triad are suggestive of the same movements of a similar volume. During the dance class participants are engaged in directed activity such that they are likely to be making the same movements at the same time, as supported by the triad data, therefore it is not surprising per se that the Parkinson's participants were no different to controls. However, it is important to note that this had not be explored quantitatively prior to the current study. While these results appear to suggest that people with Parkinson's are able to perform a similar volume of movement to older adults without Parkinson's, it is unknown whether this finding could be due to age-matched controls modifying their movement to mirror that of the person with Parkinson's. Future research should focus on replicating the current study using a non-partnered style of dance in order to provide further insight into whether people with Parkinson's are able to actively engage in dance to a similar level as controls.

It is of interest to note that the svm triad data appears to indicate higher peaks and general volume of movement for the young adults during the rest session compared to the participants with Parkinson's and controls. Given that some of the young adults were volunteers at the dance class and therefore helped with serving refreshments during the rest session, it would be anticipated that their volume of movement differed significantly to the other groups of participants who predominantly spent the time sat and socialising. In contrast, on inspection of the svm triad data for the dance class the peaks and volume of movement seem to be more similar between the individuals of each triad. However, statistical analysis of the svm data did not result in an interaction effect, therefore indicating that the young adults were generally more active across both the dance and rest session. One possible explanation for this could be that using total svm is not a useful way for capturing the difference in pattern of movement for young adults compared to people with Parkinson's. The svm combines several movement parameters into one metric, therefore this might have a diluting effect on distinguishing parameters that would have otherwise been significant. Future research may benefit from using several movement parameters, such as the number of bouts and amount of time spent at certain intensities, as well as total svm, when investigating active engagement in a dance or exercise class.

A limitation of the current study is that the dance classes were not filmed and so there is no observational data to map against the accelerometer-derived movement data. Therefore, it is not clear what movement the participants are performing when there is a peak in svm triad data for the dance class. Future research would benefit from being able to examine how particular dance movements correspond to volume of movement. In particular, mapping acceleration data against observed movements would allow for further investigation of differences between people with Parkinson's and controls in regard to specific movements.

Another limitation is that although minute-by-minute movement data was plotted for each participant triad, it is not known the peak volume of movement for participant groups statistically differed. For future research it may be informative, and aid further interpretation of the data, to calculate the maximum volume of movement achieved for each participant group and to statistically compare these.

The data shows promise for the accurate tracking of movement by the accelerometer, however it could also be argued that further analysis is needed to provide a stronger evidence base for this conclusion. One such approach is to use Functional Data Analysis (FDA), a type of time-series analysis used with accelerometer data (Bai et al., 2016), to examine the distribution and pattern of svm over the hour dance class and rest session. FDA has been used in this way to compare diurnal activity patterns between participants with mild cognitive impairment and healthy controls (Rockell et al., 2021).

The present study confirmed that it is feasible and useful to use accelerometers to measure the movement of people with and without Parkinson's while they participate in a dance class. Furthermore, it was shown that people with Parkinson's had a significantly lower volume of movement than young adults during the dance and rest session, however did not differ to age-matched controls. As discussed above, several possibilities for future research remain open. As such, in Chapter 4 wrist-worn accelerometers will be used to measure the movement made by people with and without Parkinson's during the hours and days following a dance class shedding light on the pattern and volume in a free-living, unconstrained environment. Chapter 5 will focus on the development of population specific, in this case Parkinson's, cut-point values that will allow for greater accuracy when translating svm data derived from Parkinson's participants into intensity levels.

4. Chapter 4

Wrist-worn accelerometer measures of movement by people with Parkinson’s over the week following a dance class.

4.1 Introduction

The few quantitative studies using accelerometry have focused on measuring movement during a class (such as Delextrat et al., 2016 and Chapter 3) as opposed to investigating the possible effect of dance on movement following participation in a class. People with Parkinson’s anecdotally report that the physical and psychological benefits of attending a dance class are maintained for the hours immediately following the class, however these may wear off over the subsequent days. Studies undertaken with people with Parkinson’s (Beerenbrock et al., 2020; Bognar et al., 2017), and their caregivers (Prado et al., 2020), provide supporting evidence for these anecdotal accounts.

Beerenbrock et al., (2020) conducted interviews with people with Parkinson’s to explore the effect of attending a 10-week Tango Argentino course on participants’ perceptions of the body. One of the themes that emerged centred around participants’ perceptions of their motor symptoms and movement. Under this theme, the sub-theme of “perceived effects at symptomatic level and mobility” captured participants’ accounts of improved ability to undertake routine, everyday activities and engagement in physical activity. A separate sub-theme of “motivation for more exercise” was identified based on participants’ reports of an increased longing to be active outside of the dance class in their everyday life. Likewise, an interview study conducted by Bognar et al., (2017) found that the majority of Parkinson’s participants who regularly participated in a weekly community dance for Parkinson’s class reported lasting physical effects of dance, such as an increased energy, flexibility and coordination, ranging from hours through to days. Observations of caregivers attending the same dance class as the individual with Parkinson’s further validate the subjective reports of lasting physical benefits from and following dance (Prado et al., 2020). Semi-structured interviews with caregivers, some of whom cared for an individual who attended dance classes, were undertaken to explore perceptions of wellbeing and reasons for attending (or not) the same activities as the person with Parkinson’s. One of the themes identified was “The Benefits of Participating in Social and Physical Activities – the perceived benefits of dance from the viewpoint of caregivers of people with PD”. In line with the findings of

Bognar et al., (2017), several caregivers noted an increase in the energy of the people with Parkinson's outside of the dance classes. Taken together, the results of these studies indicate that dance classes may have an observable impact on the general mobility of people with Parkinson's in the hours and days following participation in a class. Specifically, both individuals living with the condition and their caregivers have been found to recognise this effect; the former is particularly important in that if movement were to be measured quantitatively, it would perhaps indicate a clinically meaningful effect of dance on mobility. Therefore, quantitative assessments of mobility are warranted when exploring the physical benefits of dance for people with Parkinson's to further explore whether valid and reliable assessments are a useful tool for capturing the reported changes in movement.

Research by Coe et al., (2018) indicated that accelerometers may also be valuable in detecting change in sleep characteristics following participation in a 6-month weekly exercise or handwriting (control) intervention. People with Parkinson's wore a GENEActiv device on their wrist for seven days before and after the intervention. Differences between groups according intensity levels and different time slots were analysed; specifically, intensity levels were averaged over two 12-hour time slots (daytime; 08:00-20:00 and overnight; 20:00-08:00), an 8-hour overnight time slot (24:00-08:00) and a 4-hour evening time slot (20:00-00:00). Sedentary time was found to significantly increase for both intervention groups for the evening and overnight time slots. Time spent in light activity was significantly reduced for the exercise group when considering the evening and overnight time periods. Coe et al., (2018) argue their findings suggest a positive effect of both interventions, specifically that less movement during the night indicates better sleep quality. However, the study was limited to using sedentary behaviour to infer sleep times. It is unclear whether the increased sedentary behaviour at night of people with Parkinson's reflects a change in sleep characteristics (e.g. total sleep time and sleep efficiency) that would be suggestive of improved sleep quality following participation in physical activity. The GENEActiv original, alongside relevant data processing software can be used to obtain defined sleep metrics, such as total sleep time, sleep efficiency, number of active periods during the night and sleep start/end time; though Coe et al., (2018) did not use software to extract these metrics.

The findings of the abovementioned studies have limited generalisability and accuracy due to factors such as the wear location of the device and the device type selected. Depending on an individual's preferred bedtime, a participant may need to remove a hip-worn device early/mid evening, therefore precluding exploration of the effect of an intervention on movement parameters for the evening time period; a time frame which may reflect increased fatigue or sleepiness (Coe et al., 2018). The results of studies using a consumer device, such as a FitBit, as opposed to a research grade accelerometer, are also likely to reflect the impact of the interactive experience of wearing such a device (i.e. Colón-Semenza et al., 2018; T. Ellis et al., 2019; Hermanns et al., 2019). Lastly, the lack of control group in some studies (i.e. Colón-Semenza et al., 2018; Hermanns et al., 2019) means that it is not clear how the selected movement parameters compare to those without Parkinson's taking part in the same intervention or to a non-active Parkinson's group.

The present study sought to address the abovementioned limitations and investigated the feasibility of using accelerometers to measure the volume of movement, as well as sleep characteristics, of people with Parkinson's and age-matched controls following attendance at a dance class. Specifically, the aims of the study were to i) consider participant compliance with wearing an accelerometer continuously for 24 hours/day for six days, ii) to quantify the volume of movement of people with Parkinson's for a Friday afternoon and over the days following a dance class and to compare these outcomes to those obtained on a no-dance week and to AM-Ds, iii) explore whether the volume of movement made by PD-Ds during a dance week differed to PD-Cs who had never attended dance classes, iv) investigate whether the volume of movement made by PD-Ds and AM-Ds during a no-dance week differed to PD-Cs, v) to quantify the sleep characteristics of people with Parkinson's for a Friday afternoon and to compare these outcomes to those obtained on a no-dance week and to AM-Ds, and vi) to characterise the pattern of movement made over a dance and no-dance week for PD-Ds and AM-Ds and descriptively compare this to PD-Cs.

To this end, PD-Ds and AM-Ds were asked to continuously wear an accelerometer on their wrist during a day they attended a dance for Parkinson's class at the University of Hertfordshire and for the following six days. Participants were also asked to wear the device on their wrist during a week when they did not attend a dance class. A third group of people with Parkinson's who had no experience of dance classes were asked to wear a device on their wrist during a usual week. The daily volume of movement was used to characterise the pattern of activity over 6 days for all participant groups. The average daily volume of movement, total volume of movement made on a Friday afternoon (following a dance class) and sleep characteristics from a Friday night (following a dance class) were calculated for each participant group, and for a dance and no-dance week.

It was predicted that volume of movement for all time frames (daily average and Friday afternoon) would significantly differ for a dance week compared to a no-dance week for both PD-Ds and AM-Ds (Beerenbrock et al., 2020; Bognar et al., 2017; Prado et al., 2020). It was also predicted that the volume of movement made by PD-Ds over a dance week would significantly differ to PD-Cs for all time frames. It was expected that there would be a difference in sleep characteristics for the night following a dance class compared to a no-dance week for PD-Ds and AM-Cs (Coe et al., 2018 and Nascimento et al., 2014). Given the positive reports regarding participant compliance with wearing a wrist-worn device (Farina & Lowry, 2017; Huberty et al., 2015; McLellan et al., 2018), it was expected that all participant groups would be compliant with wearing the device continuously for six days. Finally, it was anticipated that the volume of movement made by PD-Ds during a no-dance week would be similar to that of PD-Cs, but that AM-Ds would significantly differ to both Parkinson's groups.

4.2 Method

4.2.1 Participants

Fourteen people with Parkinson's (*n* = 11 females, *n* = 3 males, age range = 44 to 75 years) who attended dance classes at the University of Hertfordshire were recruited (PD-D). Ten age-matched dancers (*n* = 4 females, *n* = 6 males, age range = 60 to 77 years) were recruited from the pool of partners (*n* = 6) of people who attended the Dance for Parkinson's class at the university (AM-D). Twelve age-matched people with Parkinson's (*n* = 5 females, *n* = 7 males, age range = 58 to 72 years) who did not attend dance classes were recruited (PD-C). Full demographics for all three groups are reported in Table 4.2.

Eleven of the PD-Ds reported having a rest tremor, of which seven were predominantly affected on their left side and four on the right side. Six participants wore the device on the wrist that corresponded with the side affected by tremor. Six of the PD-Cs reported tremor; three reported their left side being predominantly affected, two participants were affected on their right and one participant did not provide this information. Of the participants with tremor, three wore the device on the side that corresponded with the side affected by tremor. Wrist placement and handedness for all three participant groups are reported in Table 4.1.

Table 4.1 Number of participants displayed for handedness and wrist wear location for each participant group.

		Participant group		
		PD-C (n = 12)	PD-D (n = 14)	AM-D (n = 10)
Wrist location	Left	3	4	3
	Right	9	10	7
Handedness	Left	-	1	-
	Right	12	13	10

4.2.2 Design

Volume of movement was explored for the different time frames. A 16-hour period (08:00-24:00) was selected in order to characterise the daily movement of participants. A 12-hour period (08:00-20:00) was used by Coe et al., (2018), but this was extended to 16 hours for the current study as inspection of activity diaries indicated the bedtime of most participants (irrespective of group) was later in the evening, therefore activity may have been missed if an earlier time cut-off was used. Average daily volume of movement over 6 days (equating to a 96-hour period; 6-day total) was selected to provide a single summary metric of the average physical activity over a dance and no-dance week for the dance participants, and over a usual week for the Parkinson's controls. Finally, a time frame of Friday afternoon from 13:00-24.00 (an 11-hour period) was chosen to capture movement in the hours following the Dance for Parkinson's class, which was held between 11:00-12:00.

To compare the movement made by the PD-D group during the week following a dance class to that of PD-C group during a usual week, a between-subjects design was implemented with participant group as the independent variable and the daily average and Friday 13:00-00:00 volume of movement as the dependent variables.

To compare the movement made by dancers during a no-dance week to the movement of the Parkinson's controls made during a usual week, a between-subjects design was implemented with participant group as the independent variable (3 levels; PD-D, AM-D and PD-C) and the daily average and Friday 13:00-00:00 volume of movement as the dependent variables.

To explore differences in volume of movement and sleep characteristics on a Friday night between the dance groups and week, a 2 (participant group: PD-D and AM-D) x 2 (week: dance and no-dance) mixed design was implemented. The dependent variables were the volume of movement (daily average and Friday 13:00-00:00) and sleep characteristics (measured as sleep efficiency, total sleep time and number of active periods on a Friday night).

4.2.3 Materials/apparatus

4.2.3.1 GENEActiv accelerometer

The GENEActiv Originial (device detailed in section 2.1.4.1) was programmed to be activated by the press of a button which could be done by the participant at home.

4.2.3.2 MH&Y

For details about this measure please refer to the general methodology section 2.1.1.4. The MH&Y scores for the Parkinson's participants are presented in Table 4.2.

4.2.3.3 Demographic questionnaire

For details about participant demographics please refer to the general methodology section 2.1.4.2. Demographic measures for each participant group are presented in Table 4.2.

4.2.3.4 Activity diary

Each participant was given a paper diary alongside instructions on how to complete the diary. The diary consisted of a page per day with each day divided into hour time slots, starting at 6-7am and ending at midnight. Each page was divided into three columns, the first to record removal of the device, the second to record periods of sleep and the third to record general activities undertaken during the day (see appendix 6). To estimate wear-time compliance, the activity diaries were used to identify non-wear periods as recorded by the participant.

4.2.4 Procedure

Where possible participants met with the researcher on the university campus where demographic information was collected for both participant groups, and MH&Y data for the Parkinson's participants.

Each participant was given an accelerometer to wear on the wrist of their choice and asked to wear it continuously for seven consecutive days. All participants were told that the device is waterproof and that they could continue wearing it when undertaking water-based activities (i.e. showering, washing up, swimming).

In some instances, the researcher was required to travel to meet with the participant in order to give them the accelerometer. A portable stadiometer and set of electronic scales were used where possible to measure height and weight. However, some participants preferred to meet at a coffee shop and so measures of height and weight from their most recent hospital visit were used as an alternative. All participants were given a diary and were instructed to record accelerometer non-wear time, in addition to sleep times (including those during the day) and activities undertaken, such as shopping, meeting with friends or attending a singing class.

The PD-D and AM-D participants wore an accelerometer on their wrist for seven consecutive days over two different weeks, one where they took part in their regular dance class (dance week) and the second during a week where they did not take part in a dance class (no dance week). For the dance-week the participants attended the dance class from 11:00-12:00 on a Friday morning at the University of Hertfordshire. Participants were given a device to wear on the wrist of their choice prior to the start of the class. The time of activation and wear location were recorded by the researcher using the activity diary.
The participant took part in the class as usual and then continued to wear the device for the remaining seven days in their home environment.

Due to the documented physical and psychological benefits of participating in exercise for people with Parkinson's (i.e. Ferraz et al., 2018; van der Kolk et al., 2019), it was considered to be unethical to ask participants to miss a dance class. Instead, the no-dance week was scheduled to coincide with a break in the season of classes for school holidays (i.e. February half term). Participants were instructed to activate the device on a Friday morning, preferably before 1pm to provide matching data for the dance-week. The start date and time were noted in the activity diary. Participants continued with their usual routine during the seven days they wore the device, apart from dancing.

The PD-C participants did not attend dance classes; therefore, individuals were given an accelerometer to wear on the wrist of their choice for seven days during a usual week.

Participants were asked to activate the accelerometer on a Friday morning before 1pm and to continue wearing it for the following seven days.

All groups of participants were encouraged to continue with their usual routine during the week/s of wearing the device.

4.2.5 Data extraction and analysis

Data were extracted from the accelerometer as detailed in section 2.1.4.1.2. On receipt of the device from the participant the data was converted to 60 second epoch compressed files. For each participant the svm values between 08:00- 00:00 for each day the device was worn were extracted (Friday through to Thursday) and summed for each day to give a daily total. The average daily volume of activity was calculated by averaging across Saturday through to Thursday. Friday was excluded from the calculations as the majority of the participants had less than 15 hours of data for this day. To examine the movement made during the hours immediately following a dance class, the svm values from 13:00 to 00:00 on the Friday were summed to give a total volume of movement for this time frame. For PD-D and AM-D groups, the volume of movement for the time frames outlined above were calculated for a dance and no-dance week, whereas for the PD-Cs these variables were calculated using the svm data from a usual week.

Sleep characteristics calculated for each participant included sleep efficiency, total sleep time and number of active periods. The definitions of sleep parameters that can be extracted from accelerometers are outlined by te Lindert & Van Someren (2013). Total sleep time is defined as the number of epochs detected as sleep multiplied by the length of the epoch. Sleep efficiency is defined as the ratio of total sleep time to the time between the onset of sleep and final wake time. Number of active periods is defined as "the number of continuous blocks of length > 1 epoch(s) in which each epoch is detected as wake [between onset of sleep and final wake time]" (te Lindert & Van Someren, 2013, p.784). These were obtained from the bin files using a bespoke activity analysis (activity R markdown), provided by Activinsights Limited, used with R and RStudio version 1.3.959. The activity R markdown extracts the metrics for 24-hour periods (i.e. 3pm- 3pm) and produces a summary file containing the sleep characteristics for each day the device was worn. The R markdown estimates the sleep metrics by identifying the main sleep block, which is the point in the day with the highest concentration of sleep events. Sleep onset and rise time reflect the start and end of the main sleep block (J. Langford, personal communication, 22 August 2020). Additional metrics extracted included non-wear-time, device start/stop time and total wear-time.

Due to the small, unequal sample sizes between participant groups, and several of the movement and sleep distributions being non-normal, non-parametric analyses were run. In terms of the analysis of demographic variables Levene's test of homogeneity of variances indicated that the p-values for age and weight were approaching significance. Therefore, the variance ratio was calculated for age, height, weight and BMI to further check homogeneity of variances for each variable between participant groups (Field, 2013). The ratio for each dependent variable indicated variances were not homogenous (see Table 4.2); therefore, the Welch F-ratio is reported in section 4.3.1. In terms of analysing differences in the volume of movement and sleep characteristics, the main effect of week type was calculated by entering the svm and sleep values for the dance and no-dance, ignoring group, into a Wilcoxon signed ranks test. The main effect of group was calculated by averaging the svm and sleep values for the dance and no-dance week for each level of group and entered into an Independent-Samples Mann-Whitney U test. The interaction between group and week type was analysed by calculating the difference in svm and sleep values between the dance and no-dance week for each level of group and an Independent-Samples Mann-Whitney U test used to compare the differentials between groups. Effect sizes are reported as Pearson's r ($r = \frac{\mathrm{Z}}{\sqrt{\mathrm{N}}}$; Field, 2013), where effects were classified as small (0.10-0.29), moderate (0.30-0.49) and large (>0.50; Cohen, 1988, 1992).

Data were analysed using the IBM Statistical Package for Social Sciences (SPSS) for Mac OSX, version 26 (Armonk, NY). The daily total volume of movement was plotted for each of the six days the device was worn for each participant group using Microsoft Excel for Mac, version 16.39. Raincloud plots were used to visualise the effect of week on the volume of movement and sleep characteristics for the different time frames. A raincloud plot illustrates the distribution of data using a "cloud" (green and purple formations in Figure 4.1), raw jittered data (the small green and purple dots, see Figure 4.1), combined with a boxplot displaying measures of central tendency (the mean and median, see Figure 4.1). Raincloud plots were generated using R (M. Allen et al., 2019).

4.3 Results

4.3.1 Demographic measures

An analysis of demographic measures was conducted to ensure that there were no differences between the participant groups in terms of age, height, weight and BMI; variables which have been shown to impact on physical activity as measured using accelerometry (Elhakeem et al., 2018; Ramirez et al., 2018). There was no significant effect of participant group on age ($F(2, 21.02) = 2.11$, $p = .146$), height ($F(2, 15.43) = 0.26$, $p = .778$), weight (Weight= $F(2, 15.30) = 0.14$, $p = .870$) or BMI ($F(2, 17.33) = 0.82$, $p = .459$).

Table 4.2 Demographic measures for each participant group

Demographic measures		Participant group			Variance ratio
		PD-C (n = 12)	PD-D (n = 14)	AM-D (n = 10)	
Age (years)		65.50 (4.80)	65.50 (9.44)	70.00 (5.64)	3.87
Height (cm)+		166.21 (13.59)	166.87 (10.20)	170.10 (10.99)	1.78
Weight (kg)^		76.19 (13.38)	72.43 (21.51)	76.61 (14.77)	2.58
BMI˜		27.83 (5.91)	25.65 (5.94)	25.06 (3.12)	3.63
Age of diagnosis (years)		60.58 (7.55)	58.50 (11.45)	-	-
MH&Y *	Stage 1	5	1	-	-
	Stage 1.5	2	4	-	-
	Stage 2	3	-	-	-
	Stage 2.5	1	2	-	-
	Stage 3	1	5	-	-
	Stage 4	1	1	-	-
Dopaminergic medication		9	13	-	-

All values are means and standard deviations, except for MH&Y scores and medication which are presented as frequencies.

+Height = missing data for one PD-C, three PD-D and three AM-D.
^Weight = missing data for one PD-C, three PD-D and three AM-D.
˜BMI = missing data for one PD-C, three PD-D and three AM-D.
*MH&Y = missing data for one PD-D.

4.3.2 Compliance

Two of the PD-C participants reported in their diary that they removed the accelerometer on different occasions over the seven days. However, the R activity report indicated that only one of these participants had removed their device, with a total non-wear- time of 11.79 hours (707.4 minutes). The remaining 10 participants wore the accelerometer for the entirety of the seven days as indicated by both the activity diary and R activity report. Therefore, the average total wear-time was 167.02 hours.

Four participants (n = 3 PD-D and n = 1 AM-D) reported non-wear-time in their activity diary for the dance week. The R activity report did not corroborate these accounts and identified non-wear-time (a total of 78.6 minutes) over the seven days for one participant who did not report removal of the device during this time. The average total wear- time as indicated by the R activity report was 167.91 hours for PD-D and 168 hours for AM-D.

For the no-dance week, four PD-D participants reported non-wear-time in their activity diary. The R activity report matched two of these accounts and indicated a total non-wear-time of 13 hours for one participant and 2.5 hours for the other. All AM-D participants wore the accelerometer for the entirety of the seven days as indicated by both the activity diary and R activity report. Therefore, the average total wear-time over seven days was 167.31 and 168 hours for the PD-D and AM-D group, respectively. All participants wore the accelerometer for 24 hours for at least three of the seven days. Table 4.3 and Table 4.4 show the volume of movement and extracted sleep characteristics, respectively.

Table 4.3 Summary of measures extracted from accelerometer data. Volume of movement for a dance and no-dance week for different time frames.

Week	Time frame	Participant Group		
		PD-C (n = 12)	PD-D (n = 14)	AM-D (n = 10)
Dance week	Daily	-	287688.69 (82053.51)	355839.07 (110446.45)
	Friday 13:00-00:00	-	203480.33 (74336.79)	229881.95 (98856.51)
No-dance week	Daily	296328.77 (107995.20)	290093.32 (79722.64)	315777.63 (118572.44)
	Friday 13:00-00:00	201592.19 (109826.14)	188888.80 (75854.24)	206513.61 (83419.15)

For illustration purposes only, values provided are means and standard deviations for the PD-C, PD-D and AM-D groups. The analyses were conducted using non-parametric tests; medians are reported in the sections below.

4.3.3 Exploring the effect of a dance class on volume of movement

4.3.3.1 PD-D versus AM-D

4.3.3.1.1 Average daily

In order to examine the effect of week (dance vs no-dance) on daily volume of movement made over a week, a Wilcoxon-signed rank test was run on the svm values, which did not show any difference between the two weeks (z = -1.49, p = 0.137, r = -0.21, No-dance week: median = 276802.14; Dance week: median = 310871.34). No effect of participant group was found (PD-D vs AM-D) on total volume of movement, as indicated by an Independent-Samples Mann Whitney U test (U = 85.00, z = 0.88, p = 0.403, r = 0.18, AM-D: median = 292402.36; PD-D = 303789.31). No significant interaction was found between week and group (U = 100.00, z = 1.76, p = 0.084, r = 0.36, AM-D: median = 52310.26; PD-D = 10.75). See Figure 4.1.

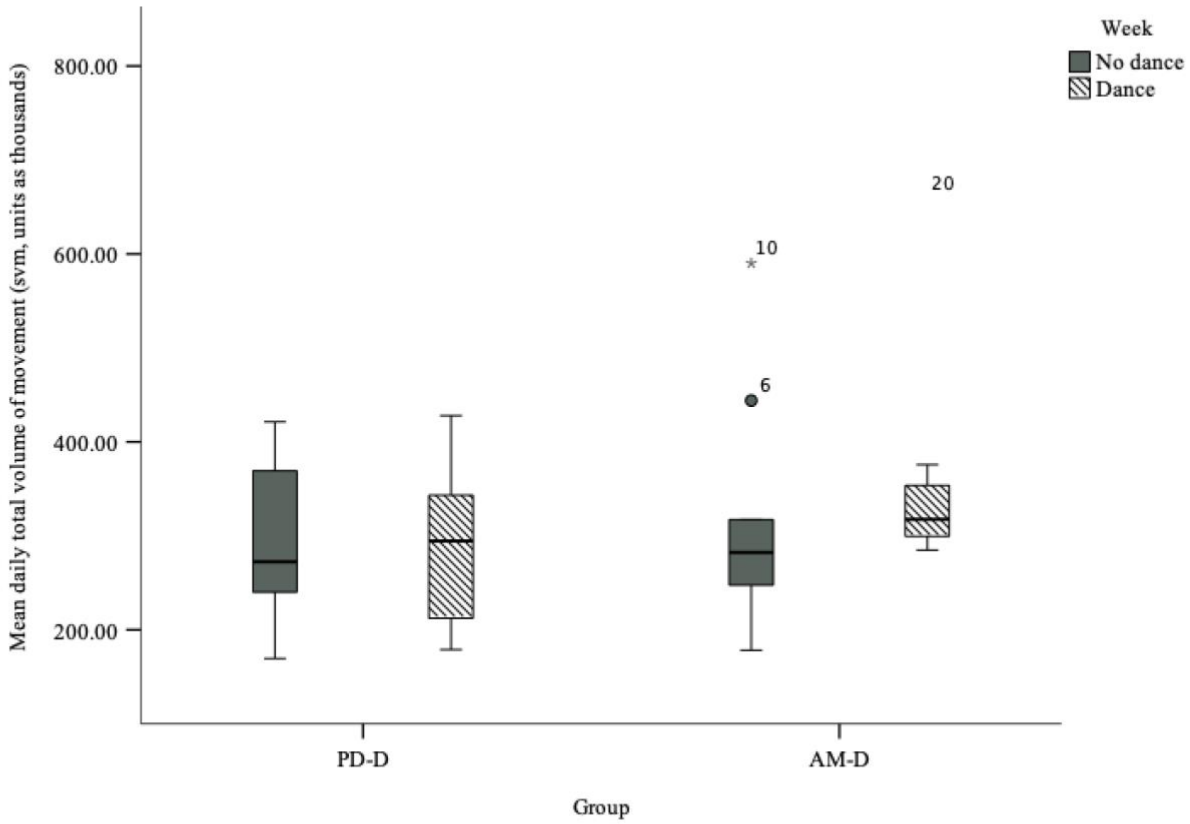


Figure 4.1 Mean daily values for total volume of movement for PD-D and AM-D groups for a dance and no-dance week.
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

4.3.3.1.2 Friday afternoon 13:00-00:00

A Wilcoxon-signed rank test run on the total svm values for the Friday afternoon indicated no effect of week (dance vs no-dance) on volume of movement (z = -1.14, p = 0.253, r = -0.16, No-dance week: median = 200730.83; Dance week: median = 184630.21). No effect of participant group was found for volume of movement, as indicated by an Independent-

Samples Mann-Whitney U test (U = 78.00, z = 0.47, p = 0.666, r = 0.10, AM-D: median = 197553.47; PD-D = 182709.01). No significant interaction was found between week and group (U = 73.00, z = 0.18, p = 0.886, r = 0.04, AM-D: median = 4094.74; PD-D = 22828.20). See Figure 4.2.

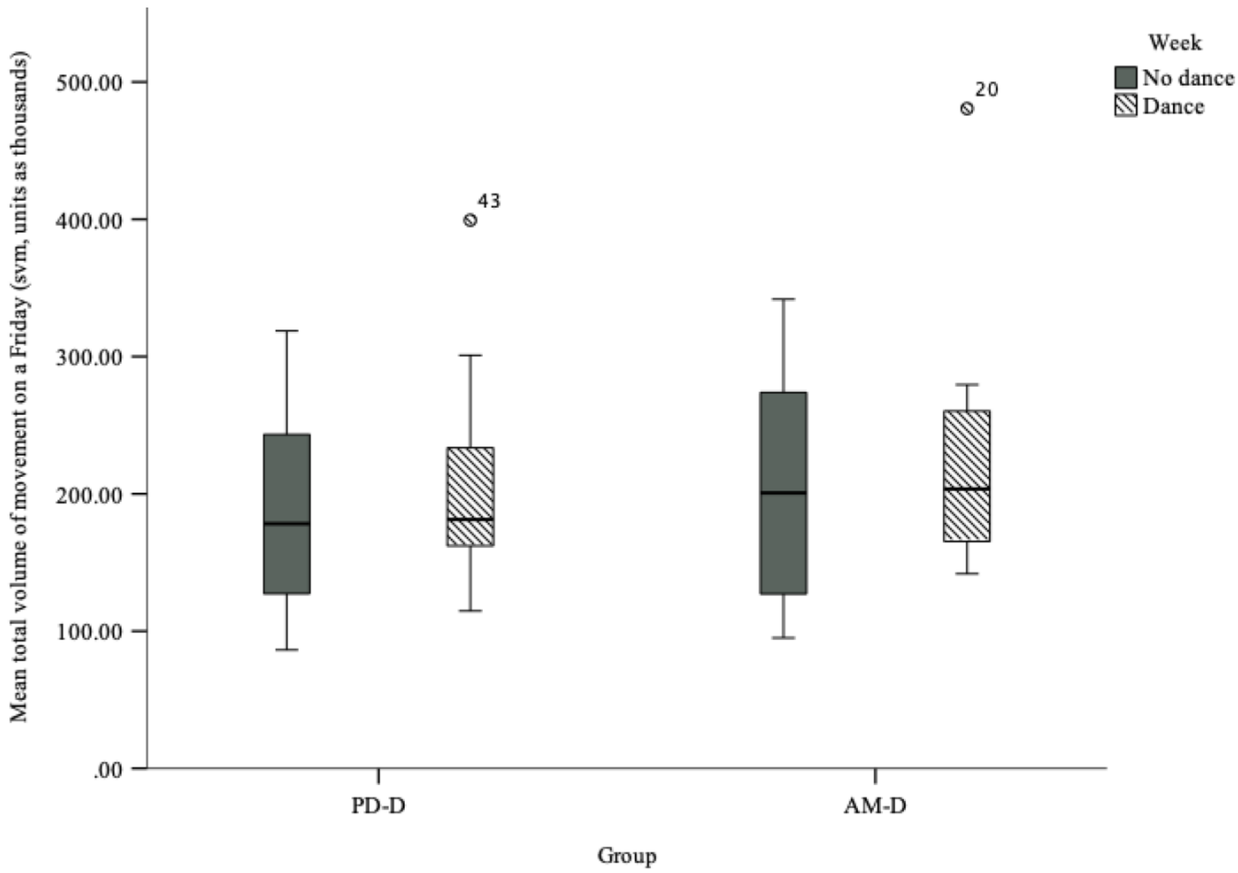


Figure 4.2 Mean total volume of movement made on a Friday between 13.00-24.00 for the PD-D and AM-D groups for a dance and no-dance week.
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

4.3.3.2 PD-D versus PD-C

4.3.3.2.1 Average daily

In order to examine whether the daily volume of movement made over a dance week differed between PD-D and PD-C groups, an Independent-Samples Mann-Whitney U test was conducted. No significant difference was found between the two groups (U = 87.00, z = 0.15, p = 0.90, r = 0.03, PD-D: median = 294636.26; PD-C: median = 264238.92).

4.3.3.2.2 Friday afternoon 13:00-00:00

An Independent-Samples Mann-Whitney U test indicated there was no significant difference between the PD-D and PD-C groups for the total volume of movement made between 13:00 and 24:00 on a Friday afternoon (U = 102.00, z = 0.93, p = 0.37, r = 0.18, PD-D: median = 181439.87; PD-C: median = 147715.00).

4.3.3.3 Comparing a no-dance week to the Parkinson's control week

4.3.3.3.1 Average daily

In order to examine whether the daily volume of movement made over a no-dance week differed between participants who danced (PD-D and AM-D) and those who did not (PD-C), an independent-samples Kruskal-Wallis test was conducted. No significant difference in daily volume of movement was found between groups (H(2) = 0.41, p = 0.815, PD-D: median = 272435.10; AM-D: median = 282283.13; PD-C: median = 264238.92).

4.3.3.3.2 Friday afternoon 13:00-00:00

An independent-samples Kruskal-Wallis test was run to investigate whether the total svm for a Friday afternoon on a no-dance week differed between participants who danced (PD-D and AM-D) and those who did not (PD-C). No significant difference was found between groups; H(2) = 0.05, p = 0.978, PD-D: median = 178403.02; AM-D: median = 200730.83; PD-C: median = 147715.00.

<u>4.3.4 Exploring the effect of week and dance group on sleep characteristics</u>

To investigate whether there are any differences in accelerometer-derived measures of sleep quality the night following a dance class compared to a no-dance night, the main effect of week (Friday dance night and Friday no-dance night) and group (PD-D and AM-D) on total sleep time, sleep efficiency and number of active periods were investigated.

Due to an error with the R activity report, two participants from the PD-D group were missing data for sleep efficiency, sleep time and number of active periods for the no-dance week. One participant from the PD-D group was missing data for the same three outcomes for the dance week. A participant from the AM-D group was missing data for all three outcomes for the dance week. Therefore, these participants' data were excluded from all three analyses reported below.

Table 4.4 Summary of sleep characteristics extracted from accelerometer data for a Friday evening for a dance and no-dance week and different participant groups.

Week	Sleep characteristic	Participant Group	
		PD-D (n = 11)	AM-D (n = 9)
Friday dance week	Efficiency	61.33 (13.35)	67.60 (3.95)
	Total sleep time	275.02 (79.14)	313.92 (292.20)
	Number of active periods	18.18 (5.53)	16.50 (4.28)
Friday no-dance week	Efficiency	54.37 (16.25)	66.98 (13.97)
	Total sleep time	227.95 (88.53)	299.93 (124.95)
	Number of active periods	17.55 (6.73)	17.11 (8.28)

For illustration purposes only, values provided are means and standard deviations for the PD-D and AM-D. The analyses were conducted using non-parametric tests; medians are reported below.

4.3.4.1 Sleep efficiency

In order to examine the effect of week (dance vs no-dance) on sleep efficiency, a Wilcoxon-signed rank test was run on the values extracted for the Friday night, which indicated no effect (z = -1.27, p = 0.204, r = -0.20, No-dance week: median = 62.20; Dance week: median = 65.65). No effect of participant group was found, as indicated by an Independent-Samples Mann-Whitney U test (U = 72.00, z = 1.71, p = 0.095, r = 0.38, AM-D: median = 67.20; PD-D = 62.00). No significant interaction was found between week and group (U = 31.00, z = -1.41, p = 0.175, r = -0.32, AM-D: median = -3.90; PD-D = 4.70). See Figure 4.3.

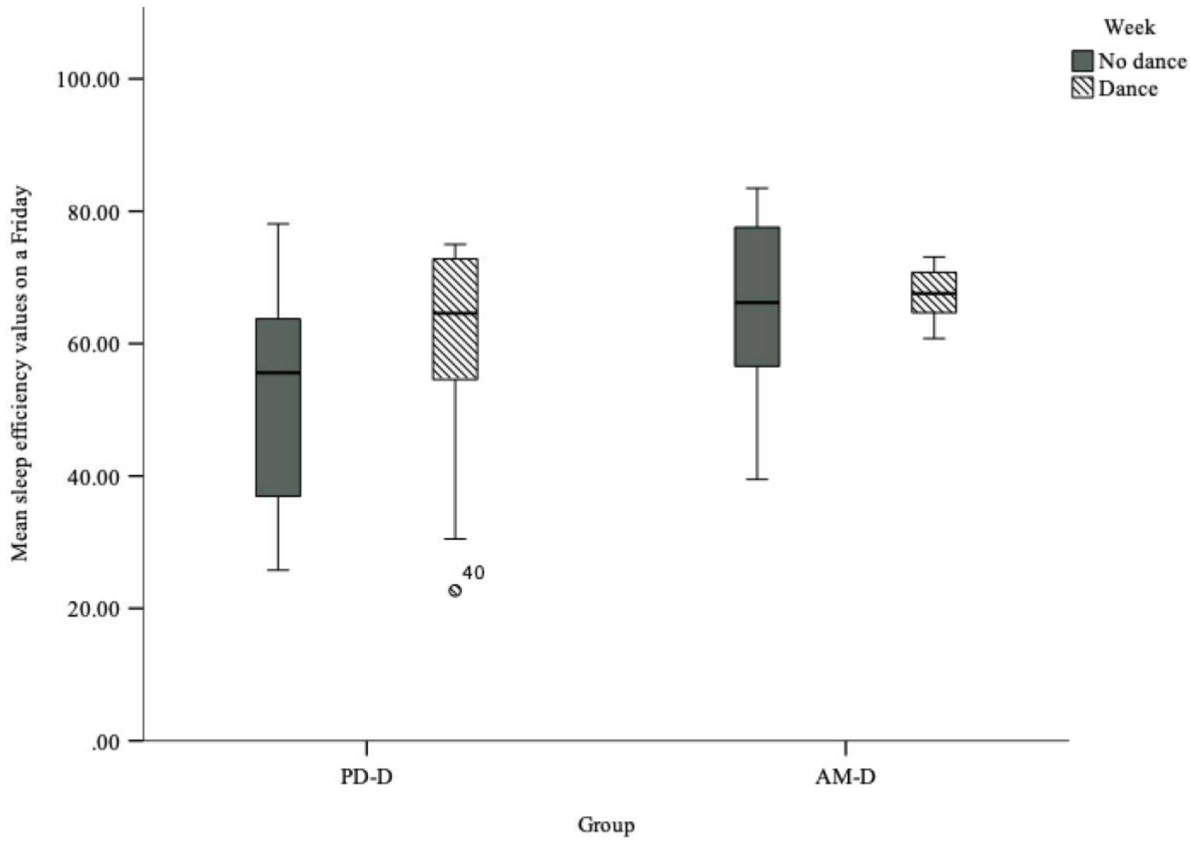


Figure 4.3 Mean sleep efficiency values on a Friday night for the PD-D and AM-D groups for a dance and no-dace week.
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

4.3.4.2 Total sleep time

In order to examine the effect of week (dance vs no-dance) on sleep time, a Wilcoxon-signed rank test was run on the values extracted for the Friday night, which indicated no effect (z = -0.80, p = 0.422, r = -0.13, No-dance week: median = 247.80; Dance week: median = 271.20). No significant effect of participant group was found, as indicated by an Independent-Samples Mann-Whitney U test (U = 71.00, z = 1.63, p = 0.112, r = 0.37, AM-D: median = 289.50; PD-D = 254.70). No significant interaction was found between week and group (U = 37.00, z = -0.95, p = 0.370, r = -0.21, AM-D: median = -22.80; PD-D = 22.80). See Figure 4.4.

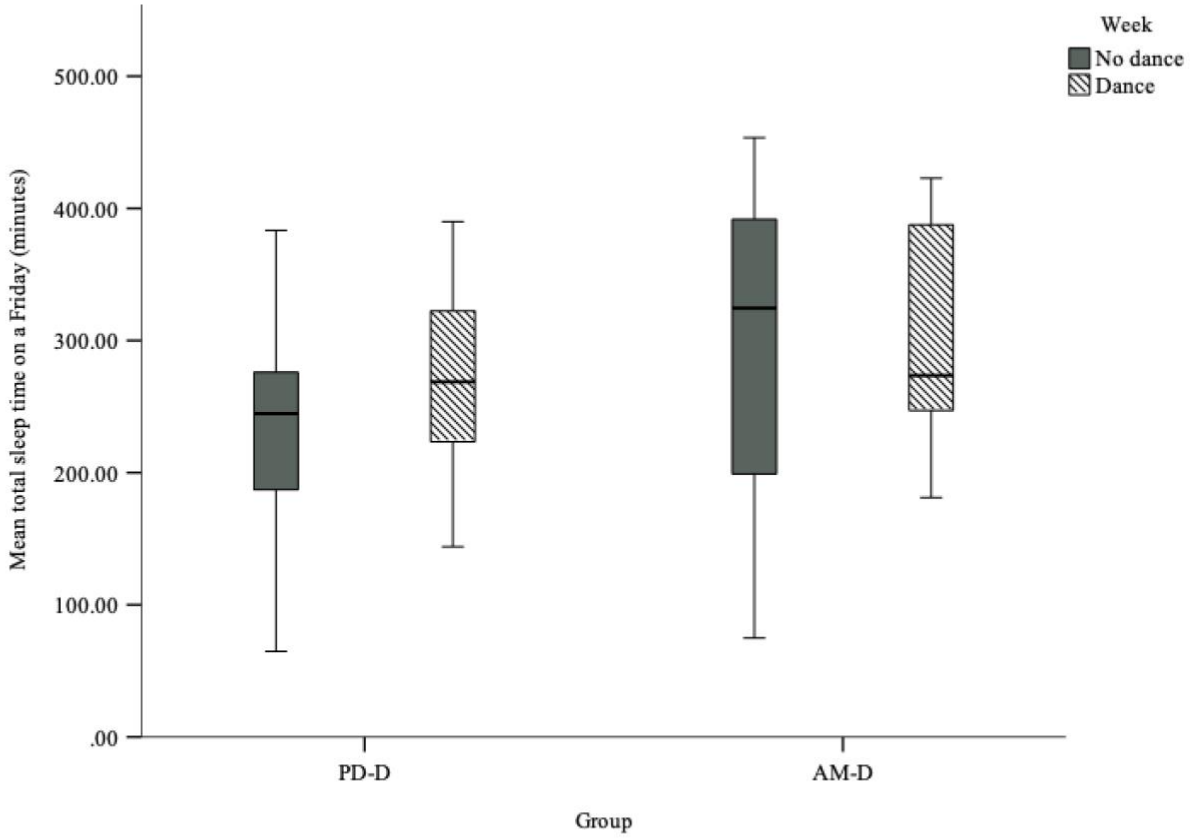


Figure 4.4 Mean total sleep time (in minutes) on a Friday night for the PD-D and AM-D groups for a dance and no-dance week.
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

4.3.4.3 Number of active periods

A Wilcoxon-signed tank test indicated no effect of week on the number of active periods during a Friday night (z = 0.02, p = 0.985, r = 0.003, No-dance week: median = 16.50; Dance week: median = 17.50). No effect of participant group was found, as indicated by an Independent-Samples Mann-Whitney U test (U = 42.50, z = -0.53, p = 0.603, r = -0.12, AM-D: median = 17.00; PD-D = 16.00). There was no significant interaction (U = 47.00, z = -0.19, p = 0.882, r = -0.04, AM-D: median = 1.00; PD-D = 1.00). See Figure 4.5.

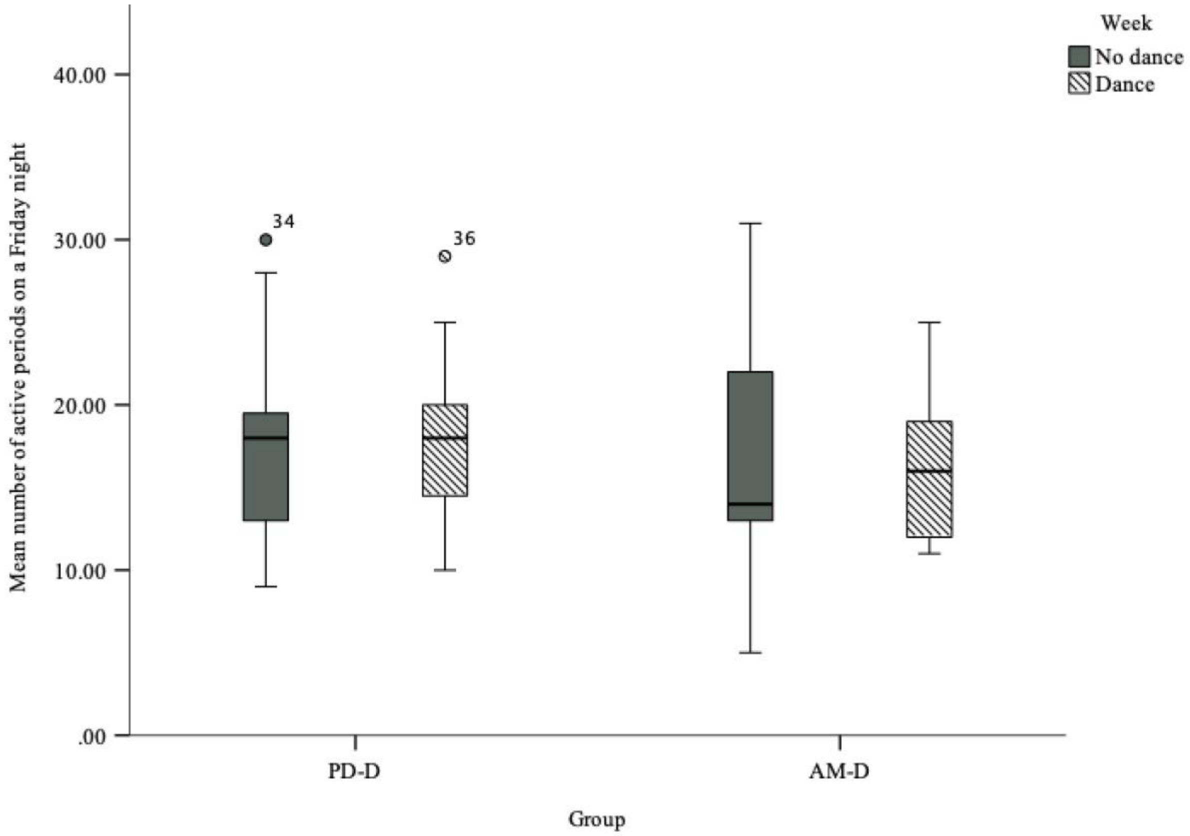


Figure 4.5 Mean number of active periods on a Friday night for the PD-D and AM-D groups for a dance and no-dance week.
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

4.3.5 Characterising the pattern of movement over a week

4.3.5.1 Dance week

To understand the pattern of movement made over a dance week by the PD-D and AM-D groups, the total svm per day was plotted for each group. On the same graph the total daily svm was also plotted for the PD-C group. Inspection of Figure 4.6 indicates that the daily volume of movement made by AM-Ds was consistently higher than both Parkinson's groups. The pattern of movement made by the PD-D group mirrored that of the AM-D group, indicated by the synchronous increases and decreases in volume of movement. The PD-D and PD-C groups made a similar amount of movement per day and over the course of the week, in line with the results of the statistical analysis.

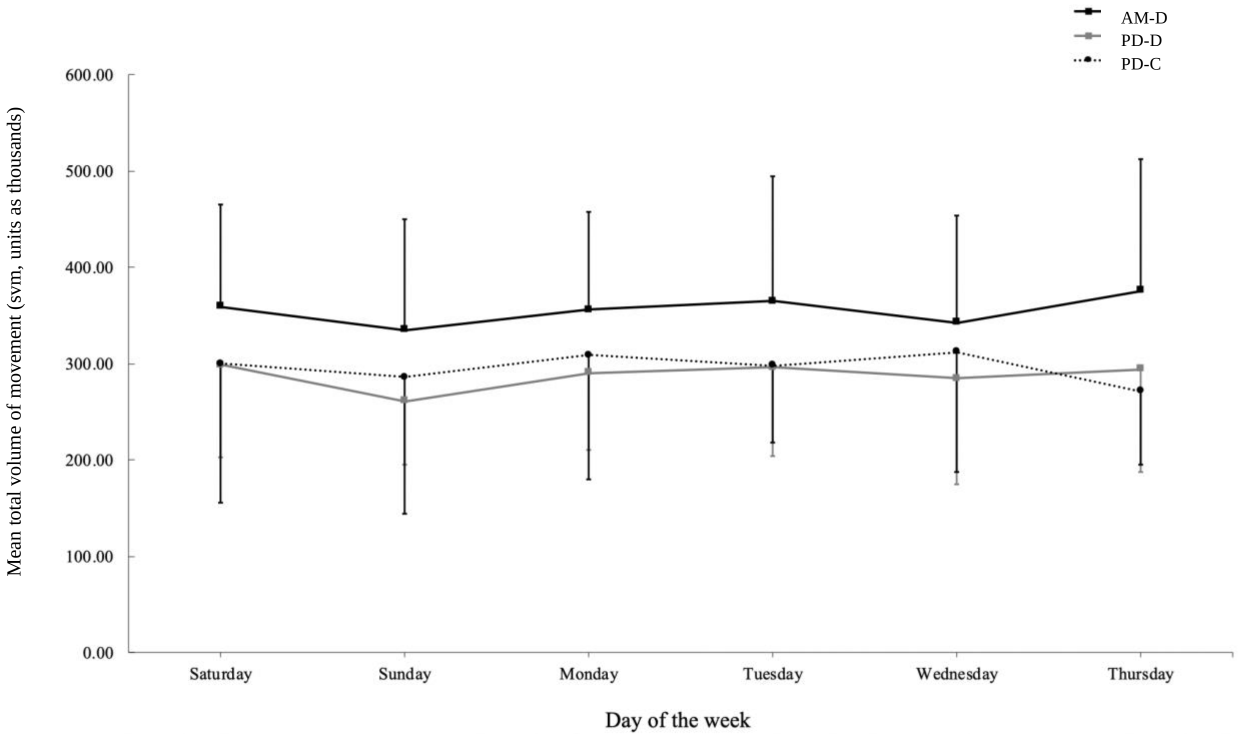


Figure 4.6 The mean total volume of movement made on each of the six days of a dance week by PD-D and AM-D groups and during a usual week for the PD-C group.
For illustration purposes.

4.3.5.2 No-dance week

To explore the pattern of movement made over a no-dance week , the total svm was plotted each day of the no-dance week for PD-D and AM-D groups, and for each day of the PD-C week. Inspection of Figure 4.7 indicates that the daily volume of movement made by AM-Ds was lower for the no-dance week compared to the dance week, such that it was comparable to that of the Parkinson's groups. Similar to the dance week, the day-to-day changes in volume of movement made by the PD-D group paralleled that of the AM-D group. The larger error bars for the no-dance week indicate greater variation in the daily movement, particularly for the Saturday, Sunday, Monday and Wednesday for the AM-D and PD-C groups.

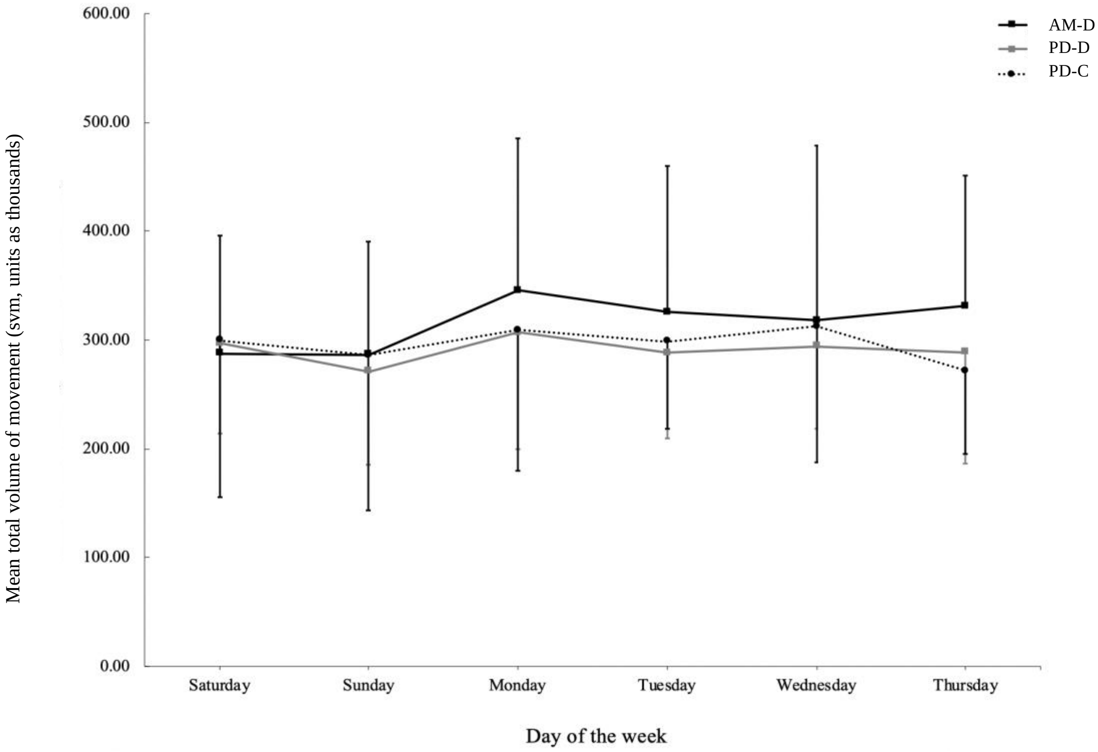


Figure 4.7 The mean total volume of movement made on each of the six days of a no-dance week by PD-D and AM-D groups and during a usual week for the PD-C group.
For illustration purposes.

4.3.6 Characterising individual differences between the dance and no-dance week

4.3.6.1 Volume of movement

To explore the possible benefit of dance for individuals, the difference in volume of movement between a dance and no-dance week was plotted for each Parkinson's and age-matched participant. Figure 4.8 displays the difference in mean daily total volume of movement and indicates that a greater number of the AM-D individuals made more movement during the dance week than the no-dance week, however it should be noted that there were fewer participants in this group. Seven of the PD-D group had higher svm for the no-dance week compared to two of the AM-D group. There also appears to be greater variation in the size of the difference for PD-D individuals compared to the AM-D individuals.

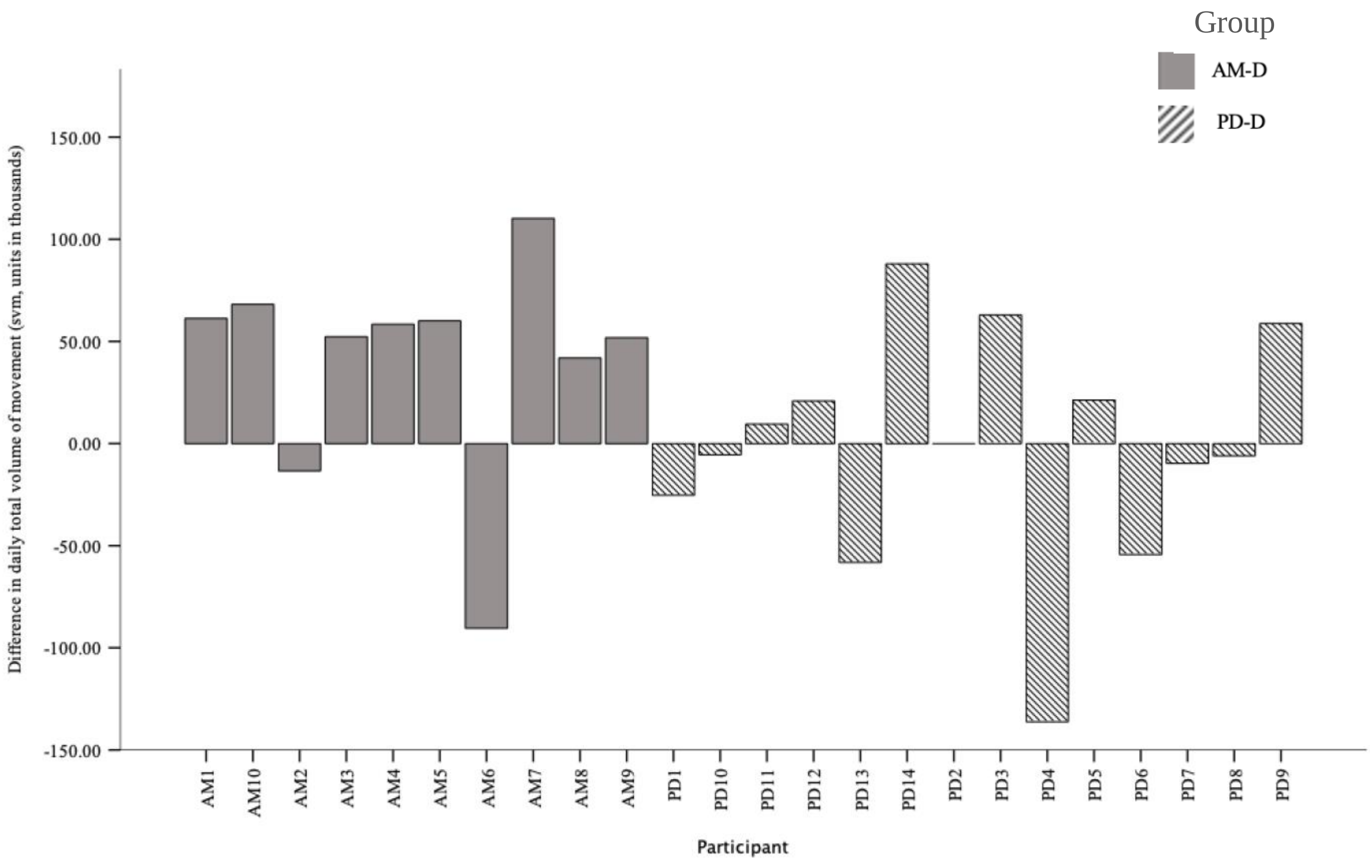


Figure 4.8 Difference in mean daily total volume of movement values between a dance and no- dance week for individual participants for individual participants for the PD-D and AM-D groups. Difference calculated as dance week minus no-dance week value. Bars below zero indicate higher svm for a no-dance week compared to a dance week.

Figure 4.9 displays the difference in the total volume made on a Friday between 13:00-24:00 and indicates that the size of the difference between weeks tended to be greater for AM-D participants compared to PD-D participants. However, the number of participants for which there was a positive and negative difference in movement between a dance and no-dance week was approximately equal for the two groups.

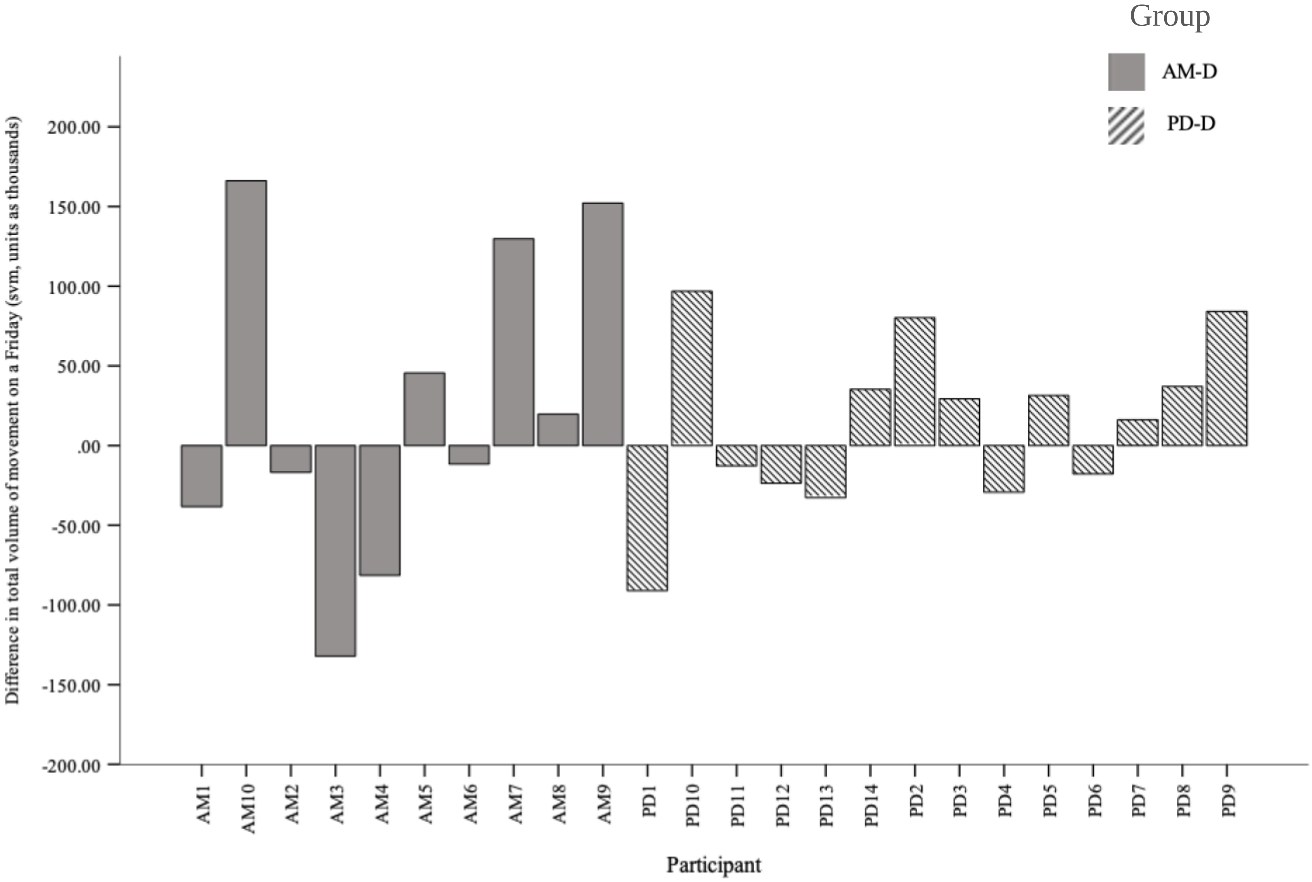


Figure 4.9 Difference in total volume of movement made on a Friday between 13:00-24:00 between a dance and no- dance week for individual participants for the PD-D and AM-D groups. Difference calculated as dance week minus no-dance week value. Bars below zero indicate higher svm for a no-dance week compared to a dance week.

4.3.6.2 Sleep characteristics

To explore the possible benefit of dance on sleep for individuals, the difference in accelerometer-derived sleep metrics between a dance and no-dance week was plotted for each Parkinson's and age-matched participant. Figure 4.10 displays the difference in sleep efficiency on a Friday night and indicates that the greatest size difference was for a PD-D participant. There also appears to be a greater number of participants in the PD-D group for which there was a positive difference in sleep efficiency. Of the individuals from the PD-D group there were three participants with a negative difference in sleep efficiency compared to five in the AM-D group. For these participants the size difference between dance and no-dance week sleep efficiency was lower compared to individuals with a decrease in sleep efficiency.

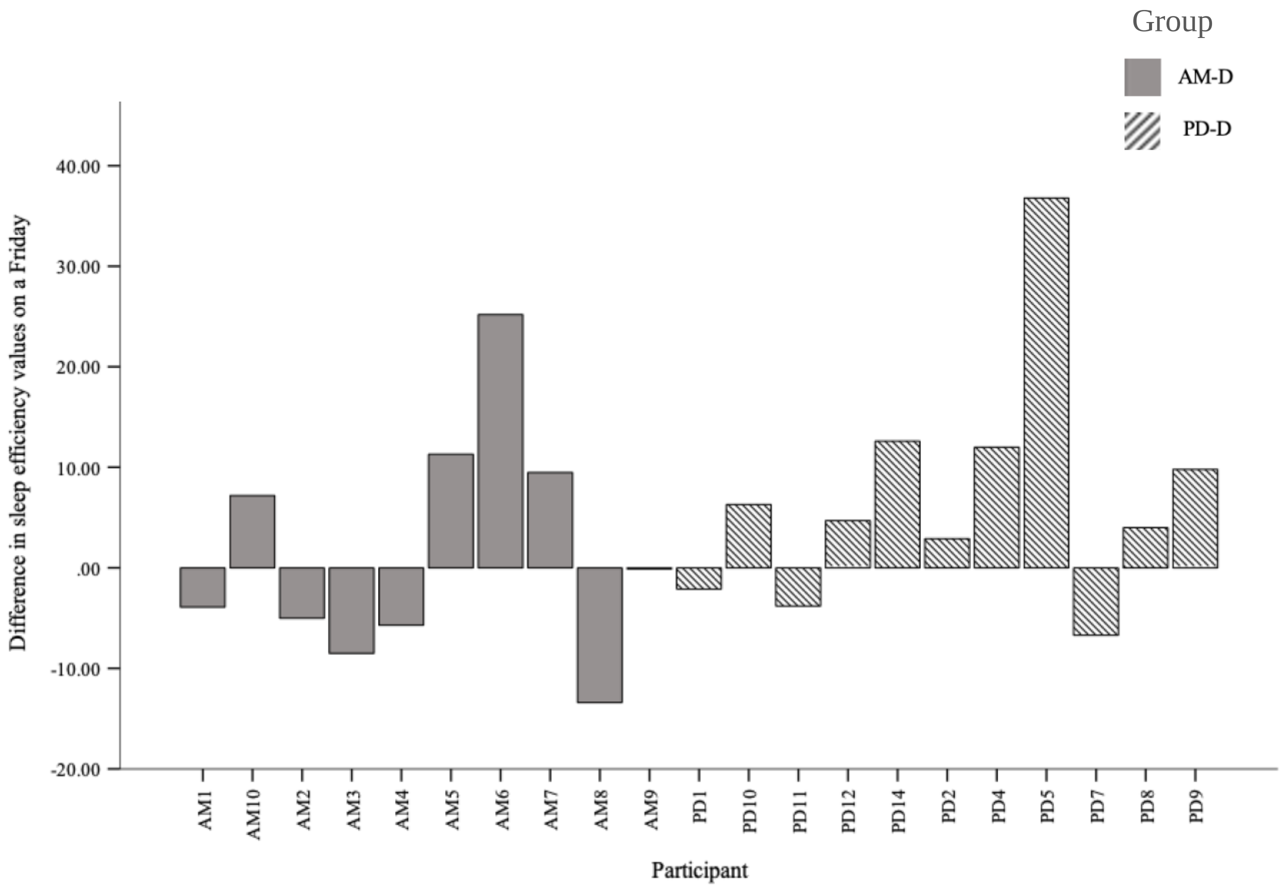


Figure 4.10 Difference in sleep efficiency values on a Friday night between a dance and no- dance week for individual participants for the PD-D and AM-D groups.
Difference calculated as dance week minus no-dance week value. Bars below zero indicate an increase in sleep efficiency for a no-dance week compared to a dance week.

Figure 4.11 displays the difference in total sleep time on a Friday night and indicates that there was a positive difference in this metric for the majority of the PD-D participants, such that there was a decrease in total sleep time on the Friday of a no-dance week compared to the dance week. For five of the AM-D group there was an increase in total sleep time and the size of the difference between a dance and no-dance week was greater for these individuals when compared to the PD-D participants. Similarly, for the AM-D individuals with lower values for total sleep time on a no-dance week, the size of the difference between the dance and no-dance week tended to be higher, particularly for participants AM1 and AM6.

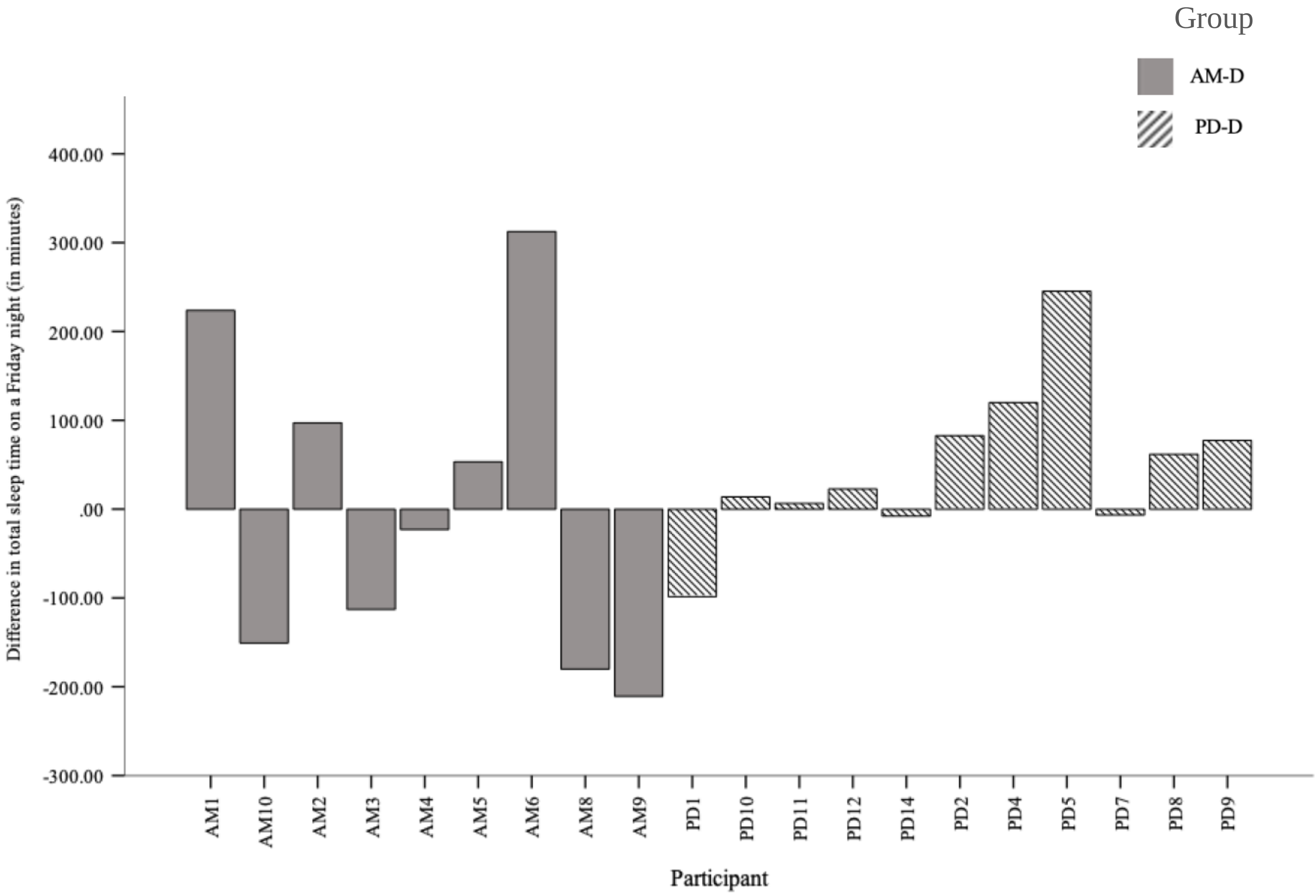


Figure 4.11 Difference in total sleep time values on a Friday night between a dance and no- dance week for individual participants for the PD-D and AM-D groups.
Difference calculated as dance week minus no-dance week value. Bars below zero indicate an increase in total sleep time for a no-dance week compared to a dance week.

Figure 4.12 displays individual differences in the number of active periods between a dance and no-dance week. The figure indicates that approximately an equal number of PD-D and AM-D participants had an increase and decrease in the number of active periods. The variation in size difference also appears to be similar across individuals in the two groups.

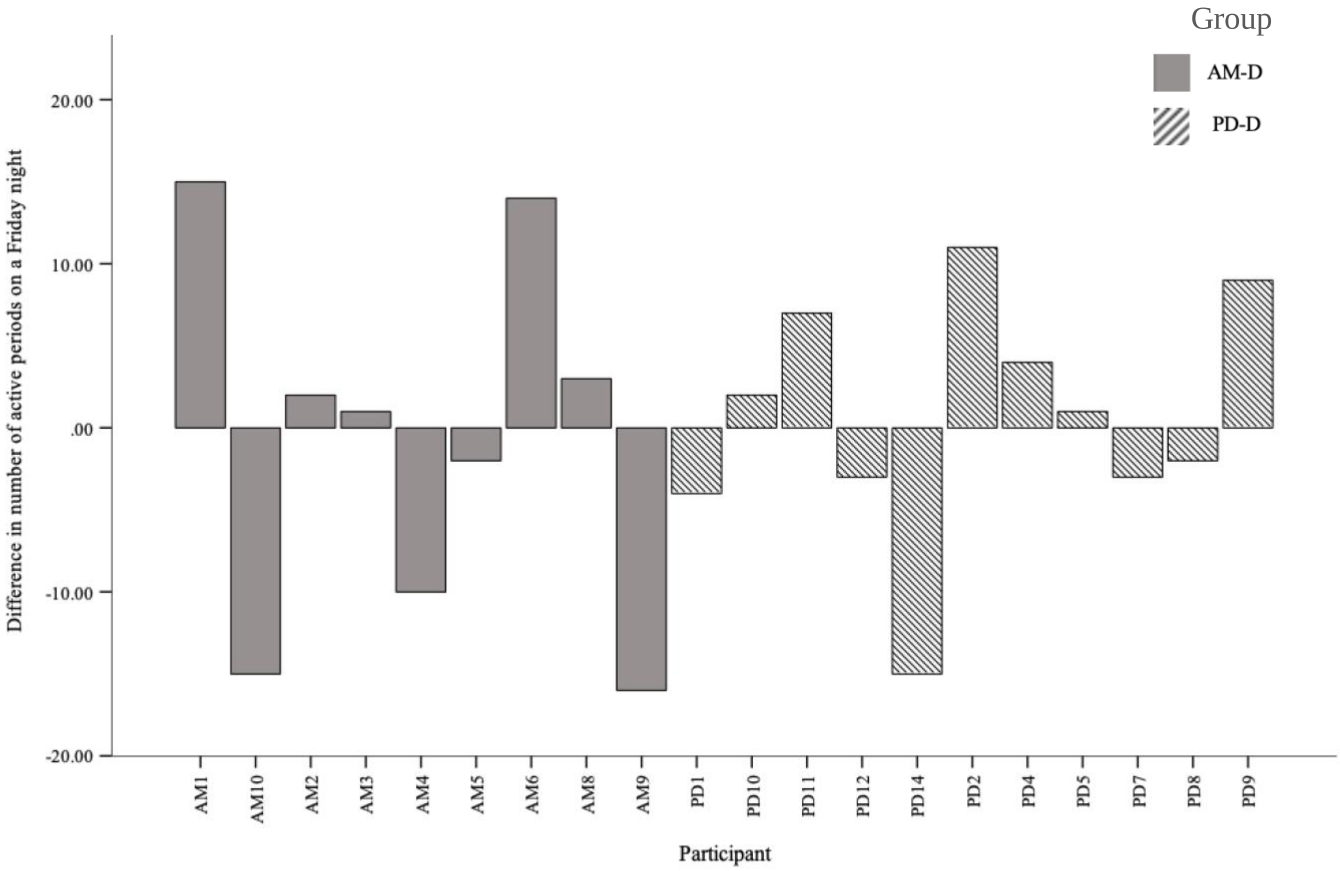


Figure 4.12 Difference in number of active periods on a Friday night between a dance and no- dance week for individual participants for the PD-D and AM-D groups.
Difference calculated as dance week minus no-dance week value. Bars below zero indicate a higher number of active periods for a no-dance week compared to a dance week.

4.3.7 Activity diary

All 12 participants of the PD-C group completed and returned the activity diary. All 14 participants of the PD-D group and eight of the AM-D group completed and returned the activity diary for both the dance and no-dance week. One of the AM-D group did not return a diary for the no-dance week and the other participant did not complete a diary for either week. Of the participants that completed and returned a diary, all of them made at least one entry for all seven days (from Friday-Thursday). For the PD-C group, the average number of entries per day was 6. For the PD-D group the average number of entries per day was 13 for a no-dance week and 12 for a dance week. For the AM-D group, the average number of entries per day was 11 for both the dance and no-dance week.

Participants from all three groups noted attending or taking part in other physical activities, in addition to the dance class held at the University, on both the dance and no-dance weeks. Activities that were reported by all three groups included going for a walk, attending the gym, bowls, gardening, housework, swimming, attending an exercise class, at home exercises and physiotherapy. Participants in the AM-D group also reported taking part in archery and tai chi. Activities that were only reported by the PD-D group included going for a bike ride, hydrotherapy, badminton and stretch class. For all three groups the activities reported on a dance week tended to also be reported on a no-dance week.

In terms of added notes for the night time period in the diaries, four of the PD-C group referenced disturbed sleep. For the PD-D group seven and five participants referenced disturbed sleep for a dance and no-dance week, respectively. The notes were similar across both the PD-C and PD-D groups and included references to needing the toilet, restless legs, taking medication and nightmares. Of the AM-D participants, three noted disturbed sleep for a no-dance week, but none made any notes about disrupted sleep for a dance week.

4.4 Discussion

The application of accelerometers within the Parkinson's and physical activity literature is limited and does not yet include the use of the devices to investigate parameters of movement following participation in dance, therefore the current study sought to address this gap. In the current study accelerometers were used to measure the volume of movement and sleep characteristics of people with Parkinson's, aiming to explore the feasibility of using the wearable devices to objectively capture the subjective reports of maintained mobility in the hours and days following attendance to a dance class. Specifically, movement and sleep metrics were calculated for several time frames and participant groups to investigate i) differences between PD-D, AM-D and PD-C groups and ii) differences between a dance and no-dance week.

4.4.1 Comparing dancers to non-dancers

The results indicate no difference in the daily volume of movement made during a no-dance week between PD-D, AM-D and a PD-C group with no dance experience. Therefore, this finding supports the hypothesis that there would be no significant difference in the movement parameters as measured for a no-dance week for the PD-D group and for a usual, routine week for the PD-C group. Examination of the daily vector magnitude counts as reported in several other studies indicates the results of the current study are in line with previous work (Nero et al., 2019; Wallen et al., 2015). Specifically, Wallen et al., (2015) aimed to characterise the physical activity levels and patterns of movement of people with Parkinson's, asking participants to wear an accelerometer for 7 continuous days. Wallen et al., (2015) report a total daily vector magnitude count of 293,614 for participants who wore the device for a minimum of 4 of the 7 days, comparable to the volume of movement found for the PD-C (296,328.77) and PD-D (290,093.32) groups in the present study. Likewise, Nero et al., (2019) found a baseline total activity (svm) count of 280,835 and 292,475 for a Parkinson's intervention and control group, respectively, prior to participation in a balance programme. Therefore, the movement made by Parkinson's participants in the current study appeared to be representative of a general Parkinson's population. Furthermore, the findings of the present study support and extend the feasibility of using wrist-worn accelerometers to objectively and accurately track the volume of movement made by people with Parkinson's during a dance class, as reported in Chapter 3, to free-living contexts. Though, it should be noted that both Nero et al., (2019) and Wallen et al., (2015) used waist-worn accelerometers in their studies, thus requiring participants to remove the devices for water-based activities. Whereas, the current study used waterproof devices, therefore capturing the movement made during such activities and likely providing a more accurate measure of movement. However, more studies are needed using wrist-worn rather than waist-worn devices to characterise the level and pattern of movement made by people with Parkinson's.

There is some evidence to suggest that people with Parkinson's are less physically active compared to older adults (Chastin et al., 2010; van Nimwegen et al., 2011). Therefore, it was predicted that the AM-Ds in the current study would have significantly higher daily volume of movement compared to both Parkinson's groups. In contradiction to expectation, the present study found no significant difference between groups. The lack of significant difference found in the current study may be partly due to the small sample size, such that the study was underpowered to detect a difference between groups. Closer inspection of the means suggests that these movement metrics were highest for the AM-D group compared to the PD-D and PD-C groups, even though this did not reach significance. Specifically, daily volume of movement was 12% and 15% higher for the AM-D group compared to the PD-C and PD-D group, respectively. These results are in line with those of Chastin et al., (2010), who found that people with Parkinson's spent a greater percentage of the day being sedentary compared to age-matched controls, though this difference was not significant. Taken together, these findings suggest people with Parkinson's are less active than older adults who do not have the condition. However, as noted by Wallen et al., (2015) it is not clear how volume of movement relates to health outcomes. In particular, further research is needed to understand whether reduced volume is associated with adverse health outcomes more generally, in addition to the progression of Parkinson's symptoms.

4.4.2 Comparison of week and group

For the current study it was predicted that all parameters of movement (daily and Friday afternoon), as measured using an accelerometer, would significantly differ for a dance week compared to a no-dance week for both the PD-D and AM-D group. This hypothesis was not supported by the results which show no significant difference between weeks or participant group in terms of the average daily volume of movement, in addition to the measured movement for Friday 13:00-24:00. This finding could suggest that the perceived effect of dance on movement is not objectively supported. However, examination of the means indicates that the volume of movement made for the Friday 13:00-24:00 timeslot on a no-dance week was 7% and 10% lower for the PD-D and AM-D groups, respectively, compared to a dance week. Though non-significant, this result suggests that both participant groups were more active in the hours following a dance class compared to a day when they did not attend a class, though this was more pronounced for the AM-D group. The activity involved in returning home from a dance class may account for greater volume of movement for the Friday afternoon on a dance week

This pattern was not found for the average daily time frame, perhaps indicating that any effect of dance on movement does not extend beyond the day on which the dance class takes place. One explanation for the null finding could be that the no-dance weeks were "exceptional" weeks, with data being captured during periods which aligned with half-term. However, the activity diary data indicates that both PD-D and AM-D participants were engaged in a variety of activities throughout a dance and no-dance week, such as swimming, and attending the gym and other types of exercise classes. Of these activities, most were reported for both weeks suggesting participants routinely attended these. Therefore, a more likely explanation for the null finding might be that these groups were particularly active individuals.

Further examination of different time frames is needed to shed light on how movement may vary over the course of a day, such as calculating hourly trends of volume of movement, and compared to other days of the week. Further studies are needed with larger sample sizes in order to gain a better understanding of the effect of dance on subsequent movement. In particular, future work should consider using parameters of movement that facilitate intuitive interpretation (i.e. time spent at certain intensity levels and frequency of intensity bouts) alongside volume of movement. The current findings indicate that using svm as a measure of physical activity over extended periods of time is too blunt of a measure. Furthermore, it is not intuitive to interpret how a change in svm relates to meeting recommended daily physical activity levels. Whereas, intensity levels (such as light, moderate and vigorous) directly map onto the language used in published guidelines, such as the NHS (2019) physical activity guidelines for older adults. However, no validated cut-point values exist for wrist-worn accelerometers used with people with Parkinson's, thus the literature is limited in terms of providing an accurate picture of whether people with Parkinson's meet activity guidelines.

4.4.3 Sleep characteristics

The results of the current study show there was no significant difference between week or participant group in terms of total sleep time and number of active periods. Therefore, this study failed to find an effect of dance on these sleep characteristics for people with Parkinson's and age-matched controls. The results of previous research (Coe et al., 2018) suggest that participation in exercise may result in increased sedentary behaviour of people with Parkinson's at night; thus, indicative of a positive effect on sleep quality. However, rather than use accelerometer-derived sleep characteristics, Coe et al., (2018) used sedentary behaviour measured by an accelerometer to infer sleep times. In the current study, increased sedentary behaviour during the night was expected to be reflected as a reduction in the number of active periods, however this remained stable when comparing a dance and no-dance week. Effective strategies for improving the quality of sleep has been identified as one the key priorities for people with Parkinson's, caregivers and healthcare professionals (Deane et al., 2014). Yet, recently published reviews indicate that there are few studies investigating the effect of complementary therapies on sleep disturbances in Parkinson's (Amara & Memon, 2018; J. Lee et al., 2018).The types of activities that have been explored to date include resistance (Silva-Batista et al., 2017), aerobic (Nascimento et al., 2014; Rodrigues de Paula et al., 2006) and Qigong (Wassom et al., 2015; Xiao & Zhuang, 2016), but not dance, with mixed effects reported in terms of impact on sleep. Typically, these previous studies have used subjective measures of sleep quality (such as the Pittsburgh Sleep Quality Index), as opposed to accelerometer-derived measures. The current study is limited in that changes in sleep characteristics were assessed as a secondary outcome, therefore a self-report measure of sleep quality was not included. Consequently, the findings are not comparable to those of previous research. Future studies would benefit from including both questionnaire and accelerometer measures of sleep quality to further understand whether participation in dance leads to subjective improvements in sleep quality and whether such improvements are matched by a change in objective assessments of sleep.

It should be noted there was a trend towards a difference between the PD-D and AM-D groups for sleep efficiency, with means and medians indicating poorer sleep efficiency for the PD-D group. This finding is to be expected given that sleep dysfunction is a commonly experienced non-motor symptom of people with Parkinson's. In particular, individuals report a frequent need to use the toilet during the night as being one of the most common issues (Lees et al., 1988), which consequently impacts on sleep quality. People with Parkinson's may also experience sleep disorders such as periodic limb movement (involuntary jerking movements of the legs and arms) and insomnia (Amara & Memon, 2018). Inspection of the activity diary data supports this idea, indicating that several of the Parkinson's participants (control and dance group) experienced disturbed sleep due to reasons in line with the research reported above. Though non-significant, the difference detected in sleep efficiency between the two groups demonstrates that accelerometers are a useful tool for capturing sleep characteristics and are sensitive to between group differences. However, it is unclear why a trend towards a significant difference was only found for sleep efficiency and did not extend to total sleep time and number of active periods. The use of sleep diaries alongside accelerometers may aid interpretation of the accelerometer-derived sleep characteristics. Alternatively, future studies should aim to recruit age-matched controls who do not have any association with the Parkinson's participants.

4.4.4 Compliance

Given that the accelerometers were waterproof and required to be worn on the wrist (therefore less intrusive during sleep), it was expected that wear-time compliance would be high for all participant groups. This prediction was supported by the low non-wear-time as obtained using the accelerometer-derived activity summary and participant diaries. This is in accordance with previous studies using wrist-worn devices with people with Parkinson's (Hermanns et al., 2019), older adults (Farina & Lowry, 2017) and multiple sclerosis (Kos et al., 2007). However, it should be noted that there was some mismatch between the diary and accelerometer-derived reported non-wear-time, thus highlighting the importance of including both measures within a study. The discrepancy in non-wear-time may be due to participant error when completing the diary. In particular, agreement between diary and accelerometer-derived wear-time has been shown to worsen with increasing age (Winkler et al., 2016). Despite this discrepancy, Winkler et al., (2016) concluded that using an algorithm to determine accelerometer-derived wear-time was unlikely to reduce the quality of the data when compared to a diary method. The results of the current study support the consensus that wrist placement of an accelerometer encourages wear-time compliance with a 24 hour per day protocol. A high level of compliance is important for studies that require long-term wear of a device in order to achieve continuous monitoring of movement and reliable results (Porta, Pilloni, et al., 2018).

4.4.5 Limitations and future work

The current study also presents some methodological limitations. Firstly, the study did not include any self-report assessment of mobility during the weeks the accelerometer data was collected. Therefore, it is unclear whether the PD-D and AM-D groups perceived any changes in mobility for the hours and days following participation in the dance class. While qualitative work has highlighted that some people with Parkinson's perceive a change, this has not been explored with quantitative measures. Therefore, future studies could incorporate both accelerometry and self-report assessments to further understand the characteristics of perceived changes (i.e. onset and duration) and explore how these might translate to changes in volume of movement, or other relevant accelerometer-derived parameters.

Secondly, improved mood and self-efficacy could account for perceptions of changes in volume of movement made after participation in dance. It is not known whether it is the dance movements or the associated psychological benefits from taking part in dance that may influence the volume of movement during the hours following a class. Both mood and self-efficacy have been shown to significantly increase for people with Parkinson's after participation in dance (tango, Koch et al., 2016; social dance, C. Lewis et al., 2016). Further studies are needed that implement measures of mood/self-efficacy to better understand the contribution of these factors in the perception of mobility following participation in dance.

Thirdly, the participants in the current study were a highly motivated group of individuals (indicated by the regular attendance to dance classes, activities reported in the diary and their willingness to be involved with the study) with predominantly mild to moderate symptom severity. The current study does not account for the effect that participation in other types of exercise may have had on movement, particularly in the no-dance week. Future studies should systematically control for how physically active participants are and the types of activities they regularly take part in outside of the dance class. Future studies may also benefit from including people with Parkinson's who are not physically active to address this limitation.

Finally, a sub-set of the AM-D participants were the partners of people with Parkinson's. Their volume of movement may be impacted by this relationship, particularly as people with Parkinson's are reported to be less physically active (Chastin et al., 2010; van Nimwegen et al., 2011). The similar pattern of movement made on each of the six days for a dance and no-dance week for the PD-D and AM-D group seems to support this suggestion. This may account for the null finding regarding between group differences for volume of movement for the AM-D and PD-D group. Future studies should include age-matched controls who are independent of an association with someone with Parkinson's.

4.4.6 Conclusion

This study is the first to present preliminary quantitative data that suggests people with Parkinson's and age-matched controls may be more active in the hours following a dance class compared to a day when they do not participate in dance, though not significantly so. Although useful as it combines several metrics and relatively easy to obtain, the current study highlights some limitations of using volume of movement as the only outcome measure. The main issue with using this outcome is that interpreting change in svm in a meaningful way is difficult without the use of other metrics, such as activity intensity levels. Combining all metrics into one parameter may actually be too broad of an outcome as it prevents detection of variation in individual metrics that may provide important insights regarding behaviour change. However, the use of intensity levels to analyse data obtained from people with Parkinson's is also limited due to there being no availability of validated cut-point values for wrist-worn devices used with this population . The next chapter aims to address this gap in the literature by developing these cut-points.

5. Chapter 5

Development of cut-points for the assessment of physical activity intensity of people with and without Parkinson's.

5.1 Introduction

The intensity (i.e. sedentary, light, moderate and vigorous) and time spent at a specific intensity level have been shown to be useful parameters in previous studies; for example, exploring the daily pattern of activity made by people with Parkinson's (Dontje et al., 2013) and investigating the physical activity levels of people with Parkinson's following participation in a combined aerobic and strength exercise programme (Coe et al., 2018 and Collett et al., 2017). However, these studies, and others (Delextrat et al., 2016 and Wallén et al., 2015), have typically used devices that have not been calibrated for use with people with Parkinson's.

Several studies apply cut-points generated from a sample of older adults to classify svm data as measured in a population with Parkinson's (Coe et al., 2018 and Delextrat et al., 2016). This is likely to be problematic because age and disease related decline in physical activity (Mantri et al., 2018; Ploughman, 2017; Varma et al., 2017) contribute towards differing physical activity patterns across populations (Sparling et al., 2015). Whilst it could be argued that many older adults have impaired gait that is not attributable to a chronic disease (Herman et al., 2005), there are certain motor features of Parkinson's that are unlikely to be present in a sample of older adults. Postural instability, shortened stride length, in addition to variability and FOG, are hallmarks of the condition (Chastan et al., 2019 and Nutt et al., 2011) that negatively impact on mobility, consequently restricting participation in physical activity including exercise (Cavanaugh et al., 2015). Furthermore, reduced arm swing, the most commonly reported motor impairment of Parkinson's (Lewek et al., 2010), and postural tremor are likely to differently impact on the data collected using an accelerometer depending on the wear location. Wrist-worn accelerometers have proven to be useful in the detection of arm swing asymmetry in people with Parkinson's (Mirelman et al., 2016). Therefore, the impact this symptom, alongside others, may have on the data used to generate cut-points is of relevant consideration, particularly in relation to the placement of the device.

There do not appear to be any studies that compare the placement of the GENEActiv accelerometer in people with Parkinson's for accuracy of cut-points generated using vector magnitudes. Reviewing the ActiGraph GT3X/+, Migueles et al. (2017) note the lack of published studies comparing device placement on accelerometer outcomes, such as cut-points, for older adults. However, a study with healthy adults indicated that the wrist was comparable to hip and ankle placement in terms of reliability, indicated by high intraclass correlations (0.99, 0.97 and 0.99, respectively), for the assessment of activity counts when participants undertook activities of daily living (Ozemek et al., 2014). Likewise, Phillips et al. (2013) found the wrist to be a useful and acceptable wear location (compared to the hip) when generating cut-points from children undertaking activities of different intensities. Accelerometers placed on the wrists were found to distinguish between the different intensity levels of activity; though the hip-worn device resulted in greater precision in discrimination of intensity level as indicated by the Receiver Operator Characteristic (ROC) analysis.

Studies validating brands of accelerometers other than GENEActiv, such as the activPAL and ActiGraph, have generated cut-point values from older adults using devices worn on the hip (Hall et al., 2013) and the wrist (Koster et al., 2016). The few studies conducted with people with Parkinson's have not used wrist placement. Nero et al.(2015) used a hip-worn Actigraph GT3x to produce cut-points for different walking speeds (slow, normal and brisk) for people with Parkinson's. It is argued that cut-points, such as those of Nero et al. (2015) lack generalisation to free-living contexts, where a range of activity are undertaken (Porta et al., 2018). People with a neurological disability report feeling physically challenged when undertaking household chores (Ploughman, 2017), therefore engagement in activities of moderate to vigorous intensity is perhaps less likely. A study investigating the daily physical activity of people with Parkinson's using an accelerometer found that 82% of participants did not meet the recommended guideline of 30 minutes, in bouts of 10 minutes, of moderate to vigorous activity per day (Dontje et al., 2013). Furthermore, only 17% of the participants could be classified as semi-active. Therefore, using everyday activities that are representative for the chosen population is a relevant consideration when generating cut-points.

Different methods exist for validating accelerometer output to generate cut-points that are representative of different physical activity intensity levels. The raw accelerometer data needs to be translated into a physiologically meaningful measure, such as metabolic equivalent task (MET; Swartz et al., 2000), or a biomechanical measure, such as walking speed (Nero et al., 2015). Using wrist, ankle and hip-worn accelerometers, the current study aimed to determine cut-point values for general and specific types of activity for people with mild to moderate Parkinson's and age-matched controls, equating these to a physiological ($\dot{V}O_2$ converted to METs) and biomechanical measure of energy expenditure (EE) to understand the intensity of the activity. To this end, people with Parkinson's and age-matched controls wore a portable spiroergometry device (used to measure EE as $\dot{V}O_2$) and accelerometers across three body locations (wrist, ankle and hip) whilst they undertook eight different activities in a sports laboratory. These activities included rest, three differently paced walks (slow, normal and brisk, as taken from Nero et al., 2015), household and dance tasks. Differences between the cut-points generated for the two participant groups were expected, with higher cut-point values predicted for the age-matched group for all device locations compared to the people with Parkinson's. In terms of energy expenditure, it was hypothesised that $\dot{V}O_2$ values would significantly differ between the activities. Given the previous findings of studies comparing wrist to hip-worn devices (K. Ellis et al., 2014), the volume of movement recorded by a wrist-worn device was expected to be higher for the dance and household tasks compared to a hip-worn device, for which the volume of movement was predicted to be greatest for locomotive tasks, such as the walking. It was also predicted that there would be an effect of participant group, with a lower volume of movement made by people with Parkinson's compared to age-matched controls. It was also hypothesised that people with Parkinson's would rate certain activities, such as sweeping and brisk walking, as more physically exerting compared to age-matched controls even if the energy expended does not differ between the groups (Christiansen et al., 2009; Werner et al., 2006).

A secondary aim of the research was to investigate which accelerometer location (wrist, ankle or hip) best predicted EE for all participants, inclusive of both groups. Based on previous findings (Ozemek et al., 2014; Phillips et al., 2013; Swartz et al., 2000), it was anticipated that wrist placement would significantly predict EE, though hip placement would result in greater accuracy.

5.2 Method

5.2.1 Participants

Thirteen people diagnosed with mild to moderate Parkinson's (mean age= 62.90, SD= 9.31, Hoehn &Yahr score 1-3) voluntarily participated in the current study. Thirteen participants without Parkinson's (mean age= 66.17, SD= 10.17) formed part of an age-matched control group. A small number of the control group were partners or friends of the participants with Parkinson's. Full demographics for both participant groups are reported in Table 5.1.

5.2.2 Design

The study was a mixed factorial 2 (participant group: Parkinson's and age-matched controls) x 3 (device location: wrist, ankle and hip) x 7 (task: brisk walk, normal walk, slow walk, Irish dance, Jai ho dance, sweeping and dish washing) design. Both device location and task were repeated measures. Only the order of the dance and household tasks were randomised across participants. This was done to minimise fatigue effects. The dependent variables were heart rate (measured as beats per minute; bpm), oxygen consumption ($\dot{V}O_2$ per minute as measured using a portable spiroergometry device), movement (sum of vector magnitude per 15 seconds from three accelerometers), rating of perceived exertion (median score; as measured using Borg's scale; Borg., 1982) and walking speed (km/h).

5.2.3 Measures

5.2.3.1 Accelerometer

For device specifications please refer to the general methods, section 2.1.4.1. An accelerometer was worn on the left wrist, the left ankle (just above the medial malleolus) and on the anterior superior iliac spine along the anterior axillary line of the right hip. The same device was worn at the same body location across all participants for measurement consistency. Accelerometers were also worn on the right wrist and ankle but due to equipment error with the device worn on the right wrist the data is not reported here. Each accelerometer was programmed to start recording on removal from the docking station.

5.2.3.2 Indirect calorimeter

Breath-by-breath oxygen uptake ($\dot{V}O_2$) was measured using the Metamax 3B (Leipzig, Germany), a portable spiroergometry device, whilst participants undertook each task. The gas analyser was connected to the mains for the first nine participants in order to power the device. A wireless battery powered model became available, so this was used with the remaining fifteen participants (see Figure 5.1a for an example). In both cases, the gas analyser system was attached to a fabric harness which allowed the housing to sit on the participant's chest. The system was connected to a mask that was worn over the nose and mouth (see Figure 5.1b). Both oxygen and carbon dioxide are measured through a sample line and the volumes of the gases recorded and transmitted via Bluetooth to the MetaSoft software. Prior to each testing session the CO_2 and O_2 were calibrated with gases of a known concentration (14.70% oxygen/4.96% C02) for both versions of the device using the MetaSoft Studio software. $\dot{V}O_2$ was expressed in milliliters per minute. In accordance with previous studies $\dot{V}O_2$ was used as an indication of energy expenditure (METs; Hildebrand et al., 2014; Phillips et al., 2013; Swartz et al., 2000). Participant characteristics, including height and weight, were entered into the software prior to testing. After each testing session the data for each participant was exported from MetaSoft as an Excel file containing the breath-by-breath $\dot{V}O_2$ data (l/min), in addition to anthropometric data (height, weight, BMI, age). For each participant the anthropometric and $\dot{V}O_2$ data were used to calculate the average MET per task.

5.1a 5.1b

Figure 5.1 Set up of Metamax 3B.
Fig 5.1a Battery powered Metamax 3B. Fig 5.1b Wireless portable Metamax 3B.

5.2.3.3 Heart rate

The Polar H7 heart rate sensor was used to obtain live heart rate data whilst participants undertook each task. The device was attached to a fabric strap that was worn with direct contact to the skin just below the sternum. The monitor was synchronised with the IOS Polar

Beat application and the live data for each task was transferred via Bluetooth to the mobile phone application. This data was later accessed through Polar Flow, the companion website, and downloaded as a CSV file containing the second-by-second heart rate data. Inspection of the data indicated heart rate was greatly variable within and between participants, particularly in relation to the Parkinson's participants, thus mirroring previous research with this population (Nero et al., 2015). Therefore, it was decided that this data could not be used, however the summary statistics are reported in appendix 7.

5.2.3.4 Perceived exertion

Borg's Rating of Perceived Exertion (RPE; Borg, 1982, 1998; Borg & Noble, 1974) scale was used immediately after each task to assess the level of perceived effort experienced (see appendix 8). To aid use of the scale, the individual is instructed to think about the physical sensations they experience whilst undertaking the activity, such as changes in breathing and increased sweating. The rating scale ranges from a score of 6 (indicating no exertion) to a score of 20 (representing maximal exertion), with nine of the scores accompanied by a descriptor. The scale has been designed so that it can be used once or multiple times during an activity, with the respondent required to select only one score per administration of the scale.

5.2.3.5 Demographics

Refer to the general methodology section 2.1.4.2 for details about the demographic information collected from participants.

5.2.3.6 Anthropometrics

Refer to the general methodology section 2.1.4.3 for details about the equipment and procedures used to ascertain height, weight and body mass index.

5.2.3.7 MH&Y

For details about this measure please refer to the general methodology section 2.1.4.4. The MH&Y scores for the Parkinson's participants are presented in section 5.3.1.

5.2.3.8 MDS-UPDRS motor examination subsection

The MDS-UPDRS (Goetz et al., 2008) is a revised version of the Unified Parkinson's Disease Rating Scale (UPDRS; Fahn et al., 1987). The scale is subdivided into four sections. The motor examination, part III, involves the individual with Parkinson's undertaking several motor tasks under the observation of a rater, such as finger and toe tapping. In the current study the examination was used to assess the extent of motor severity. The examination consists of 18 items rated on an 0-4 scale across different limbs, with each score representing a progressive increase in impairment (see appendix 9). A maximum score of 132 indicates that the individual experiences all the motor symptoms featured in the examination across all limbs (upper, lower and neck/jaw) at a frequency/intensity that severely impacts on daily functioning.

5.2.4 Procedure

All equipment was calibrated using the same computer so that each device was synchronised to the same time piece. Individual testing sessions lasted approximately 3-4 hours. Participants arrived having fasted for two hours, and completed demographic and anthropometric measures before undertaking any of the tasks. Participants with Parkinson's also completed the MH&Y scale and the MDS-UPDRS motor subsection. The participants were then helped with putting on the heart rate monitor, accelerometers and gas analyser. These were worn concurrently for the duration of the study.

Tasks included a rest session, followed by 3 different walking speed tasks, two dance tasks and two household tasks. For the rest session the participant sat still in a chair for 20 minutes. The data from this session was used to obtain resting state measures for oxygen consumption and movement. While previous studies have required participants to lie in the supine position (Phillips et al., 2013, Powell et al., 2017 and Sanders et al., 2019), the height of the physiotherapist table available in the sports laboratory was not appropriate for use with participants with reduced balance and mobility. Each participant was instructed to rest for at least five minutes between tasks. Due to equipment issues participants completed a minimum of 7 tasks, always including the rest session. Borg's RPE scale was used immediately after each task to assess the level of perceived effort.

5.2.4.1 Walking tasks

Participants completed the walking tasks in order of highest to lowest intensity to prevent fatigue effects. Participants walked for 3 minutes following a 34-meter indoor circular track at three different self-paced speeds: brisk, normal and slow (in line with Nero et al., 2015). The participant was given a 15 second countdown to the start of the walk and a 10 second countdown to the end of the task. Halfway through each walk the researcher verbally acknowledged the pace of the participant as a prompt to ensure they maintained their pace. The total distance the participant travelled (in meters) was recorded and used to calculate speed in km/h.

For the brisk pace participants were instructed to walk at a pace they would adopt if they were running late to catch a bus. For the normal pace walk participants were instructed to walk at a casual pace that was easy to maintain, such as if they were walking to the shops but without any time pressure. For the slow pace participants were instructed to walk at pace similar to a leisurely amble, such as when walking around a museum. An extreme example was given as pilot testing had indicated that participants had difficulties reducing their speed such that it differed from normal pace.

5.2.4.2 Dance tasks

Participants were presented with video clips of an instructor demonstrating two different dance routines. Each clip began with a practice session to familiarise participants with the movements. After one full sequence an instructional slide notified the participant of the start of the actual testing session. Both dance routines were taken from the dance class held at the University of Hertfordshire and were appropriate for people with differing levels of mobility. One routine primarily consisted of arm movements intended to mimic Bollywood style movements and was performed to the song Jai Ho by the artists A.R. Rahman and The Pussycat Dolls (video clip of the dance routine: https://youtu.be/-mxMLo9a7LE. The second routine focused on leg movements and was performed to the song Tell Me Ma by the artist Sham Rock (video clip: https://youtu.be/GuUfDb8Me8Y).

5.2.4.3 Household tasks

Participants undertook two different household tasks. They were asked to sweep a predefined area with a broom for 10 minutes. To make the task more realistic shredded paper was dispersed across the floor for participants to sweep. Participants were also asked to wash and dry an assortment of objects for 10 minutes.

5.3 Results

5.3.1 Demographic results

Participants with Parkinson's (MH&Y score 1-3) had an average age of 56.77 years (SD= 10.69) at diagnosis, years living with the condition was 6.23 (SD= 4.73) and UPDRS part III motor score was 17.54 (SD= 7.94). A Kolmogorov-Smirnov Z test (see Table 5.1) indicated there were no significant differences between the Parkinson's and control group for the demographic measures. A two-sided Fisher's Exact Test indicated that the participant groups did not significantly differ in self-reported hours (> 4 hours vs < 4 hours) spent exercising during the week (*p*=0.23).

Table 5.1 Demographic data (mean [SD]) for the Parkinson's and age-matched group.

Demographic measures		Group		Kolmogorov-Smirnov Z	
		Parkinson's	Age-matched		
Height (cm)		169.31 (9.78)	165.65 (10.91)	Z = 0.98	p = 0.29
Weight (kg)		83.31 (11.88)	68.65 (15.92)	Z = 1.18	p = 0.13
BMI (kg/m^2)		29.16 (4.81)	24.84 (4.62)	Z =0.98	p = 0.29
Age (years)		62.92 (9.31)	67.00 (10.19)	Z = 0.78	p = 0.57
Sex	Male	7	5		
	Female	6	8		
Handedness	Left	-	2		
	Right	12	11		
	Ambidextrous	1	-		

5.3.2 Generating validated cut-points using ROC analysis

5.3.2.1 Data processing

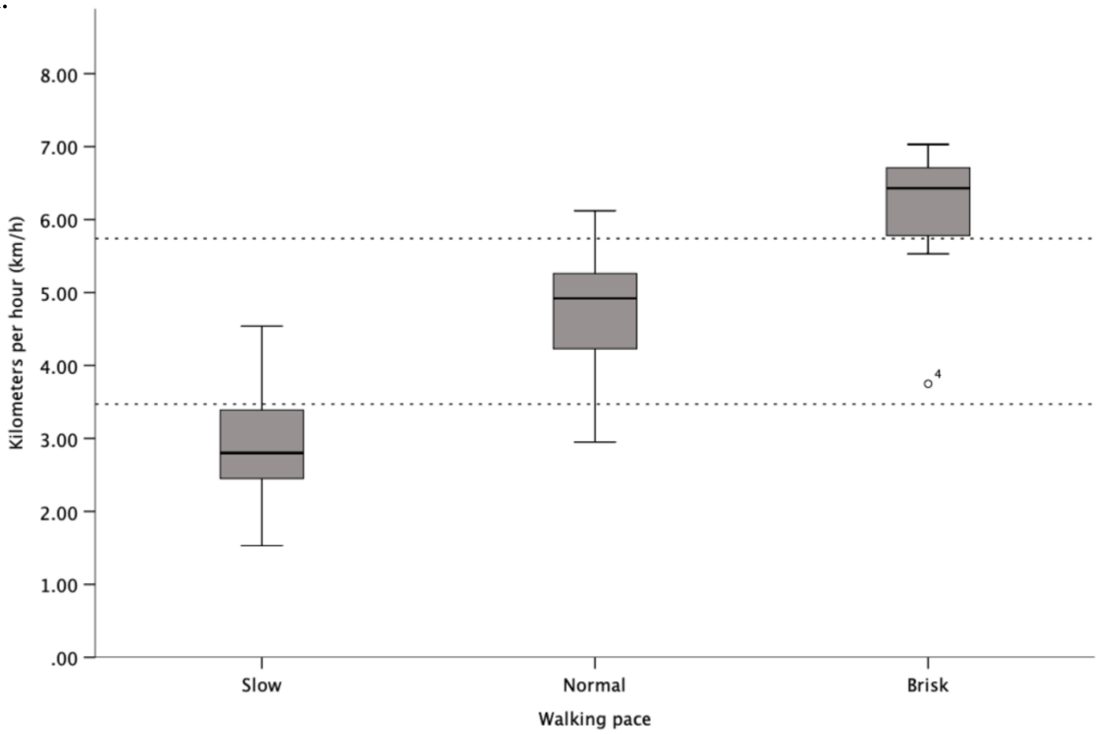
5.3.2.1.1 Movement data

The .bin file for each participant was converted to a 15 second epoch CSV file (as in Nero et al., 2015). Each CSV file provided the svm for each 15 second timestamp. The average volume of movement (using the svm) for the last ten minutes of the rest session was calculated to match the time period used for oxygen consumption. During pre-processing of the brisk and normal pace walking data it became evident that the accelerometers captured deacceleration during the last 15 seconds of the task. Therefore, the average volume of movement for the walking tasks was calculated for the middle of the three minutes e.g. using data starting at the first minute of the task. The household tasks were 10 minutes long, therefore, to reduce any effect of boredom might have had on the data the middle minute was also used to calculate the average volume of movement. The first few minutes of the dance tasks were a practice trial, therefore the last minute of the data was used to calculate average movement.

5.3.2.1.2 Restructuring of walking data for ROC analysis.

In order to facilitate the generation of accurate cut-point values, individual walking speeds for each walking task were used to reclassify the acceleration data in preparation for the ROC analysis, in line with previous research (Nero et al., 2015). For example, there were some participants whose walking speed for a given pace was closer to the average speed of a different pace e.g. they were asked to walk slowly but in fact walked at a normal pace. Therefore, these participants were reclassified as normal walking speed. To restructure the data the 75th percentile for the speed of the slow pace and the 25th percentile for the brisk pace task were used to define the lower and upper bounds of the normal pace walking task respectively. See Figure 5.2a and 5.2b for boxplots of the restructured data for the age-matched and Parkinson’s group respectively. Based on the restructured data the mean walking speed (km/h) and volume of movement (svm) were calculated for each walking pace, participant group and device location, see Table 5.2 for details. The effect of task and participant group on the unstructured svm data is reported in section 5.3.3.

5.2a.



5.2b

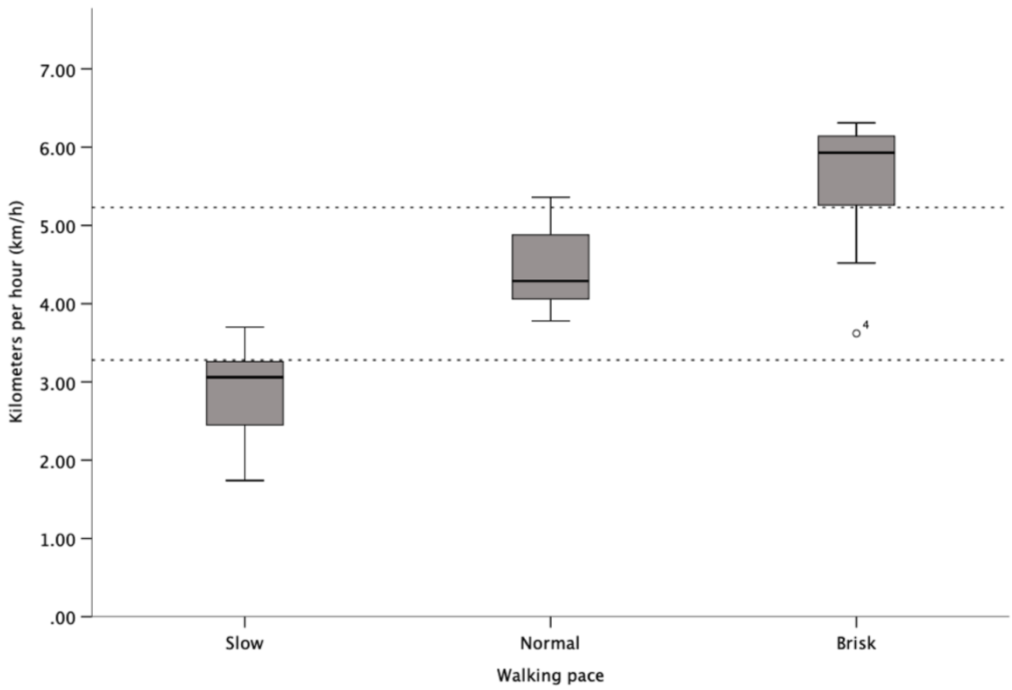


Figure 5.2 Boxplots showing the different walking paces in kilometres per hour for each participant group.
Fig 5.2a Age-matched group. The lower dotted line indicates the 75th percentile (3.47 km/h) for slow walking and the upper dotted line indicates the 25th percentile (5.74 km/h) for brisk walking. These percentiles were used to restructure the data for ROC analysis. Fig 5.2b Parkinson's group. The lower dotted line indicates the 75th percentile (3.28 km/h) for slow walking and the upper dotted line indicates the 25th percentile (5.23 km/h) for brisk walking.

Table 5.2 Summary statistics (mean and SD) for restructured data for each walking pace and participant group.

Walking pace	*Measures*		*Group*	
			Parkinson's	*Age-matched*
Brisk	N		9	12
	Speed (km/h)		6.01 (0.27)	6.43 (0.45)
	Device location	SVM at wrist	605.49 (357.84)	464.95 (120.74)
		SVM at ankle	1158.46 (131.78)	1170.34 (214.46)
		SVM at hip	521.89 (111.32)	525.58 (100.15)
Normal	N		17	16
	Speed (km/h)		4.38 (0.61)	4.67 (0.69)
	Device location	SVM at wrist	347.01 (102.97)	352.48 (196.69)
		SVM at ankle	712.82 (291.84)	786.72 (241.68)
		SVM at hip	299.52 (81.78)	301.87 (77.87)
Slow	N		10	11
	Speed (km/h)		2.70 (0.61)	2.62 (0.50)
	Device location	SVM at wrist	202.30 (98.66)	156.40 (54.78)
		SVM at ankle	388.15 (155.86)	370.77 (105.74)
		SVM at hip	140.00 (42	135.17 (41.35)

5.3.2.2 ROC analysis

ROC analysis is a non-parametric test therefore assumptions regarding sample size and distribution did not need to be met when generating cut-points. All statistical analyses were undertaken using IBM SPSS version 25. The ROC analyses were conducted separately in SPSS for the Parkinson's and age-matched group using the restructured data. Cut-points were generated for the brisk and slow paced walking tasks (in line with Nero et al., 2015) for each of the device locations, in addition to activity of moderate and light intensity.

Once restructured, the svm data for each device location (wrist, ankle and hip) were entered into separate columns in SPSS, with each row representing a single participant walking at a particular pace. A fourth column was created, and a label assigned in reference to the pace of the walk for which the svm were obtained i.e. brisk, normal or slow. In all, for the Parkinson's participants there were 9 rows of svm data entered into SPSS for the brisk walk, 17 rows for the normal paced walk and 10 for the slow walk. In order to calculate a cut-point for the brisk walk using the wrist data, a fifth column was created to binary code the data. The pace column was used to guide binary coding, such that rows labelled as brisk were assigned a 1. Rows labelled as normal or slow were assigned a 0 to represent data that were not brisk. ROC analysis was then undertaken using the wrist svm as the test variable and the binary coded variable as the state variable, specifying 1 as the value of interest. This process was then repeated using the data for the remaining device locations (ankle and hip) and then for the slow-paced walk. The resulting output were used to ascertain the statistical significance of the test and area under curve value (AUC; presented in Table 5.4). The sensitivity and specificity values were used to guide selection of the cut-point (see Figure 5.3).

A similar process was used to obtain cut-points for light and moderate activity. These were derived from a combination of the walking, dance and household tasks in order to represent general activity rather than only walking, a critique made by Porta, Pilloni, et al., (2018) of the cut-points from the Nero et al., (2015) study. Rather than walking speeds, tasks of different intensities were compared using ROC analysis to generate cut-point values. Inspection of the mean METs for each task and for each participant group (see appendix 7) indicated that the brisk and normal walk, in addition to the Irish dance and sweeping task were of moderate intensity (according to criteria as outlined by Tse et al., 2015) for the age-matched group. Tasks of moderate intensity were similar for the Parkinson's participants, apart from the sweeping task which was of a light intensity. The measured METs indicated that the slow walk, Jai ho dance and dish washing tasks were of light intensity for both participant groups, with the addition of the sweeping task for the Parkinson's group.

The svm data for each individual for each task, including the rest session, were entered into SPSS with a column per device location. Therefore, each participant contributed several rows of svm data, one row per each task type. Another column was created, and a label assigned to each row in reference to the intensity of the activity i.e. moderate, light or sedentary. In order to generate a cut-point for moderate intensity activity using wrist data, a column was created to binary code the data. A value of 1 was assigned to rows containing svm data for activities of moderate intensities (according to the METs as described above). A value of 0 was assigned to code for light activities. Rest data was not included in this analysis. The ROC analysis was undertaken in the same way as described above and the same output used to determine the appropriate cut-points (see Table 5.3). To generate a cut-point for light activity using wrist data, rows of svm data for light activity (as described above) were assigned a value of 1 and rest data were assigned a value of 0.

5.3.2.2.1 Walking speeds

In order to determine the cut-point value for the wrist using the brisk walk data for the Parkinson's participants, the ROC curve (see Figure 5.3) and corresponding values (see Table 5.3) were inspected. Inspection of these favoured higher specificity compared to sensitivity to reduce the possibility of misclassifying participants who walked slower (Nero et al., 2015). Examination of Table 5.3 indicated that there were three different specificity values corresponding to the sensitivity of 0.67. Therefore, the average was calculated to obtain a specificity of 82%. The cut-point for each of the three sensitivity and specificity values were also used to obtain an average of 427.25 (svm). The same process was then used to determine cut-point values for the ankle and hip wear locations for the brisk walk, and for all device locations for the slow walk for both participant groups. See Table 5.4 for cut-point values.

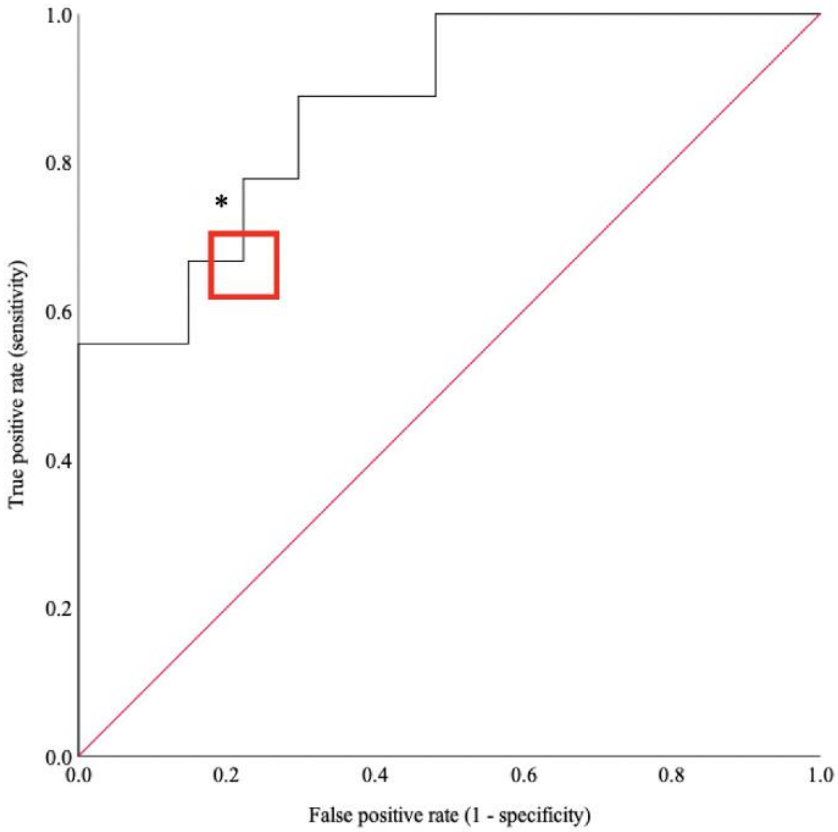


Figure 5.3 ROC curve using wrist accelerometer data for the Parkinson's group.
The * and red square denote the point on the curve that was used as the cut-point between brisk and normal walking. See Table 5.3 for the corresponding values.

Table 5.3 Wrist generated cut-point values between brisk and normal walking for Parkinson's participants and corresponding coordinates of the ROC curve.

Cut- point value	True positive rate (sensitivity)	False positive rate (specificity – 1)
81.92	1.00	1.00
103.73	1.00	0.96
126.33	1.00	0.93
145.68	1.00	0.89
164.75	1.00	0.85
167.17	1.00	0.82
171.40	1.00	0.78
194.21	1.00	0.74
219.85	1.00	0.70
229.84	1.00	0.67
234.08	1.00	0.63
237.34	1.00	0.59
245.65	1.00	0.56
264.96	1.00	0.52
283.80	1.00	0.48
298.93	0.89	0.48
311.02	0.89	0.44
327.79	0.89	0.41
348.42	0.89	0.37
358.85	0.89	0.33
370.94	0.89	0.30
388.13	0.78	0.30
400.94	0.78	0.26
406.85	0.78	0.22
411.71	0.67	0.22
424.81	0.67	0.19
445.20	0.67	0.15
455.65	0.56	0.15
461.12	0.56	0.11
475.16	0.56	0.07
490.10	0.56	0.04

Table 5.4 Cut-points generated from the ROC analysis for each walking speed, participant group and device location.

Group	*Device location*	*Speed (km/h)*	*Sensitivity (%)*	*Specificity (%)*	*AUC (95% CI)*	*Cut-point*
Parkinson's	Wrist	Brisk ≥5.23	67	82	0.87 (0.75-1.00)	>427.24
		Slow ≤3.28	90	61	0.90 (0.78-1.00)	<358.85
	Ankle	Brisk ≥5.23	89	100	0.98 (0.94-1.00)	>1071.72
		Slow ≤3.28	100	88	0.91 (0.81-1.00)	<588.18
	Hip	Brisk ≥5.23	89	96	0.97 (0.91-1.00)	>413.24
		Slow ≤3.28	100	85	0.99 (0.95-1.00)	<230.63
Age-matched	Wrist	Brisk ≥5.74	83	89	0.89 (0.79-1.00)	>379.95
		Slow ≤ 3.47	100	82	0.96 (0.91-1.00)	<269.10
	Ankle	Brisk ≥5.74	83	89	0.93 (0.85-1.00)	>948.255
		Slow ≤ 3.47	100	89	0.98 (0.95-1.00)	<611.67
	Hip	Brisk ≥5.74	92	96	0.99 (0.96-1.00)	>409.14
		Slow ≤ 3.47	100	93	0.98 (0.95-1.00)	<227.19

Note: All analyses significant at $p < 0.001$.

5.3.2.2.2 Moderate and light activity

Cut-points between physical activity of moderate and light intensity and light and sedentary intensity were calculated for both participant groups and device location (Table 5.6).

Before determining the cut-point value between moderate and light activity for the wrist for the Parkinson's participants, the statistical significance of the ROC analysis and AUC value were obtained. Next, inspection of the ROC graph (Figure 5.4) suggested that selecting the value of 0.64 for sensitivity and 0.38 for specificity resulted in the best balance between these parameters. Further examination of Table 5.5 indicated that for the specificity value of 0.38, there were two corresponding sensitivity values. Therefore, the cut-point for each of the sensitivity values were used to obtain an average of 249.33 (svm). The average was also calculated for the sensitivity and specificity values (63% and 62%, respectively). The cut-point values for the remaining wear locations and between activities of light and sedentary intensity were determined in the same way as described above for the Parkinson's and age-matched participants separately, see Table 5.6 for values.

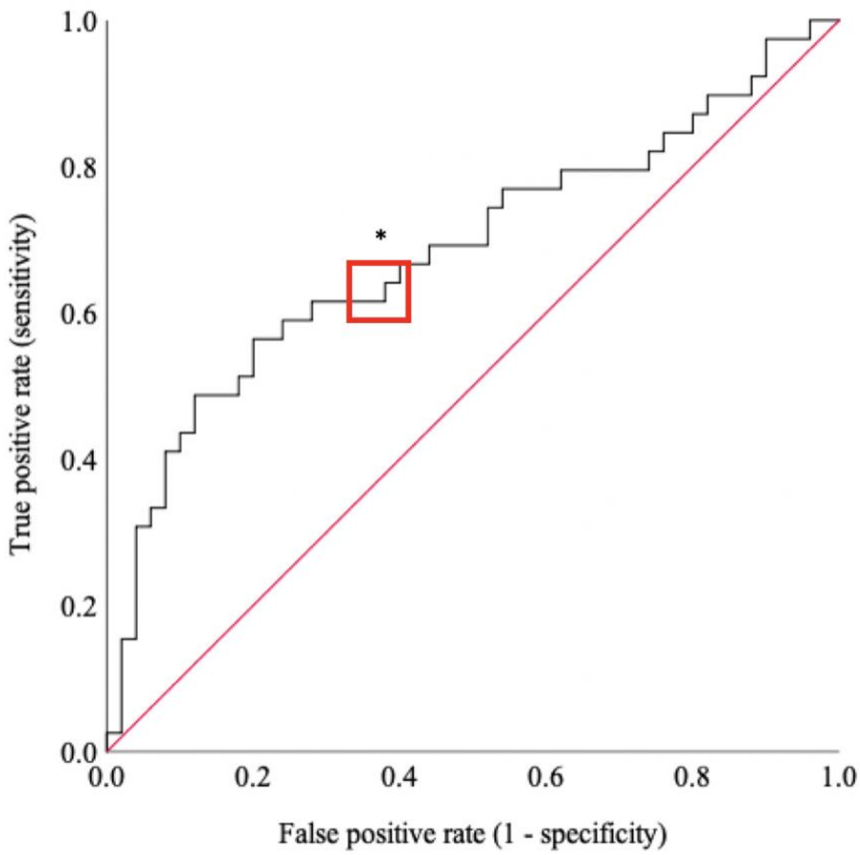


Figure 5.4 ROC curve using wrist accelerometer data for the Parkinson's group. The * and red square denote the point on the curve that was used to determine the cut-point between moderate and light intensity activity. See Table 5.5 for the corresponding values.

Table 5.5 Wrist generated cut-point values between moderate and light intensity for Parkinson's participants and corresponding coordinates of the ROC curve.

Cut-point value	True positive rate (sensitivity)	False positive rate (specificity- 1)
212.59	0.74	0.52
215.91	0.72	0.52
219.14	0.69	0.52
221.44	0.69	0.50
223.76	0.69	0.48
225.06	0.69	0.46
225.66	0.69	0.44
226.05	0.67	0.44
229.89	0.67	0.42
234.08	0.67	0.40
237.34	0.64	0.40
245.65	0.64	0.38
253.01	0.62	0.38
255.38	0.62	0.36
255.92	0.62	0.34
257.45	0.62	0.32
266.07	0.62	0.30
276.03	0.62	0.28
279.80	0.59	0.28
282.81	0.59	0.26
286.81	0.59	0.24
298.35	0.56	0.24
308.48	0.56	0.22
309.59	0.56	0.20
311.56	0.54	0.20
315.26	0.51	0.20
321.83	0.51	0.18
328.42	0.49	0.18
336.65	0.49	0.16
343.44	0.49	0.14
349.28	0.49	0.12

Table 5.6 Cut-points for moderate and light physical activity intensity levels for participant group and device location.

Intensity	*Group*	*Device location*	*Sensitivity (%)*	*Specificity (%)*	*AUC (95% CI)*	*Cut-point (svm)*
Moderate	Parkinson's	Wrist	0.63	0.62	0.686 (0.570-0.802)	≥ 249.33
		Ankle	0.82	0.77	0.867 (0.788-0.946)	≥ 209.39
		Hip	0.82	0.82	0.921 (0.868-0.974)	≥ 135.19
	Age-matched	Wrist	0.65	0.69	0.683 (0.571-0.795)	≥ 259.05
		Ankle	0.69	0.67	0.843 (0.761-0.925)	≥ 243.98
		Hip	0.79	0.71	0.842 (0.763-0.920)	≥ 79.82
Light	Parkinson's	Wrist	0.80	0.85	0.954 (0.898-1.000)	≥ 142.35
		Ankle	0.79	0.69	0.798 (0.669-0.928)	≥ 28.94
		Hip*	0.95	0.75	0.950 (0.900-1.000)	≥ 12.65
	Age-matched	Wrist	0.97	1.00	1.000 (1.000-1.000)	≥ 99.87
		Ankle	0.82	0.77	0.852 (0.747-0.957)	≥ 23.52
		Hip	0.92	0.81	0.960 (0.912-1.000)	≥ 14.50

Note: All analyses significant at $p < 0.05$.
*data missing for one participant.

5.3.3. Exploring energy expenditure, volume of movement and perceived exertion

5.3.3.1 Data processing

Movement data was processed as described in section 2.1.4.1.2. In order to maintain consistency across all data processing, the average MET per mid minute for the walking and household tasks and per last minute of each dance task was calculated using the gas analysis data. To account for the additional weight of the device worn on the harness and the effect this might have had on energy expenditure, weight adjusted $\dot{V}O_2$/kg was calculated for each task ($\dot{V}O_2$ litres per min*1000/weight (inclusive of the gas analyser)). Individualised resting metabolic rate (RMR) were calculated for each participant using the average weight adjusted $\dot{V}O_2$/kg for the last ten minutes of the rest task (Bassett, 2000; Swartz et al., 2000). The rest task required the participant to sit as oppose to lie for 20 minutes, therefore the RMR in the current study is not a true resting rate. Adjusted METs were calculated for each task by dividing the weight adjusted $\dot{V}O_2$/kg by the RMR. The last step was to calculate the average MET for each task using the adjusted METs.

The average heart rate (bpm) was calculated for each participant for each task, including the rest session. Due to a high level of variation in data within and between participants, heart rate data was excluded from statistical analysis. The average heart rate is reported in appendix 7. To remain consistent with the data used for movement and oxygen consumption, where possible the average of the middle minute was calculated for the walking and household tasks and of the last minute for the dance tasks. However, there were some data files where the last or first minute was used for walking tasks.

5.3.3.2 Data analysis

All statistical analyses were undertaken using IBM SPSS version 25. Normality of data was checked using the Shapiro-Wilk test. Upon violation of the assumption of normality ($p < 0.05$), ANOVA was still undertaken as it has been shown to be robust in detecting significant differences between means and minimising type 1 error (Blanca et al., 2017). The Greenhouse-Geisser correction was applied upon violation of Mauchly's test of sphericity for ANOVAs ($P < 0.05$).

To investigate differences in energy expenditure between group and task, a 2 (group: Parkinson's x age-matched controls) x 7 (task: brisk walk, normal walk, slow walk, Irish dance, Jai ho dance, Dish washing and Sweeping) mixed ANOVA was undertaken. Bonferroni-corrected planned contrasts were used to follow up any significant main effects or, interaction of group and task type. Different tasks were used to obtain METs representing different activity intensities, therefore analysis compared the brisk paced walking task to the normal and slow-paced walking tasks, to confirm the effect of pace on energy expenditure. The analysis also compared the brisk paced walking task to each of the dance tasks to investigate whether the energy expended while dancing differed to an activity of moderate intensity. Lastly, analysis compared brisk paced walking to each household task to investigate whether the energy expended undertaking typical everyday household chores differed to an activity of moderate intensity.

A 2 (group: Parkinson's x age-matched controls) x 7 (task: brisk walk, normal walk, slow walk, Irish dance, Jai ho dance, Dish washing and Sweeping) x 3 (device location: wrist, ankle and hip) mixed ANOVA was undertaken to investigate differences in volume of movement between group, task and device wear location. Group was a between-subjects factor and, task and location were within-subjects factors. The Levene's assumption of homogeneity of variances was met for 19 of the 21 combinations of the two within-subjects factors (excluded Jai Ho and ankle, and Jai Ho and hip combinations. Bonferroni-corrected planned contrasts were used to follow up any significant main effects and interactions. Specifically, the current study aimed to investigate whether task type had an effect on volume of movement, as would be indicated from the planned comparisons between the brisk walking pace and the other paced walking, dance and household tasks. The analysis also compared wrist and hip conditions to investigate the effect of device location on volume of movement, in addition to comparing the wrist to the ankle condition.

A two-way mixed ANOVA with participant group as the between subjects factor and task as the within subjects factor (7 levels; brisk, normal, slow, Irish dance, Jai ho dance, dish washing and sweeping) was undertaken to examine the effect of group and task on RPE. Bonferroni-corrected planned contrasts were used to follow up any significant main effects and interactions.

Effect sizes are reported as Pearson's r for all planned contrasts (as recommended by Field, 2013), where effects were classified as small (0.10-0.29), moderate (0.30-0.49) and large (>0.50; Cohen, 1988, 1992).

Linear regression was used to predict METs from i) svm derived from a wrist-worn accelerometer , ii) svm derived from an ankle-worn device , iii) svm derived from a hip-worn device, and iv) svm for wrist, ankle and hip locations combined for all walking tasks. Significance was set at α = 0.05.

Linear regression was also used to determine whether RPE significantly predicted energy expenditure (METs), separately for the Parkinson's and age-matched group, using data from each participant for all 7 tasks.

Finally, linear regression was also used to determine whether RPE significantly predicted wrist-derived volume of movement, separately for the Parkinson's and age-matched group, using the data from all tasks.

5.3.3.3 Results

5.3.3.3.1 Energy expenditure

Due to issues with the spiroergometry device three participants with Parkinson's were missing data for the household tasks. Three age-matched participants were missing data, one per dance task, and one participant was missing data for all seven tasks. Examination of boxplots for the METs for each task type indicated extreme outliers; one for both dance tasks (the same participant), and four for the brisk walking task. The results of the analysis reported below includes all outliers as removing them did not alter the results. Therefore, the final analysis included data from 10 participants per group. Levene's test indicated that the assumption of homogeneity of variances was met for all levels of the within-subjects variable of task ($p > 0.05$).

The analysis revealed a significant main effect of task type on energy expenditure, $F(2.74, 49.37) = 36.93$, $p < 0.001$. Planned contrasts revealed that the energy expended for the brisk walking task (mean = 4.17, SE = 0.32) was significantly higher compared to the normal paced walk ($F(1, 18) = 28.10$, $p < 0.001$, $r = 0.78$; mean = 3.18, SE = 0.18), the slow paced walk ($F(1, 18) = 56.69$, $p < 0.001$, $r = 0.87$; mean = 2.39, SE = 0.13), the Irish dance ($F(1, 18) = 19.92$, $p < 0.001$, $r = 0.72$; mean = 3.15, SE = 0.24), the Jai ho dance ($F(1, 18) = 58.00$, $p < 0.001$, $r = 0.87$; mean = 2.47, SE = 0.19), sweeping ($F(1, 18) = 24.15$, $p < 0.001$, $r = 0.76$; mean = 2.91, SE = 0.17) and dish washing task ($F(1, 18) = 76.32$, $p < 0.001$, $r = 0.51$; mean = 1.80, SE = 0.12). See Figure 5.5.

There was no effect of participant group, indicating that the amount of energy expended while undertaking the tasks in the laboratory did not differ between people with Parkinson's (mean = 2.75, SE = 0.24) and age-matched controls ($F(1, 18) = 0.54$, $p = 0.47$, mean = 3.00, SE = 0.24). The analysis also revealed that there was no significant interaction between task and group, $F(2.74, 49.37) = 1.14$, $p = 0.34$.

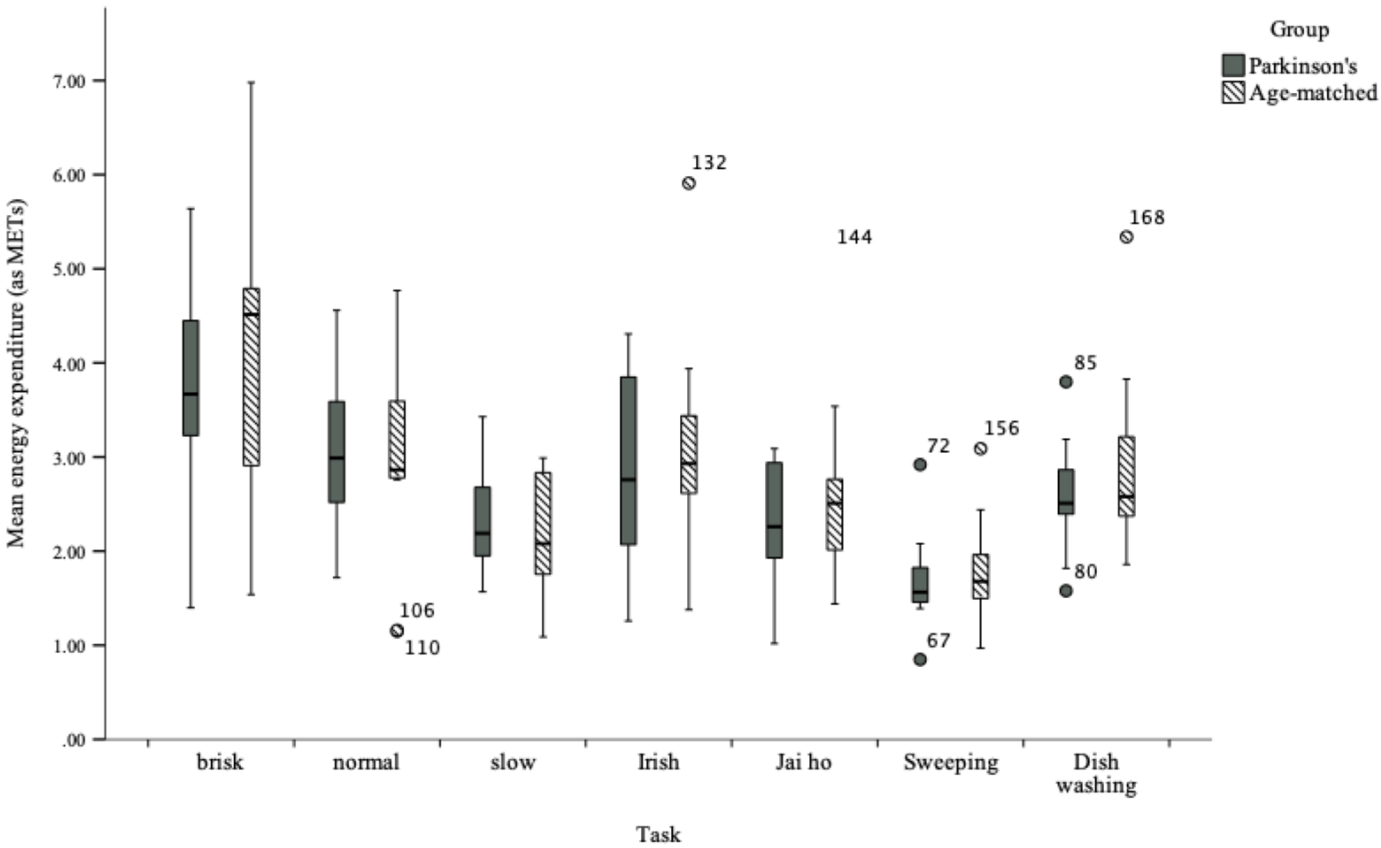


Figure 5.5 Mean values for energy expenditure for the Parkinson's and age-matched groups for each task.
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

5.3.3.3.2 Volume of movement

Due to issues with the spiroergometry device two participants with Parkinson's were missing data for the sweeping task for all three device locations and one age-matched control was missing data for the dish washing task for all device locations. Therefore, the final analysis used the unstructured svm data of 11 people with Parkinson's and 12 age-matched controls. The Levene's assumption of homogeneity of variances was met for 19 of the 21 combinations of the two within-subjects factors (excluded Jai Ho and ankle, and Jai Ho and hip combinations).

Effect of group, group by task and group by location interaction

There was no significant effect of participant group, indicating the volume of movement made by people with Parkinson's was similar to age-matched controls, $F(1, 21) = 382.04$, $p = 0.52$, see Table 5.7. There was no significant interaction effect between task and participant group ($F(2.18, 45.82) = 0.76$, $p = 0.49$) or between device location and participant group ($F(2, 42) = 0.40$, $p = 0.67$). There was no significant interaction effect between task type, device location and participant group, $F(3.109, 65.28) = 1.65$, $p = 0.18$.

Effect of task

The analysis revealed a significant main effect of task on volume of movement, $F(2.18, 45.82) = 168.51$, $p < 0.001$. Contrasts revealed that the volume of movement made for the brisk paced walk (mean = 695.66, SE = 40.58) was significantly higher compared to the normal paced walk ($F(1, 21) = 91.99$, $p < 0.001$, $r = 0.90$, mean = 456.22, SE = 24.33) and the slow paced walk ($F(1, 21) = 181.77$, $p < 0.001$, $r = 0.95$, mean = 253.10, SE = 17.63). This finding confirmed that manipulation of walking pace resulted in different volumes of movement for each walking task. The volume of movement made for the brisk walk was also significantly higher compared to the Irish dance ($F(1, 21) = 225.33$, $p < 0.001$, $r = 0.96$, mean = 191.72, SE = 17.54), Jai Ho dance ($F(1, 21) = 225.85$, $p < 0.001$, $r = 0.96$, mean = 153.30, SE = 11.01), sweeping ($F(1, 21) = 226.96$, $p < 0.001$, $r = 0.96$, mean = 167.97, SE = 12.31) and dish washing ($F(1, 21) = 252.21$, $p < 0.001$, $r = 0.96$, mean = 72.57, SE = 6.05).

Main effect of device location

There was a significant main effect of device location on volume of movement, $F(2, 42) = 59.72$, $p < 0.001$. Contrasts revealed that the volume of movement recorded by the device worn at the wrist (mean = 287.80, SE = 22.54) was significantly higher compared to the device worn at the hip ($F(1, 21) = 35.45$, $p < 0.001$, r = 0.79, mean = 174.38, SE = 8.22), suggesting that a device worn on the wrist recorded a greater amount of movement across all locomotive and household tasks. However, the volume of movement recorded by the device worn at the wrist was significantly lower compared to the device worn at the ankle ($F(1, 21) = 19.20$, $p < 0.001$, $r = 0.69$, mean = 390.91, SE = 21.27).

The task x location interaction

There was a significant interaction effect between task type and device location, $F(3.109, 65.28) = 97.25$, $p < 0.001$, indicating that the volume of movement for different tasks differed according to device wear location. Simple contrasts compared each level of task to the brisk walk across each level of location compared to the wrist placement. The first contrast revealed a significant effect of interaction when comparing the wrist location to the ankle for the brisk walk and normal walk ($F(1, 21) = 7.24$, $p = 0.014$, $r = 0.51$), with the volume of movement lower for the normal walk compared to brisk walk for both device locations, but this decrease was more pronounced for the ankle (ankle brisk: mean = 1089.93, SE = 63.87; ankle normal: mean = 752.79, SE = 44.6; wrist brisk: mean = 515.49, SE = 57.40; wrist normal: mean = 313.03, SE = 19.48, see Figure 5.6).

The second contrast revealed a significant effect of interaction when comparing the wrist location to the ankle for the brisk walk and slow walk ($F(1, 21) = 32.89$, $p < 0.001$, $r = 0.78$), with the volume of movement lower for the slow walk compared to brisk walk for both device locations, but this decrease was more pronounced for the ankle (ankle slow: mean = 415.69, SE = 30.52; wrist slow: mean = 186.63, SE = 14.59, Figure 5.6).

The third contrast revealed a significant effect of interaction when comparing the wrist location to the ankle for the brisk walk and Irish dance ($F(1, 21) = 105.34$, $p < 0.001$, $r = 0.83$), with the volume of movement lower for the Irish dance compared to brisk walk for both device locations, but this decrease was more pronounced for the ankle (ankle Irish: mean = 248.65, SE = 22.10; wrist Irish: mean = 198.01, SE = 32.10, Figure 5.6).

The fourth contrast revealed a significant effect of interaction when comparing the wrist location to the ankle for the brisk walk and Jai ho dance ($F(1, 21) = 162.60$, $p < 0.001$, $r = 0.94$), with the volume of movement lower for the Jai ho dance compared to brisk walk for both device locations, but this decrease was more pronounced for the ankle (ankle Jai ho: mean = 58.15, SE = 5.00; wrist Jai ho: mean = 343.46, SE = 30.18, Figure 5.6).

The fifth contrast revealed a significant effect of interaction when comparing the wrist location to the ankle for the brisk walk and sweeping task ($F(1, 21) = 125.36$, $p < 0.001$, $r = 0.93$), with the volume of movement lower for the sweeping task compared to the brisk walk for both device locations, but this decrease was more pronounced for the ankle (wrist sweeping: mean = 286.07, SE = 24.21; ankle sweeping: mean = 145.40, SE = 15.98, Figure 5.6).

The sixth contrast revealed a significant effect of interaction when comparing the wrist location to the ankle for the brisk walk and dish washing task ($F(1, 21) = 133.79$, $p < 0.001$, r = 0.93), with the volume of movement lower for the dish washing task compared to the brisk walk for both device locations, but this decrease was more pronounced for the ankle (ankle dish washing: mean = 25.76, SE = 2.80; wrist dish washing: mean = 171.90, SE = 15.24, Figure 5.6)

Further contrasts revealed a significant effect of interaction when comparing the wrist location to the hip for the brisk walk and Jai ho dance task ($F(1, 21) = 47.82$, $p < 0.001$, $r = 0.83$), with the volume of movement lower for the dance task compared to the brisk walk for both device locations, but this decrease was more pronounced for the hip (hip brisk: mean = 481.55, SE = 26.99; hip Jai ho: mean = 58.30, SE = 5.70, Figure 5.6).

A significant effect of interaction was found when comparing the wrist location to the hip for the brisk walk and sweeping task ($F(1, 21) = 19.34$, $p < 0.001$, $r = 0.69$), with the volume of movement lower for sweeping compared to the brisk walking task for both the hip and wrist location, but this decrease was more pronounced for the hip (hip sweeping: mean = 72.44, SE = 6.06, Figure 5.6).

A significant effect of interaction was found when comparing the wrist location to the hip for the brisk walk and dish washing task ($F(1, 21) = 8.75$, $p = 0.008$, $r = 0.54$), with the volume of movement lower for dish washing compared to the brisk walking task for both the hip and wrist location, but this decrease was more pronounced for the hip (hip dish washing: mean = 20.06, SE = 1.82, Figure 5.6).

No significant effect of interaction was found when comparing the wrist to the hip for the brisk compared to normal the paced walk ($F(1, 21) = 0.31$, $p = 0.584$, hip normal: mean = 302.83, SE = 17.57), slow paced walk ($F(1, 21) = 0.01$, $p = 0.918$, hip slow: mean = 156.98, SE = 11.83) and the Irish dance task ($F(1, 21) = 2.02$, $p = 0.170$, hip Irish: mean = 128.50, SE = 9.34, Figure 5.6).

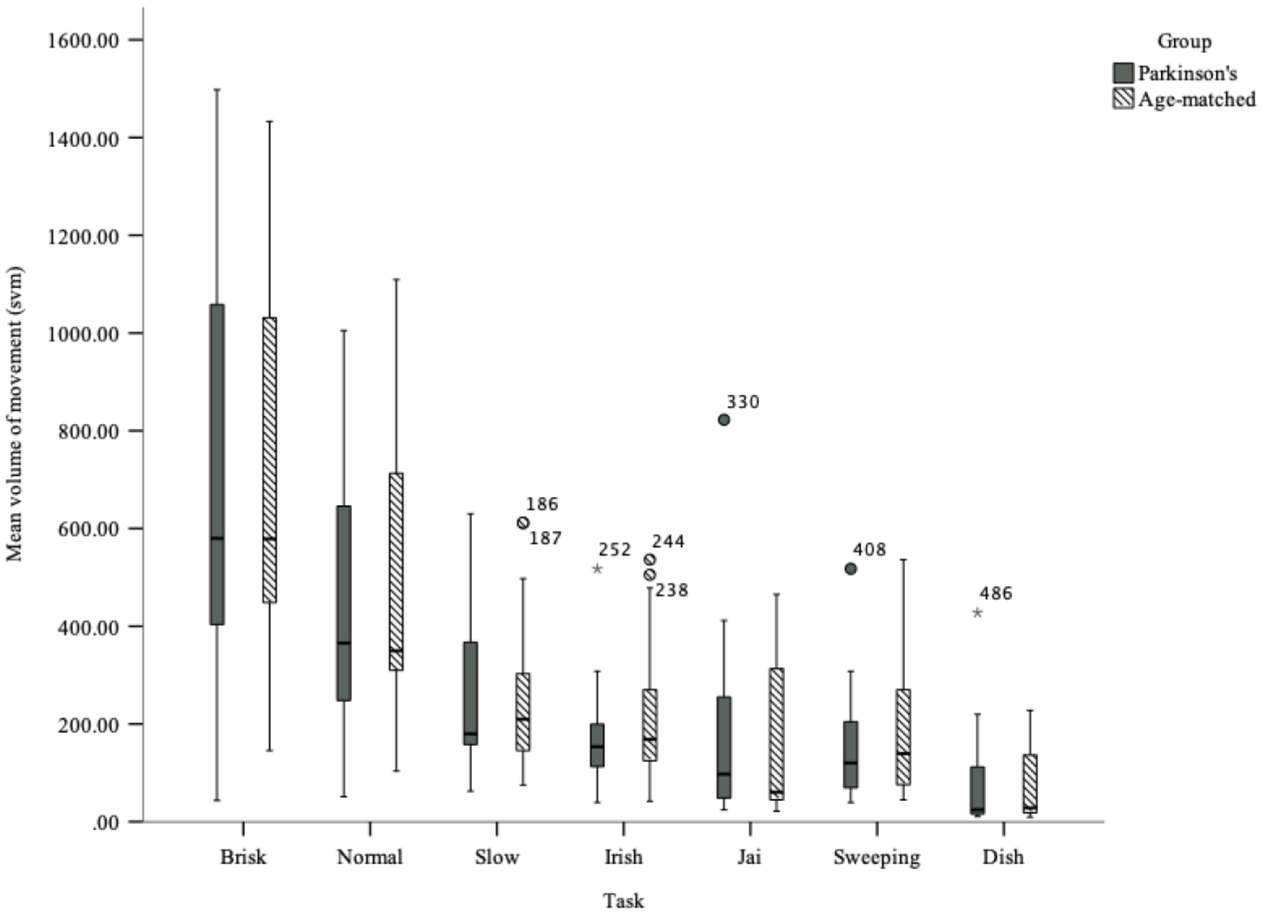


Figure 5.6 Mean values for volume of movement for the Parkinson's and age-matched group*s* for each task.
Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

Table 5.7 Mean volume of movement (svm) and standard deviation presented for task, device location and participant group.

Task	*Device location*	*Group*	
		Parkinson's	*Age-matched*
Brisk	Wrist	523.44 (332.12)	507.54 (210.02)
	Ankle	1008.38 (343.08)	1171.48 (267.91)
	Hip	455.35 (118.18)	507.76 (138.62)
Normal	Wrist	318.68 (108.08)	307.38 (77.49)
	Ankle	713.84 (249.91)	791.73 (174.50)
	Hip	283.95 (82.60)	321.72 (85.58)
Slow	Wrist	195.22 (79.12)	178.05 (60.27)
	Ankle	426.53 (166.80)	404.86 (124.60)
	Hip	154.58 (53.49)	159.39 (59.41)
Irish dance	Wrist	211.51 (196.65)	184.51 (99.98)
	Ankle	228.71 (110.28)	268.59 (101.77)
	Hip	123.36 (38.28)	133.64 (49.92)
Jai ho dance	Wrist	332.01 (176.78)	354.90 (107.21)
	Ankle	66.97 (33.44)	49.32 (8.90)
	Hip	67.63 (35.54)	48.96 (16.51)
Sweeping	Wrist	241.18 (114.93)	330.95 (116.91)
	Ankle	131.85 (42.21)	158.94 (97.86)
	Hip	67.30 (20.25)	77.58 (35.20)
Dish washing	Wrist	175.96 (98.90)	167.83 (35.90)
	Ankle	23.57 (11.54)	27.96 (14.88)
	Hip	21.47 (10.65)	18.65 (6.53)

5.3.3.3.3 Rating of perceived exertion

Due to equipment error two participants with Parkinson's and one age-matched control were unable to complete the sweeping and dishwashing tasks, respectively. Therefore, these participants were missing RPE ratings for these tasks and subsequently were not included in the analysis.

Examination of Q-Q plots and histograms of the RPE scores for each task at each level of participant group indicated non-normal distribution of the data. A boxplot indicated one extreme outlier for the brisk walk, a participant with Parkinson's who was also an outlier for the normal paced walking task. The participant's data was not included in the analysis. Inspection of Levene's test for homogeneity of variances indicated that this assumption was not for three of the tasks: normal paced walking, the Irish dance and sweeping ($p < 0.05$). Mauchly's test of sphericity indicated that the assumption of sphericity was met ($p > 0.05$).

The final data set included 10 participants in the Parkinson's and 12 in the age-matched group.

The results of the ANOVA confirmed a significant main effect of task, $F(6,120)= 31.91$, $p<0.001$, as indicated in Figure 5.7. Bonferroni adjusted pairwise comparisons indicated that ratings of perceived exertion were significantly higher for brisk walking (mean = 12.21) compared to normal walking (mean = 9.35, $p <0.001$), slow walking (mean = 7.35, $p <0.001$), jai ho (mean = 10.26, $p <0.05$) and dish washing (mean = 7.58, $p <0.001$). Ratings of perceived exertion were significantly higher for normal paced walking compared to slow walking ($p <0.001$), dish washing ($p <0.05$) and significantly lower compared to Irish dancing (mean = 11.06, $p < 0.05$). Ratings of exertion for slow paced walking were significantly lower compared to jai ho ($p < 0.001$), Irish dancing ($p <0.001$) and sweeping (mean = 10.65, $p <0.001$). Perceived exertion scores for the jai ho dance task were significantly higher compared to dish washing ($p <0.001$). Likewise, the RPE scores for the Irish dance task were significantly higher compared to the dish washing task ($p <0.001$). The RPE scores for the sweeping task were significantly higher compared to the dish washing task ($p = 0.001$). There was also a significant main effect of group, $F(1,20)= 11.22$, $p <0.05$ with the RPE scores significantly greater for the Parkinson's group (mean = 10.49, SE = 0.31) compared to the controls (mean = 9.07, SE = 0.29). There was no significant interaction between task and group, $F(6, 120) = 0.59$, $p = 0.74$.

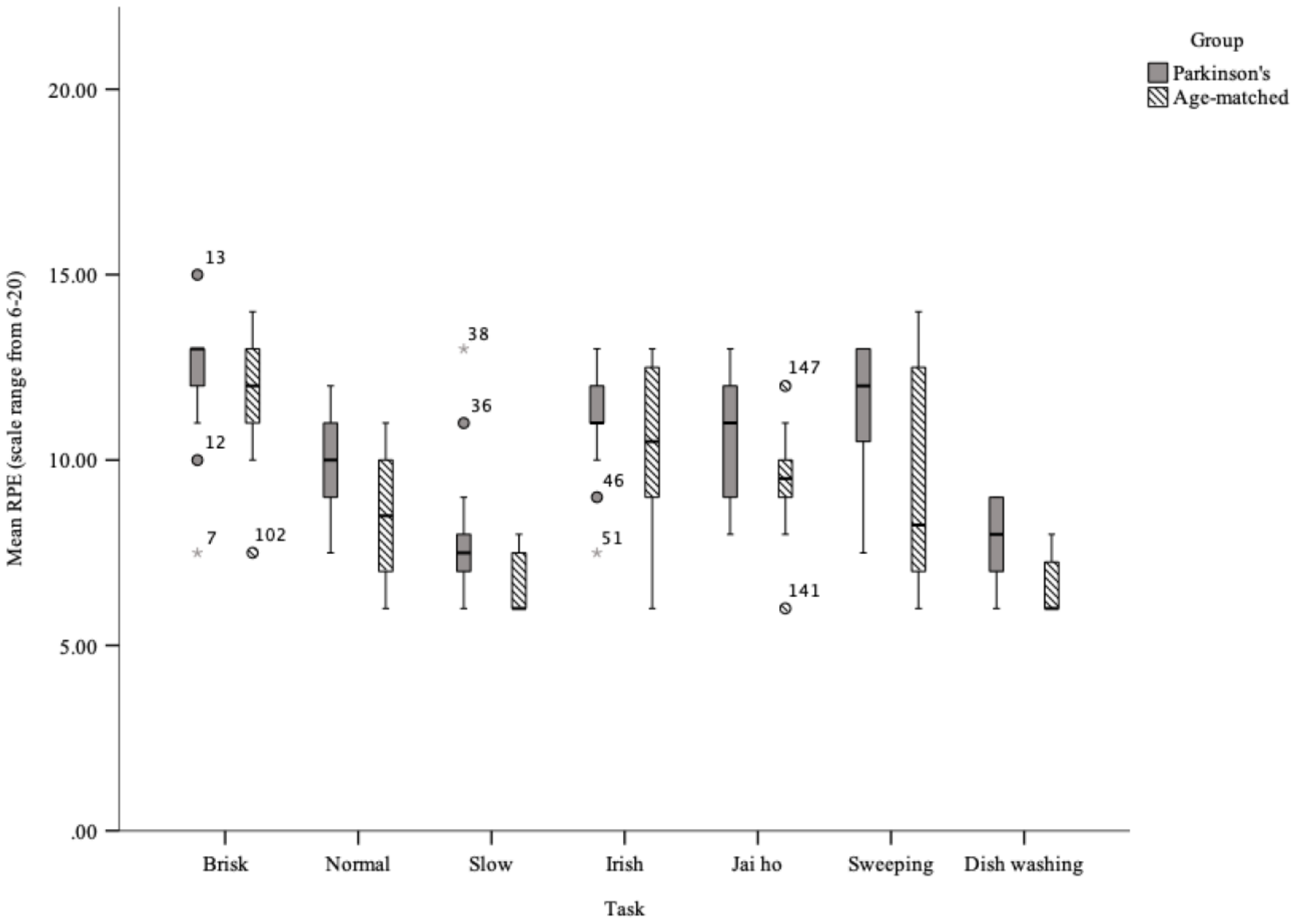


Figure 5.7 Mean values for RPE for the Parkinson's and age-matched group*s* for each task. Solid line = median; Whiskers: upper whisker = min(max(x), Q_3 + 1.5 * IQR); lower whisker = max(min(x), Q_1 – 1.5 * IQR).

5.3.3.3.4 Predicting METs from sum of vector magnitudes

There was no significant difference in the volume of movement between participant groups for the walking tasks, therefore the analysis for the regression was undertaken using all group data combined. Due to an error with the spiroergometry device, one participant was missing METs data for all tasks, resulting in 75 data points (3 walking tasks and n = 26). Checks for outliers, using centred leverage values, indicated three influential cases. These cases were not included in any of the analyses. Inspection of Cook's distance values indicated that no cases exceeded 1. Inspection of individual P-P plots indicated normal distribution of svm data derived from the wrist and ankle-worn devices, in addition to the METs data. There was some evidence of slight skew for the hip-derived svm data. Checks for homoscedasticity indicated unequal variances for the ankle and hip-derived svm data. Therefore, bootstrapping was used to obtain robust bias corrected confidence intervals (BCa CI) for the Pearson correlation and regression (as recommended by Field, 2013).

Pearson's correlation coefficients were calculated to check the relationship between movement data from each device location (wrist, ankle and hip) and measured METs. All correlations were statistically significant and coefficients indicated a relationship of moderate effect size (as outlined by Field, 2013) between METs and svm for all device locations, see appendix 10 for coefficients.

The results of three separate linear regression analyses indicated wrist svm (r = .307, b= .002 [BCa CI = .001-.004], p = .007, R^2 = .094, shown in Figure 5.8), ankle svm (r = .421, b= .001 [BCa CI = .001-.002], p = .002, R^2 = .177, see Figure 5.9) and hip svm (r = .440, b= .003 [BCa CI = .001-.005], p = .001, R^2 = .193, see Figure 5.10) all significantly predicted energy expenditure (METs). Accounting for the hip and ankle location in addition to the wrist significantly improved the correlation (r = .484, p = .003) and accounted for an additional 14% of variance in METs compared to the wrist alone, which accounted for 9.4% of variance. However, closer inspection of the bootstrapped coefficients indicated that when all locations were entered into the same model, only the wrist svm (b = -.003, p = .031, BCa CI = -.007, -.001) and hip (b = .005, p = .001, BCa CI = -.001, -.010) remained significant predictors of energy expenditure, thus indicating that the addition of the ankle svm did not significantly improve the model.

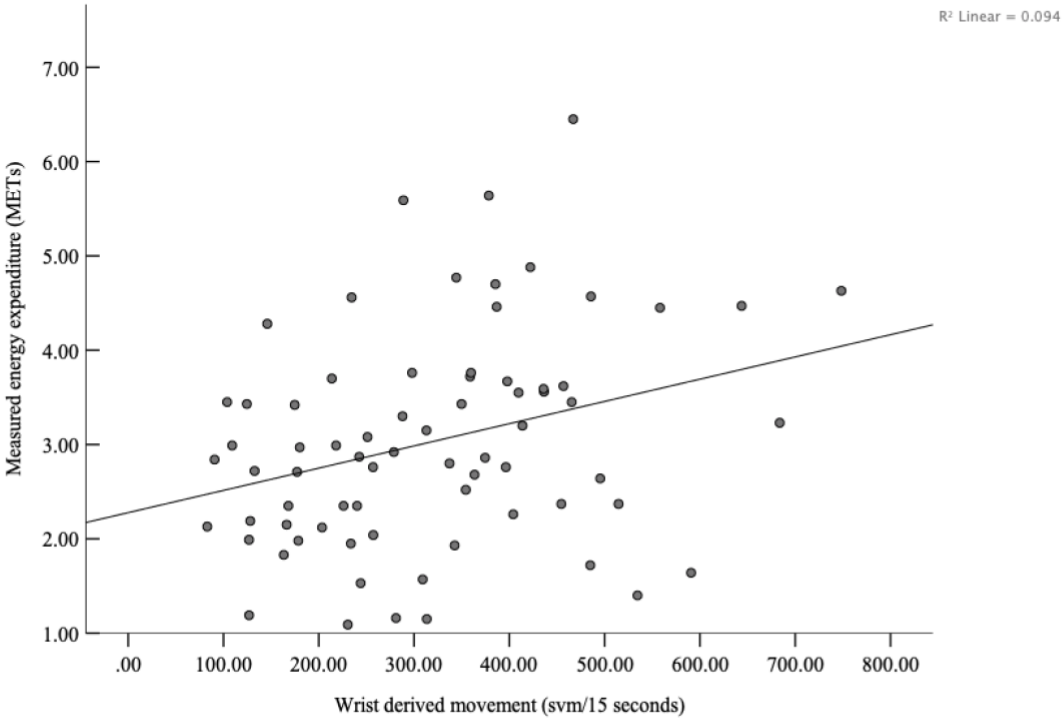


Figure 5.8 The relationship between mean METs and total svm as measured by the wrist-worn accelerometer for all walking tasks

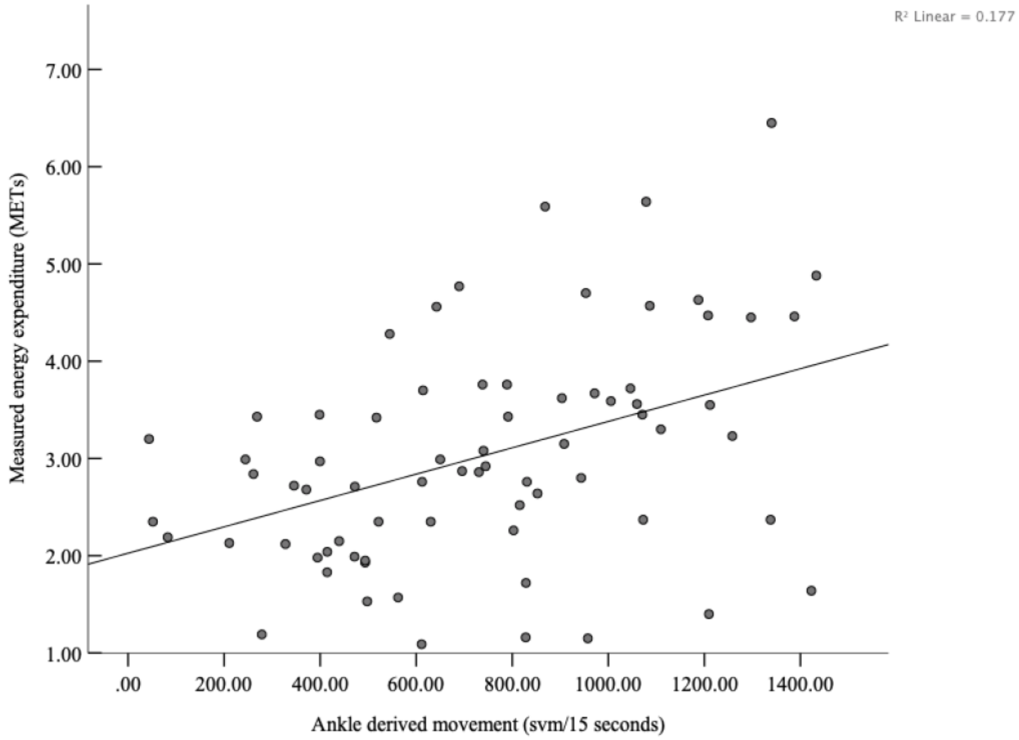


Figure 5.9 The relationship between mean METs and total svm as measured by the ankle-worn accelerometer for all walking tasks.

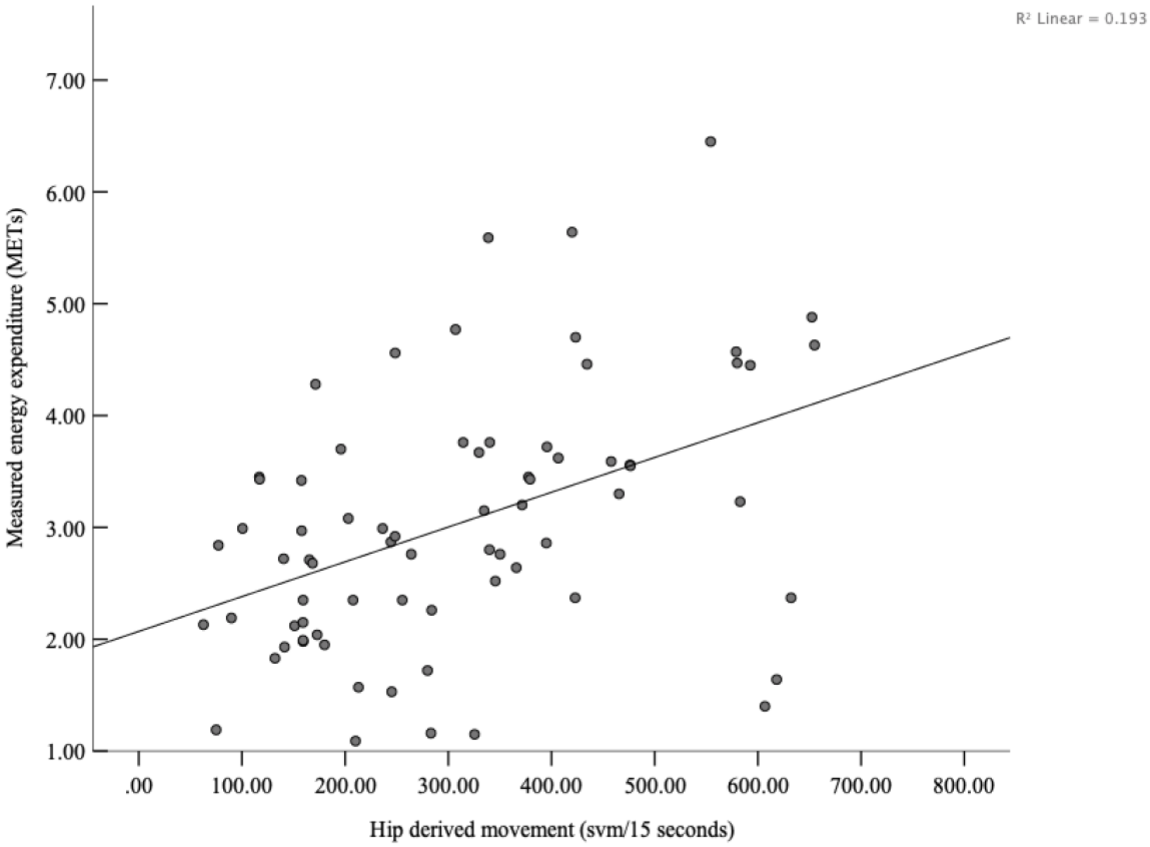


Figure 5.10 The relationship between mean METs and total svm as measured by the ankle-worn accelerometer for all walking tasks.

5.3.3.3.5 Predicting energy expenditure from perceived exertion

To explore whether RPE is related to actual energy expenditure for the participants with Parkinson's, linear regression was undertaken to determine whether RPE significantly predicted METs using the data for all tasks (7 tasks x n = 13, total n = 91). Assumptions regarding linearity, homoscedasticity and multicollinearity were met. Checks for outliers were also undertaken. The casewise diagnostics indicated that two cases had a standardised residual value greater than 2.50, and a separate case had a centred leverage value two times higher than the average leverage value. Therefore, these three cases were removed from the regression analysis. None of the Cook's distance values exceed 1. Three participants had missing METs data due to an error with the spiroergometry device. The final total n for the regression analysis = 85.

The analysis yielded a statistically significant positive correlation between RPE and METs (r = 0.32) of a small effect size (Field, 2013), indicating that higher ratings of exertion were associated with increased energy expenditure. Examination of the R^2 value indicated that RPE only accounted for 10.4% of the variance in METs. The model coefficients (t = 3.11 and p = .003) indicate that RPE makes a significant contribution to predicting METs, see Table 5.8 for model parameters.

A separate linear regression was undertaken for the age-matched controls using the data for all tasks. Assumptions regarding linearity, homoscedasticity and multicollinearity were met. Checks for outliers were also undertaken. Two cases had a standardised residual value greater than 2.50 and a separate case had a centred leverage value double the average value. Therefore, these three cases were excluded from the analysis. None of the Cook's distance values exceed 1. One participant had missing MET data for all 7 tasks, and two participants were missing MET data for one of the tasks (final n = 79). A statistically significant positive correlation was found between RPE and METs (r = 0.29, see Table 5.8 for model parameters), indicating that as perceived exertion ratings increased so did energy expenditure. Examination of the R^2 value indicated that RPE only accounted for 8.2% of the variance in METs. The model coefficients (t = 2.62 and p = 0.01) indicate that RPE makes a significant contribution to predicting METs.

Table 5.8 Linear model of RPE predicting METs for Parkinson's participants and age-matched controls.

Group		b	SE B	ß	p
Parkinson's					
	Constant	1.32 [.45, 2.15]	.41		.002
	RPE	.13 [.05, .21]	.04	.32	.003
Age-matched	Constant	1.62 [.75, 2.51]	.41		.001
	RPE	.21 [.03, .21]	.05	.29	.01

Note. 95% bias corrected and accelerated confidence intervals reported in parentheses. Confidence intervals and standard error based on 1000 bootstrap samples.
B = unstandardised beta, SE B = bootstrapped standard error, *ß* = standardised beta

5.3.3.3.6 Predicting volume of movement from RPE

To explore whether RPE is related to a biomechanical measure of energy expenditure for the participants with Parkinson's, linear regression was undertaken to determine whether RPE significantly predicted svm using the data for all tasks. Assumptions regarding linearity, homoscedasticity and multicollinearity were met. Checks for outliers were undertaken and indicated three cases violated several of these checks and so were removed from the analysis. A further five cases had a centred leverage value two times higher than the average leverage value, however these were left in. None of the Cook's distance values exceed 1. Three participants were missing MET data due to an error with the spiroergometry device, resulting in a final n = 88. Once the outliers were removed the analysis yielded a non-significant relationship between RPE and wrist-derived svm (r = 0.18, R^2 = 0.03, p >0.05, see Table 5.9 for model parameters).

A separate regression analysis was undertaken to explore the relationship between RPE and wrist-derived svm for the age-matched controls. Five cases violated some of the outlier checks and therefore were removed from the analysis. Three participants were missing MET data, therefore the final n = 84. The results of the analysis indicated that perceived exertion did not significantly predict volume of movement for age-matched controls (r = 0.15, R^2 = 0.02, p > 0.05, see Table 5.9 for model parameters).

Table 5.9 Linear model of RPE predicting wrist-derived svm for Parkinson's participants and age-matched controls.

Group		b	SE B	ß	p
Parkinson's					
	Constant	150.55 [9.87, 295.82]	71.19		.03
	RPE	12.09 [-1.89, 25.73]	7.42	.18	.12
Age-matched	Constant	202.24 [94.84, 309.75]	54.46		.003
	RPE	8.37 [-3.84, 20.25]	6.41	.15	.19

Note. 95% bias corrected and accelerated confidence intervals reported in parentheses. Confidence intervals and standard error based on 1000 bootstrap samples.
B = unstandardised beta, SE B = bootstrapped standard error, *ß* = standardised beta

5.4 Discussion

5.4.1 Primary aim: development of validated cut-points

The results of the ROC analyses indicate that the optimal wrist-derived cut-points for participants with Parkinson's are < 358.85 svm/15 seconds and > 427.24 svm/15 seconds for slow (<3.28 km/h) and brisk walking (>5.23 km/h) respectively. A slightly higher AUC value (0.90) for slow paced walking, compared to brisk walking 0.87, indicates that the wrist-derived GENEActiv cut-point provides marginally greater discrimination for the slow walk, in line with the findings of Nero et al., (2015). The resultant cut-point values of the current study are lower than those published by Nero et al., (2015), who found a cut-point of < 470 svm/15 seconds for a walking speed of < 3.6 km/h and a cut-point of > 851 svm/15 seconds for a walking speed of > 4.68 km/h. This difference in values may be due to the use of a hip-worn device in the Nero et al., (2015) study, with literature indicating that hip placement may be more sensitive to locomotive tasks (K. Ellis et al., 2014). However, the hip-derived cut-points of >413 svm/15 secs and < 230 svm/15 secs for brisk and slow walking, respectively, of the current study are also substantially lower compared to the Nero et al., (2015) values. Methodological differences, such as the brand of accelerometer used and size of the walking track, may account for some of the variance in cut-point values. Further research is needed to compare the newly generated cut-points against previously established cut-points for the estimation of physical activity levels of people with Parkinson's.

A further source of variance in cut-points may have been the walking task. Rather than a treadmill task, as used in some other studies (multiple sclerosis; Motl et al., 2009, healthy adults; Diaz et al., 2018), the current study used an over-ground walking task that implemented self-defined walking paces. Due to the mobility and balance impairments associated with Parkinson's, a treadmill with additional support (such as a harness) would be required. Not only might this have discouraged people from participating in the research, it has been suggested that the additional support is likely to affect energy expenditure (Sandroff et al., 2014), in addition to speed and gait. Over-ground walking was chosen as a safe alternative that more closely resembled real life physical activity and was based on research using a similar protocol with participants with neurodegenerative conditions (Parkinson's; Nero et al., 2015, Multiple Sclerosis; Sandroff et al., 2014).

Inspection of the restructured average walking speeds indicates that the people with Parkinson's in the current study walked more slowly (2.70 km/h), compared to reported speeds in similar studies (3.96 and 3.74 km/h for Nemanich et al., 2013 and Nero et al., 2015, respectively). The slower walking speed may account for the lower cut-point value for the slow-paced walk, compared to previous research, likely resulting in fewer steps taken and less movement made more generally (such as accompanying arm swing). In contrast, for the brisk paced walk, Parkinson's participants walked at faster average speed of 6.01 km/h when compared to previous literature (5.51 and 4.72 km/h for Nemanich et al., 2013 and Nero et al., 2015, respectively). Future research producing cut-points using a similar protocol may benefit from regulating walking speed using a GPS tracker, a technique implemented by Barnett et al., (2016) in their study with older adults. However, people with moderate to severe Parkinson's symptoms, particularly motor, are likely to find it difficult to walk to a prescribed speed.

In contrast to expectation, the age-matched participants had lower cut-point values compared to Parkinson's participants for all locations, except for the ankle-derived cut-point for the slow-paced walk. One possible explanation is that one of the Parkinson's participants had dyskinesia and another participant stated that they purposely made a conscious effort to swing their arms when walking. This additional movement may have resulted in higher svm values and consequently cut-point values. The purpose of the current study was to produce valid cut-points that reflect the movement profile (e.g. altered gait, dyskinesia, reduced arm swing) of people with Parkinson's. However, Parkinson's is heterogenous in terms of both motor and non-motor symptoms (Burn et al., 2012), therefore it may be necessary to develop cut-points for sub-groups. Further research is needed to compare cut-points between groups with differing symptom profiles.

Analysis revealed that the energy expended for each task did not significantly differ between the participants with Parkinson's and age-matched controls. However, the Parkinson's group had MET values for the seven tasks that were generally 8% lower than the age-matched controls. There are inconsistent findings in the literature in regard to the energy expenditure of people with Parkinson's. In line with the current study, some studies have reported similar values for Parkinson's participants and age-matched controls (Canning et al., 1997; Protas et al., 1996), while others have reported energy expenditure to be 20% lower (Katzel et al., 2011) or 10% higher for individuals with Parkinson's (Christiansen et al., 2009). The use of treadmill and cycle training tasks and $\dot{V}O_2$ as an outcome measure, as opposed to METs, in previous studies makes it difficult to directly compare the results of the current study to past research. The present study may benefit from further analysis comparing the Parkinson's and age-matched groups using the measured $\dot{V}O_2$ values to address this gap in understanding.

The lower AUC values for the wrist-derived cut-points for moderate intensity activity, for both participant groups (0.69 and 0.68 for Parkinson's and age-matched controls, respectively), indicates poorer discriminatory accuracy between moderate and light activity compared to the values obtained for the hip and ankle locations (Smoot et al., 2011). The greatest accuracy, as indicated by a high AUC value, was for the hip cut-points (0.92 and 0.84 for Parkinson's and age-matched controls, respectively), supported by high sensitivity and specificity values. This pattern was reversed for light intensity activity, such that the highest AUC values were found for the wrist-derived cut-points for both participant groups (0.95 and 1.00 for Parkinson's and age-matched controls, respectively) indicating near and perfect diagnostic accuracy (Mandrekar, 2010). The discriminatory accuracy between light and sedentary activity of the hip and ankle cut-points was similar. Taken together, these findings suggest that hip-derived cut-points are superior in terms of consistently good accuracy for discriminating between different activity intensity levels for both people with Parkinson's and non-Parkinson's controls .

5.4.2 Secondary aims

In contrast to expectation, a similar volume of movement was made by both participant groups across all tasks and device locations. This may be due to the types of activities used in the current study, which were defined, and time limited tasks based on previous laboratory studies. It may also reflect the characteristics of the Parkinson's participants, all of whom experienced the condition at mild to moderate severity. In particular, none of the participants experienced severe motor impairments (assessed using the MDS-UPDRS motor examination) which, if present, may have impacted on the svm values. For example, FOG can be accurately detected using a single accelerometer (Del Din et al., 2016; Moore et al., 2013). Future research may benefit from including participants across a wider range of symptom severities to understand if volume of movement differs according to the stage of Parkinson's and the resulting impact on the development of cut-points using svm data. The feedback given to participants during the walking task about their pace may also have contributed to the null finding for differences in volume of movement across tasks. At the mid-point of each three minute walk the researcher reminded the participant of the required pace (i.e. brisk, normal or slow). This approach was taken as it has been noted participants tend to slow their pace while undertaking similar tasks (Nero et al., 2015). However, the average walking speed for both groups for each pace may be higher than if no feedback was provided. Future studies should consider using a time frame that will provide valid data while eliminating the need for feedback.

It was expected that svm values derived from the wrist-worn device would be higher for dance and household tasks compared to the hip-worn device. Hip-derived svm values were expected to be significantly higher for the walking tasks compared to the wrist-worn device. These predictions were partially supported. However, in contradiction to previous research (K. Ellis et al., 2014), no significant difference was found between the wrist and hip location for any of the walking tasks and the Irish dance. For researchers interested in measuring the amount and pattern of volume of movement made by people with and without Parkinson's, the current findings indicate that using a wrist-worn device may be more sensitive to movement made across a variety of activities compared to a hip or ankle-worn device.

It was of interest to explore whether RPE differed between participant groups and tasks, particularly given that previous research has found people with Parkinson's rate some physical activities as significantly more exerting compared to healthy controls (Christiansen et al., 2009). The results partially supported the hypothesis. Participants with Parkinson's had significantly higher RPE scores than age-matched controls, however this was across all tasks rather than for specific activities as predicted. People with Parkinson's may experience problems with executive functioning (Majbour & El-Agnaf, 2017) and so this finding may reflect a greater cognitive demand of movement when undertaking the tasks for this group. Participants with a known diagnosis of another neurodegenerative condition, such as Alzheimer's, were excluded from taking part in the study. However, the current study did not include an assessment of cognitive functioning, for either participant group, so it is not clear whether this had an impact on the results reported here. It would be informative for future studies to explore the relationship between cognitive demand, participant group and perceived effort.

Though participants with Parkinson's reported higher perceived exertion for all tasks, this was not supported by the physiological and biomechanical measures. Specifically, walking speeds were similar between participants with Parkinson's and age-matched controls. One speculative factor could be differences in physical fitness between the two groups. Physical fitness, defined as "set of characteristics or attributes that influence physical work capacity" (Sebastião et al., 2017, p. 1776), has been shown to be lower in Parkinson's (aerobic capacity, Katzel et al., 2011; muscle strength; Moreno Catalá et al., 2013), as well as for Multiple Sclerosis (Sebastião et al., 2017). Therefore, the similar walking speeds but significantly higher RPE for people with Parkinson's may represent greater physiological effort compared to the age-matched controls. Future studies should consider including physiological measures of aerobic fitness in addition to RPE to shed further light on this finding.

Another contributing factor might be Parkinson's symptoms, linked to reduced physical fitness. Both motor and non-motor, have been found to impact on individuals ability to participate in ADLs. For example, postural instability, gait dysfunction and increased susceptibility to falls are all likely to impact on an individual's general mobility, as indicated by lower health-related quality of life (Kadastik-Eerme et al., 2015). Furthermore, higher levels of fatigue, one of the most commonly experienced non-motor symptoms of Parkinson's (Herlofson & Kluger, 2017), is reported to be associated with limiting routine activities and hobbies (Agarwal et al., 2018). Though not officially recorded in the current study, many of the Parkinson's participants commented that they found the sweeping task particularly challenging due to having to bend over and the range of movement needed to carry out the task. All participants completed the sweeping task, however those with Parkinson's may not usually undertake such activities in the home due to the resulting discomfort. The findings of the current study highlight that using RPE with people with Parkinson's is a useful measure for providing insight regarding how physically demanding individuals find a task and may be superior to using physiological assessments.

The results of separate linear regression analyses indicated that RPE scores significantly predicted energy expenditure for both people with Parkinson's and age-matched controls, with greater variance in METs explained by RPE for the Parkinson's group. However, the percentage of explained variance was still relatively low (10.4%) for the Parkinson's group, suggesting that 86% of the variance in METs is shared with variance in other variables that were not accounted for in the current study. For example, the additional variance in METs, if any, explained by Parkinson's specific characteristics, such as condition severity, MDS-UPDRS motor score and medication, needs further consideration in future studies. The contribution of these factors was not considered in the current study due to the limited sample size and narrow range of Parkinson's severities. The correlation coefficient for the Parkinson's group (r = .32) indicated a weak relationship between RPE and METs, suggesting that RPE is not a primary mediator of energy expenditure. The correlation coefficient found in the present study is lower compared to other studies examining this relationship. A meta-analysis by Chen et al., (2002) reported an overall weak to moderate association between RPE and $\dot{V}O_2$ (r = 0.51), but demonstrated that coefficients significantly differed according to gender, type of exercise and mode of RPE scale. In a study of people with Multiple Sclerosis (MS), Cleland et al., (2016) found a moderate association between RPE and $\dot{V}O_2$ (r = 0.69), in addition to a group of non-MS controls (r = 0.61) who were part of the same research. Methodological differences in the way RPE ratings were obtained from participants and the frequency of ratings may account for the weaker relationship with METs in the current study. Participants rated their exertion at the end of each task, whereas Cleland et al., (2016) asked participants to give multiple ratings while undertaking a single cycling task.

It was of interest in the present study to explore whether a biomechanical measure of energy expenditure significantly predicted wrist-derived svm for both Parkinson's and age-matched controls. Both linear models were initially significant, however once the outliers had been removed RPE did not predict svm for either participant group. Inspection of the R^2 values indicates that only 3% and 2% of variance in svm was shared with RPE for the Parkinson's and age-matched groups, respectively. Similar to the present study, Kayes et al., (2009) asked participants to undertake six activities of sedentary to moderate intensity (i.e. reading, clothes washing, vacuuming and 6 minute walk test) in a laboratory while wearing an accelerometer on their hip. After each task participants rated their perceived exertion using Borg's (1982) scale. A significant relationship between RPE and acceleration counts was found for two of the six tasks, specifically the 6-minute walk test and stair climb. As previously noted, hip placement of an accelerometer has been shown to be the most accurate in prediction of energy expenditure for locomotive tasks (K. Ellis et al., 2014; Swartz et al., 2000), a finding replicated in the current study, therefore it is perhaps unsurprising that Kayes et al., (2009) found a significant relationship for walking based tasks. In particular, Kayes et al., (2009) argue that placement of an accelerometer on the part of the body from which the movement is being generated is likely to result in the greatest measurement accuracy of movement. Therefore, on this basis it would be expected that RPE would significantly predict hip-derived svm data for the walking, Irish dance and sweeping tasks in the current study. Future research using laboratory-based tasks may benefit from exploring the relationship between RPE and volume of movement for each individual task, rather than combining them all into one analysis as done in the current study.

In line with previous research (Swartz et al., 2000), it was found that a combination of wrist and hip-derived svm accounted for significantly more variance in METs for the walking tasks compared to the wrist alone (23.4% compared to 9.4%, respectively). However, the overall variance in energy expenditure as explained by the combined wrist and hip svm is much lower than the 34.3% reported by Swartz et al., (2000). This discrepancy may be due differences in the samples given that the Swartz et al., (2000) study included only healthy adults. Furthermore, the current study only used the walking data to compare predictive relationships between device locations and energy expenditure, whereas Swartz et al., (2000) included range of tasks undertaken both in a laboratory and field setting. It is important to note that the results of present study also show that svm values from a singular wrist, hip, or ankle-worn GENEActiv device significantly predicted energy expenditure (measured as METs), accounting for 9.4%, 17.7% and 19.3% of the variance in METs, respectively. Therefore, for researchers who do not have access to multiple accelerometers or studies where participants are required to wear a device over a long period of time (and so multiple devices are impractical), using the svm values from a singular device to predict energy expenditure is acceptable, though highest accuracy is achieved using a hip-worn device.

The current study presented some methodological limitations. Firstly, the walking and intensity-based cut-points were generated using data from people with mild to moderate Parkinson's severity. Therefore, as previously mentioned, these cut-point values may not be valid for use with people with severe Parkinson's, who experience FOG or require the use of walking aids. Further research is needed to understand the relationship between Parkinson's severity and volume of movement and to help determine whether separate cut-point values are needed for use with people at different stages of the condition. Secondly, the tasks of moderate intensity tended to be at the lower end of the METs classification (towards 3.0 METs as opposed to 6.0), therefore possibly limiting the application of the moderate intensity cut-points to activities with a higher energy expenditure. However, people with Parkinson's in the current study perceived all tasks to be significantly more exerting than age-matched controls. Therefore, finding tasks that are of moderate and vigorous intensity that are manageable for people with Parkinson's may be challenging. Thirdly, it could be argued that the length of the tasks may have had an impact on the RPE for the Parkinson's group, rather than the actual task per se. The time frames were selected based on previous research, with the walking tasks replicating the protocol used by Nero et al., (2015) and the household tasks informed by the research of Bassett et al., (2000), who used a 15-minute time frame. Therefore, had the length of the task been a contributing factor to RPE scores it might be expected that people with Parkinson's rated the dish washing and sweeping tasks, which were the longest of all the tasks, as particularly exerting. However, a main effect of group was found for RPE scores indicating that people with Parkinson's had consistently higher RPE scores compared to age-matched controls.

Another limitation is that the current study did not control for the participants' familiarity with the dance tasks. The dances were taken from the class held at the University of Hertfordshire and so some of the Parkinson's and age-matched participants, who were recruited from the university-based dance class, will have been familiar with these. It could be argued that there might be a difference in participants ability to undertake the dance movements effectively based on this familiarity. However, this is unlikely as all participants were given a practice trial for each routine. Participants were also observed by the research assistant while undertaking each task to ensure full participation. Notes were made if any issues or points of interest arose during a task, though this was not necessary for any of the participants for the dance tasks.

Finally, the cut-points developed in the current study are specific to the GENEActiv Original accelerometer and consequently may not be applicable to other models or devices. There are many research grade accelerometers available, however the GENEActiv model has been used in several studies with Parkinson's samples (Coe et al., 2018; Delextrat et al., 2016; Juan Orta et al., 2018; Mavrommati et al., 2017).

In conclusion, the current study addresses the need for validated GENEActiv cut-points that can be used by researchers to analyse the acceleration data of people with Parkinson's derived from wrist-worn accelerometers. The current study also indicates an acceptable level of accuracy for using a singular wrist-worn accelerometer to measure movement when walking , however the addition of a second hip-worn device significantly improved the accuracy of predicting energy expenditure. Therefore, researchers wanting to use accelerometry should evaluate whether the advantages of using a wrist-worn device, such as ease of use and high wear-time compliance, outweigh the increased accuracy provided by multiple devices. The decision to implement a singular device or multiple is likely to depend on the population of interest (i.e. clinical or non-clinical) and the research setting (i.e. free-living environment or laboratory). Finally, the results of the current study indicate that RPE is unlikely to be an accurate alternative measure of energy expenditure (compared to both svm and METs), for people with Parkinson's and age-matched controls. Therefore, implementing the scale as a singular alternative is not advisable.

6. Chapter 6

General discussion

6.1 Introduction

The main aim of the present thesis was to explore the application of wrist-worn accelerometers to the measurement of movement within the context of dance for Parkinson's. Through a series of exploratory studies, the current body of work gained insight into important methodological considerations in the implementation of the GENEActiv accelerometers with a Parkinson's population, in addition to the processing of the recorded data and the choice of outcome measures. More specifically, the present thesis demonstrated i) the feasibility of using accelerometry to measure the movement made by people with Parkinson's during and after a dance class, ii) the strengths and limitations of using a single summary metric of movement, and iii) the need for valid cut-points within the literature to accurately measure the level and pattern of physical activity intensity of people with Parkinson's.

This body of research was initially motivated by the reports of the positive impact of dance on different aspects of movement from individuals with Parkinson's when attending a weekly dance for Parkinson's class held at the University of Hertfordshire. A review of the exercise and Parkinson's literature, as detailed in section 2.1.2, indicated that high-intensity aerobic exercise may attenuate motor decline in Parkinson's (Schenkman et al., 2018; van der Kolk et al., 2019). However, these large randomised control trials have only demonstrated this effect in an off-medication state using the MDS-UPDRS; no improvement or attenuation has been shown in an on-medication state, which suggests that people with Parkinson's may not notice an effect of the intervention. This is likely to be an important consideration for clinicians when recommending a particular type of exercise; if patients do not perceive there to be an improvement this may impact on their engagement with the activity in the longer term (T. Ellis, 2019). Therefore, while there is a growing evidence base indicating intensive aerobic exercise may slow the progression of Parkinson's, there is a need to consider alternative forms of exercise that are perceived as effective, accessible and engaging to encourage continued adherence. Qualitative research indicates people with Parkinson's report dance to be an enjoyable activity (Houston & McGill, 2013; Kunkel et al., 2018; Westheimer et al., 2015) with perceived benefits including improved movement that extends beyond dance class to activities of daily living (Holmes & Hackney, 2017). Individuals with Parkinson's participating in research often indicate they would like to continue attending dance classes (Kunkel et al., 2018; Westheimer et al., 2015). For example, the dance class at the University of Hertfordshire was a continuation of a class developed as part of a PhD (A. Hall, 2017). Furthermore, in line with the findings of qualitative studies, attendees of the dance class at the university anecdotally and informally report perceived physical and psychological benefits from participating in the dance.

However, unlike the aerobic exercise for Parkinson's literature, a review of the dance for Parkinson's literature indicated a lack of robust and consistent findings to support the anecdotal reports (and subjective observations) as given by people with Parkinson's and their partners (Beerenbrock et al., 2020; Prado et al., 2020). It is still not clear from the research to date the type of dance, frequency, length of session and amount of movement (including volume and intensity) required to achieve and maintain beneficial effects. If dance is to be a prescribed activity for people with Parkinson's by health professionals, there is a need to isolate the independent effects of each of these elements in order to progress the current understanding of the ways in which dance benefits this population. Accelerometers may be implemented to objectively measure the volume of and intensity of physical activity.

However, the literature reviewed in section 1.2.5 led to the indication that there is a paucity of evidence using wearable devices in the context of dance for Parkinson's. In particular, few studies have implemented accelerometers to explore the engagement of people with Parkinson's while they participate in dance. Furthermore, the literature reviewed in Chapter 1 also demonstrated that accelerometry has not been used to quantify the effect of dance on the physical activity of people with Parkinson's. The review of the literature also highlighted that hip-worn accelerometers are preferred for their purported increased accuracy in measuring locomotive movement (K. Ellis et al., 2014). However, the use of wrist-worn devices has been shown to increase participant compliance with wearing the device (McLellan et al., 2018) and is favoured by participants when compared to hip or ankle placement (Huberty et al., 2015). While there are some studies investigating physical activity in Parkinson's using wrist-worn accelerometers (Delextrat et al., 2016), the majority of researchers have opted to use either the hip (Nero et al., 2019; van Nimwegen et al., 2013; Wallen et al., 2015), thigh (Chastin et al., 2010) or ankle (Cavanaugh et al., 2015).

Chapter 3, 4 and 5 of the current thesis investigated the feasibility and different applications of wrist-worn accelerometry to the measurement of movement of people with Parkinson's to address the gaps in the literature as outlined above. Specifically, the focus of Chapter 3 of the current thesis was to establish the viability of using wrist-worn accelerometers to measure the movement made by people with and without Parkinson's during a dance class. In Chapter 4, the movement made and sleep characteristics of people with and without Parkinson's was explored during the hours and days following participation in a dance class using a wrist-worn accelerometer. The second aim of the thesis was to explore the usefulness of using volume of movement, a single summary metric that combined frequency, intensity and duration of movement. Chapter 3 and 4 both used volume of movement, measured as svm, as the primary outcome. In particular, Chapter 3 tracked the volume of movement made per minute of an hour dance class and refreshment session, in addition to the total volume of movement made per session. Chapter 4 measured the volume of movement made by people with and without Parkinson's over 6 continuous days to explore the usefulness of the metric when applied to a longer time frame. Chapter 5 built on the limitations identified in Chapter 4 regarding the use of volume of movement as an outcome measure when applied to research in free-living contexts. Chapter 5 focused on the development of validated wrist-derived cut-points that can be used to determine the intensity of activity undertaken by people with Parkinson's.

The key findings of each of these three chapters will be discussed below and then reviewed in the context of contribution to knowledge of accelerometry, physical activity and Parkinson's with recommendations made for future research. The strengths and limitations of methods applied in the current thesis are then discussed.

6.2 Summary of the main findings

The primary aim of Chapter 3 was to investigate the feasibility of using wrist-worn accelerometers to measure the pattern and movement made by people with Parkinson's during a Dance for Parkinson's class and the following refreshment session. Specifically, the exploratory study in Chapter 3 is the first to use volume of movement, a single summary metric, to compare people with Parkinson's engagement in dance to people without Parkinson's. In line with previous studies, participant compliance with the required device wear-time was high (Delextrat et al., 2016; Huberty et al., 2015), therefore indicating good tolerability of the wrist placement. As predicted, volume of movement was significantly higher for the dance class compared to the rest session, regardless of group, indicating that the use of svm is sensitive enough as a measure to detect between-session differences. Furthermore, group differences were found for total volume of movement, such that young adults were more physically active, regardless of session type, compared to the Parkinson's and age-matched participants. Lastly, the results of this chapter show that svm as an outcome measure is useful for understanding the pattern of activity made over the course of a structured dance class, particularly when mapped against the movement of another individual attending the same session. The results of this study confirmed that it is both feasible and useful to use a wrist-worn accelerometer and to select svm as an outcome measure when investigating the engagement of different participant groups in a dance class.

To better understand the usefulness of svm when calculated over a longer time frame, the effect of dance on the volume of movement made in the hours and days following attendance to a dance class was examined in Chapter 4. Wrist-worn accelerometers were used to investigate whether an objective measure of movement reflected the anecdotal reports of people with Parkinson's regarding increased physical activity after participating in a dance class. This chapter also used accelerometers to quantify the sleep characteristics of people with and without Parkinson's to explore the possible effect of dance on sleep quality, as indicated by previous research (Coe et al., 2018). The movement made by people with Parkinson's and age-matched controls on dance and a no-dance week, in addition to a group of Parkinson's controls who did not dance, was measured and statistically compared. The svm data was used to calculate the average daily volume of movement, in addition to the volume of movement made on a Friday between 13:00-00:00 (the hours following a dance class). In line with the results of Chapter 3, and previous research using wrist-worn accelerometers (Coe et al., 2018; Farina et al., 2019; Huberty et al., 2015), high wear-time compliance was found across all three participant groups, and for both the dance and no-dance week. Researchers wishing to measure movement over consecutive days should consider using a device similar to the GENEActiv, in that it can be worn on the wrist and is waterproof, to maximise the collection of data that encompasses all the activities of the wearer. In contradiction to expectation, the movement made by the Parkinson's dancers during a dance week was similar to that of the Parkinson's control group, who had never attended dance classes. A higher volume of movement, though non-significant, was found for a Friday afternoon following a dance compared to a no-dance week for both Parkinson's and age-matched dancers, indicative of increased physical activity during the hours immediately after a dance class. However, no difference was found between the dance and no-dance weeks for average daily volume of movement, suggesting that any effect of dance on volume of movement is short-term. In partial support of predictions and previous research (Chastin et al., 2010; van Nimwegen et al., 2011), the age-matched dancers were found to have a higher daily average volume of movement for a no-dance week, though not significantly so, compared to both Parkinson's groups, indicating this group were more physically active each day. No difference between PD-D and AM-D groups, or week (dance compared to no-dance), was found for accelerometer-derived sleep time and number of active periods, suggesting there was no effect of dance on sleep quality. However, a trend towards significantly poorer sleep efficiency was found for the PD-D compared to AM-D, irrespective of week, likely due to the impact of Parkinson's symptoms on sleep quality as documented in the literature (Schapira et al., 2017). This finding suggests that GENEActiv accelerometers are sensitive to between group differences in sleep characteristics and can feasibly be used to explore sleep quality with people with Parkinson's. Furthermore, this finding, alongside the high wear-time compliance reported in Chapter 4, indicates that wrist-worn accelerometers are suitable for the long-term monitoring of sleep characteristics, and can be feasibly applied to study the effect of exercise on sleep.

In contrast to the exploratory studies, the purpose of Chapter 5 was to provide values that can be used by researchers to measure the activity intensity levels of people with Parkinson's, either as a complementary or alternative measure to volume of movement. Cut-point values derived from a wrist, hip and ankle-worn accelerometer were developed with people with Parkinson's and age-matched controls using two different methods, 1) using walking as a biomechanical equivalent of energy expenditure (a replication of the approach used by Nero et al., 2015), and 2) using indirect calorimetry as a physiological measure of energy expenditure. The wrist-derived walking cut-points generated in Chapter 5 were found to have good-excellent discriminatory accuracy (Mandrekar, 2010), indicating that the cut-point values accurately differentiated between brisk and slow-paced walking . Currently, there are no published studies specifying cut-point values for different activity intensities that have been developed with people with Parkinson's using a wrist-worn device. The newly developed cut-points reported in Chapter 5 are lower compared to those of Nero et al., (2015) obtained from a hip-worn device. Therefore, these findings indicate that studies using hip-derived cut-points to classify the intensity of wrist-derived acceleration data may result in the underestimation of physical activity. Cut-points for light and moderate intensity activity were generated using the measured METs to indicate the amount of energy expended by Parkinson's and age-matched controls while undertaking different tasks in the laboratory. The developed wrist-derived cut-points for moderate activity were lower for the Parkinson's group compared to the values developed for the age-matched. This finding suggests that using cut-point values validated for older adults may result in underestimation of time spent being moderately active when applied to a Parkinson's population. This has implications for the results of previous research using such values to explore the physical activity levels of people with Parkinson's (Coe et al., 2018; Loprinzi et al., 2018). The reverse was found for the light intensity cut-points, such that wrist-derived values were higher for the Parkinson's group compared to age-matched controls, indicating that cut-points validated for older adults are best not used interchangeably with other populations unless validated for such a purpose. An acceptable level of accuracy (Mandrekar, 2010) was found for the moderate wrist-derived cut-points in regard to discriminating between moderate and light activity for both people with Parkinson's and age-matched controls. Excellent discriminatory accuracy was found for the wrist-derived light cut-point values for both participant groups. Taken together, these findings suggest good diagnostic accuracy of the wrist-derived cut-points when used with both people with Parkinson's and older adults to classify light and moderate activity.

A secondary aim of Chapter 5 was to explore whether measures of energy expenditure (svm and METs) differed between participant groups and types of physical activity. The volume of movement did not significantly differ for people with Parkinson's compared to age-matched controls. However, in line with some previous research (Canning et al., 1997; Protas et al., 1996), the average METs across the seven tasks was found to be lower, though not significantly so, for people with Parkinson's compared to controls. This finding suggests that people with Parkinson's expend less energy when undertaking the same tasks as age-matched controls; though comparison of self-reported RPE between groups indicated that people with Parkinson's rated all tasks as significantly more exerting compared to controls, despite expending slightly less energy. Dontje et al., (2013) investigated the time spent at different activity intensity levels for people with Parkinson's over 7 days using an accelerometer and found that the median length of moderate intensity activity was 1.6 minutes. Over half the participants in the Dontje et al., (2013) study did not achieve a single 10-minute bout of moderate activity. The moderate intensity tasks in the current study were a minimum of 3 minutes long (such as the brisk walk), so were perhaps perceived as more physically challenging by the Parkinson's participants as they may not have been used to performing such tasks for an extended period of time. It is possible that Borg's (1982) RPE scale may be influenced by psychosomatic factors which are not captured by biomechanical and physiological measures of energy expenditure. Objective measures of energy expenditure are limited in that that they do not provide insight regarding the extent to which an individual perceives a task to be physically demanding, which may be influenced by various factors. One such factor is the impact of living with a condition on mobility that can make undertaking everyday activities more challenging (Agarwal et al., 2018; Herlofson & Kluger, 2017; Kadastik-Eerme et al., 2015), but not necessarily more physiologically exerting. This argument is supported by the weak relationship found between RPE scores and METs for Parkinson's participants, in addition to the lack of significant relationship found between RPE and svm. The low R^2 value for the regression analysis exploring the relationship between RPE and METs further indicates that physiological energy expenditure only accounted for a small proportion of variance in RPE scores. Finally, the relationship between accelerometer location (wrist, ankle, hip) and measured energy expenditure (as METs), was investigated for all participants combined. The results of the regression analysis indicated that wrist-derived svm significantly predicted METs. However, when the hip and ankle-derived svm were entered as additional predictors into the same model, the percentage of shared variance between svm and METs increased, indicative of a better model. The results also indicated that only the wrist and hip were significant predictors of METs once all device locations were entered into the same model. These findings indicate that greater predicative accuracy of METs is achieved using multiple accelerometers, specifically one on the wrist and one on the hip. Wrist placement alone is an acceptable alternative if it is not feasible to use two devices, however the researcher should be aware there will likely be a compromise in accuracy.

6.2.1 Feasibility of using wrist-worn devices

One of the primary aims of the current thesis was to investigate the feasibility and usefulness of the wrist placement, which was addressed in Chapter 3, 4 and 5. The study reported in Chapter 3 used wrist-worn accelerometers to measure the movement made by people with and without Parkinson's while they participated in a social style dance class. Accelerometry is increasingly being used in novel ways to explore parameters of movement in Parkinson's. In particular, there has been much focus on measuring the movement of individuals to understand whether this population meets recommended guidelines for physical activity (Dontje et al., 2013) and whether exercise interventions have a positive effect on movement parameters (Coe et al., 2018; T. Ellis et al., 2019; Nero et al., 2019). These interventions have included aerobic exercise, a balance programme, a walking programme and physical therapy. However, dance has yet to be considered, despite the growing interest in the physical and psychological benefits of this activity for people with Parkinson's and the encouraging reports from individuals participating in classes. To the best of the researcher's knowledge, the study by Delextrat et al., (2016) is the first to use wrist-worn accelerometers to measure the engagement of people with Parkinson's while they participated in a series of Zumba classes and the movement of participants was not tracked outside of attendance to the classes. In order to understand whether dance may help people with Parkinson's towards meeting activity guidelines, more research is needed to investigate how much movement is made when participating in dance and whether this differs depending on the style of dance. Before the effect of dance style on movement can be measured, it is important to understand whether accelerometers can be used to accurately assess the pattern and volume of movement made by people with and without Parkinson's during a class. While the results of the Delextrat et al., (2016) study indicate the feasibililty of implementing accelerometry for the purpose outlined above, given the limited studies in this topic area it is not clear whether a wrist-worn device is suitable for use with other styles of dance.

The results of Chapter 3 demonstrate that accurate tracking of movement made by people with and without Parkinson's during a dance class can be achieved using a wrist-worn accelerometer. The dance class used in the study involved individuals following set routines demonstrated by the teacher. Plotting the minute by minute trend for the movement made during the dance class revealed that the wrist-worn devices detected the synchronous increases and decreases in acceleration between groups, as to be expected from a structured dance class. The results of this study also demonstrated that differences in the total amount of movement made between a dance and rest session were detectable using a wrist-worn device; this finding indicates that the wrist placement would be suitable for studies aiming to compare the amount of movement made during different types of dance classes.

Research has shown that regular engagement in exercise is associated with improved mental health in adults (Hamer et al., 2017) and there is some evidence to suggest that participating in certain types of dance may lead to a reduction in depression in people with Parkinson's (Solla et al., 2019). While several studies have demonstrated a relationship between greater accelerometer-based physical activity and reduced depression in healthy adults (Vallance et al., 2011; Yoshiuchi et al., 2006), no such studies have been undertaken with people with Parkinson's, particularly in relation to engagement in specific activities. Research has begun to address this gap in the Parkinson's literature, investigating between-and-within participant associations of affectivity (as measured using the Positive and Negative Affect Scale; Watson et al., 1988) with accelerometer-derived physical activity. The data has been collected but is yet to be analysed. In line with the results of previous studies using a similar method (R. Powell et al., 2009), it is expected that greater volume of movement will be associated with lower negative affect.

When considering which body placement is best for using an accelerometer in research, it may be important to consider the types of activities the participant will be undertaking. The results of the study reported in Chapter 3 indicate that wrist placement is acceptable to measure movement during a dance class. However, it is important to note that most of the routines in the dance class involved hand movements and so wrist placement is preferable to hip placement, such that it captures the upper limb movement (K. Ellis et al., 2014). This finding is supported by the results of the Chapter 5 study which indicated wrist-derived svm was significantly higher for the Jai Ho dance (predominantly upper limb movement), sweeping and dish washing compared to hip svm. No significant difference was found between wrist and hip-derived svm for the walking tasks. Comparison of device placement in the prediction of METs using the data from walking at three different speeds, as reported in Chapter 5, indicated that wrist-derived svm significantly predicted the energy expenditure for people with Parkinson's. This finding supports the conclusion from the Chapter 3 study that wrist placement of an accelerometer is feasible and acceptable for the measurement of movement of people with Parkinson's. However, the results of the analysis also indicated a higher percentage in shared variance between svm and METs when a wrist and hip-worn device are used together. Therefore, for greater predictive accuracy researchers should use multiple devices.

The accuracy achieved through using multiple devices also needs to be balanced with the ease of wearing the device for the participant, with studies indicating greater participant preference for wrist placement (Huberty et al., 2015). The increased accuracy gained through the use of a hip-worn device may be offset by lower wear-time compliance, thus not providing a complete representation of an individual's movement. Wear-time compliance for a wrist-worn accelerometer was considered for the studies reported in Chapter 3 and 4, but over different time periods. The study reported in Chapter 3 required people with and without Parkinson's to wear an accelerometer on their wrist for the duration of a dance class and the following refreshment session, a total of 2 hours. All participants (Parkinson's, age-matched controls and young adults) were compliant with wearing the device for duration of the study and there were no issues reported regarding skin irritation or discomfort. Wear-time compliance was also high when participants were asked to wear an accelerometer on their wrist continuously for seven days, including overnight, as in the study reported in Chapter 4. Few participants reported removing the device, which was mostly corroborated by the non-wear-time as calculated from the accelerometer data using post-processing software. Taken together, these findings indicate that researchers requiring high wear-time compliance, over a brief or extended period of time, should consider using a wrist-worn device.

6.2.2 The strengths and limitations of using volume of movement as a single summary metric.

The current thesis also aimed to investigate the usefulness of accelerometer-derived volume of movement as a measure of physical activity for people with Parkinson's assessed during (Chapter 3) and after participation in a dance class (Chapter 4). The study reported in Chapter 3 compared the effect of session (dance and rest) and group (Parkinson's, age-matched control and young adult) on volume of movement. As predicted, volume of movement was significantly higher for the dance class compared to the rest session, regardless of group, indicating that the use of svm is sensitive enough as a measure to detect between-session differences. However, it is important to note that this difference was detected under a predictable/observable condition. Specifically, the difference in volume of movement made between the two sessions was likely maximised by the very nature of the sessions. For example, the dance class was an active session involving some moderate intensity activity, as indicated by the measured METs for the dance tasks in Chapter 5. In contrast, the rest session predominantly involved sitting and so participants with Parkinson's and age-matched controls were more sedentary during this time. The results of Chapter 3 indicate that volume of movement is useful as an outcome metric to examine change over a discrete period of time. These findings are in line with studies using short time frames to explore the pattern of volume of movement made by people with Parkinson's throughout the day (Porta, Corona, et al., 2018; van Hilten et al., 1993).

The results of the study reported in Chapter 3 also demonstrate that using volume of movement as an outcome metric is sensitive to between group differences. As predicted, the young adults had a significantly higher volume of movement, irrespective of the session type, compared to both Parkinson's and age-matched participants. However, people with Parkinson's and age-matched controls did not differ in the volume of movement made over the course of the two sessions. One possible explanation for this lack of difference might be the type of dance class used in the study. The Dance for Parkinson's classes at the University of Hertfordshire mostly involve partnered dancing, with a few individual routines. Therefore age-matched controls likely partnered with people with Parkinson's, in particular some of the participants were spouses of the age-matched controls. This partnering may have led to some age-matched controls modifying their movement to match those of their dance partner. Specifically, people with Parkinson's tend to have reduced velocity and amplitude when making arm movements (Su et al., 2014).

The use of volume of movement as an outcome calculated over a lengthier time frame may be limited for studies examining physical activity in free-living conditions where movement patterns may vary hour to hour and day-to-day, with high within-and-between individual variation (R. Powell et al., 2009). The summing and averaging of svm data over a lengthy time frame dilutes this variation and may result in hourly trends being overlooked. This is illustrated by the findings of the study reported in Chapter 4, which explored the volume of movement made by people with and without Parkinson's during the hours and days following attendance to a dance class. In line with previous research (Coe et al., 2018), volume of movement was calculated over a 16 hour period to obtain a daily total. While this allowed for an examination of differences in average daily movement between a dance and no-dance week and participant groups, variation at a micro level is not observable using a gross time frame.

One of the advantages of using total volume of movement, particularly for data collected using a GENEActiv device, is that typically the processing software provided to accompany the accelerometer calculates the sum of vector magnitudes. Therefore, compared to calculating the frequency of and time spent at different bouts of activity intensities, volume of movement is a time efficient metric. Furthermore, Bassett et al., (2015) highlight that the benefit of using volume of movement is that it is summary metric in that includes most of the movement metrics that have to be calculated using cut-point values, such as frequency, intensity and duration of movement. This advantage is particularly important given that there are no published validated wrist-derived cut-points for different activity intensities that can be used with people with Parkinson's. Therefore, volume of movement is likely to more closely align with actual body movement compared to other metrics which are derived from cut-points that may lead to over or underestimation of physical activity.

The use of a metric that integrates several movement parameters also presents some limitations. As discussed in section 4.3.3, AM-D had the highest volume of movement compared to PD-D for a no dance week and controls for a "usual" week, though this was non-significant. It is not known where this difference arises from in terms of constituent movement parameters that makeup volume of movement. For example, it could be that age-matched controls engaged in moderate intensity activity more frequently or spent greater periods of time engaged in light or moderate intensity activity compared to Parkinson's participants. Furthermore, the volume of movement was found to be greater, though not significantly so, for both PD-D and AM-D groups for the hours following attendance to a dance class compared to the same time period on a no-dance week; but it is not clear what this increase in movement means in terms of physical activity behaviour change.

Another advantage of using volume of movement is that evidence suggests volume of movement is more strongly associated with cardiometabolic biomarkers, such as plasma glucose, insulin and waist circumference, compared to 10- minute bouts of moderate to physical activity in older adults (Wolff-Hughes et al., 2015). The results of the study reported in Chapter 5 partially support the findings of Wolff-Hughes et al., (2015) in that wrist-derived volume of movement was found to significantly predict the rate of oxygen consumption, a metabolic measure, in adults with and without Parkinson's. However, the strength of this relationship was not compared to alternative accelerometer-derived metrics.

Bassett et al., (2015) suggest that normal distribution makes using total volume of activity/ day advantageous compared to other movement metrics, such as minutes of moderate and moderate to vigorous activity per day. This was not the case for results of the study reported in Chapter 4. Total daily volume of activity was not normally distributed, therefore non-parametric analyses were used. However, one reason for the non-normal distribution might be the small sample size. Bassett et al., (2015) compared the skewness of several movement metrics (volume of movement, minutes of light, moderate and vigorous activity per day) obtained from a nationwide health study that included over 6,000 participants (Wolff-Hughes et al., 2014). The authors found that total daily volume of movement was within two standard deviations for skewness and kurtosis, whereas most of the other movement metrics exceeded this. Researchers recruiting from a clinical population may have smaller sample sizes, therefore consideration should be given as to whether there is an appropriate non-parametric test to suit the design of the study.

6.3 Future Directions

Chapters 3 and 4 focused on examining the feasibility of using wrist-worn accelerometers to measure the movement of people with and without Parkinson's. The results of Chapter 5 demonstrate that accelerometer-derived volume of movement for both participant groups can be translated into a measure of activity intensity. Future research could expand on the results of these studies by focusing on the application of wrist-worn accelerometers to examine the health behaviours of people with Parkinson's. Specifically, one avenue is to use accelerometers to progress the current understanding of the contribution of dance, and other activities people with Parkinson's participate in, towards individuals meeting Government guidelines for physical activity. For example, the Department of Health and Social Care (2019) recommend that older adults undertake at least 30 minutes of moderate activity per day, therefore wrist-worn accelerometers could be implemented to understand whether undertaking an hour of dance means that people with Parkinson's achieve this target and this could be compared across different dance styles or exercise classes. In particular, this could be explored in relation to the Parkinson's exercise framework (Parkinson's UK, n.d.), such as the aerobic activities recommended for people who have just been diagnosed, which include Nordic walking and high intensity boot camp. Few studies to date have explored how movement parameters such as volume and intensity relate to physical and psychological outcomes in Parkinson's.

Across the field of accelerometry and exercise research there is a lack of studies applying the devices to capture different movement metrics of people living with Parkinson's as they engage in dance. Chapter 3 focused on a social style of dance and the routines required participants to partner with another dance class attendee, often an age-matched control. Further research examining the application of accelerometry to different dance styles is warranted, such as those that are less structured and non-partnered (i.e. contemporary dance or contact improvisation; Marchant et al., 2010). The results of Chapter 3 indicate that wrist-worn accelerometers could be used in such a study and that svm would be a suitable movement metric. Such a study would benefit from recruiting a large sample of people with mild to moderate Parkinson's severity so that the effect of Parkinson's severity on engagement in the class could be explored.

Currently there is paucity of research investigating the relationship between volume of activity and health-related outcomes in healthy adults as well as clinical populations, therefore on its own volume of movement has limited meaning. Future studies would benefit from the additional use of cut-points to determine the frequency and intensity of physical activity in order to understand the specific ways in which dance interventions (or other exercises) may impact on the movement made by people with Parkinson's in the hours following attendance to a session. As discussed in section 4.4, translating the raw acceleration data into intensity metrics (e.g. sedentary, light, moderate or vigorous) may also be preferable for researchers wanting to understand whether a particular population meets physical activity guidelines.

Future studies should also seek to address the current gap in the literature regarding volume of movement and Parkinson's specific health outcomes. Amara et al., (2019) found that higher self-reported physical activity levels (measured using the Physical Activity Scale of the Elderly) of people with Parkinson's was associated with slowed motor progression, higher activities of daily living and improved mood, after adjusting for disease severity. A study similar to that of Amara et al., (2019) could be undertaken implementing wrist-worn accelerometers to measure the volume of movement made by people with Parkinson's over several weeks for a consecutive number of years. An analysis could then be undertaken to examine the relationship between objectively measured volume of movement for different time points (i.e. year 1, 2 and 3) and Parkinson's symptom specific outcomes.

Chapter 5 focused on producing validated wrist-derived cut-points for use with people with Parkinson's. These values were generated using svm data collected while participants undertook a variety of light and moderate intensity tasks in the laboratory. Follow up research should apply the light and moderate intensity cut-points to the raw acceleration data collected for each task to determine the time spent at different activity intensity levels. The values could then be used to compare the predictive strength of volume of movement to other movement metrics, such as time spent at light or moderate activity, for METs and other cardiometabolic markers. Such a study would shed light on the usefulness of volume of movement compared to cut-point derived movement metrics, particularly with a Parkinson's population.

It would also be of value to apply the newly generated cut-points from Chapter 5 and alternative cut-points, such as those of Nero et al., 2019, to a new data set to compare the resulting intensity levels of activity. Such a study would help shed light on whether using hip- derived cut-points leads to over or underestimation of physical activity in people with Parkinson's compared to wrist-derived cut-points.

This thesis focuses on examining the feasibility of using a wrist-worn device to measure movement and the usefulness of certain accelerometer-derived movement parameters. The recommendations outlined above will help further the field of accelerometry and expand upon the results of the small but novel studies reported within this thesis by building on the focus of feasibility and expanding to application.

6.4 Methodological limitations

This thesis included several exploratory studies aimed at exploring the application of GENEActiv wrist-worn accelerometers to measure the movement of people with Parkinson's during and after participation in dance classes, ranging from a free-living environment to a laboratory setting. These studies are not without some limitations, most of which are discussed in the relevant chapter. Therefore, some general considerations are outlined below.

6.4.1 Sample size

Due to the exploratory nature of the studies reported in Chapter 3 and 4, the sample sizes were small in comparison to some studies using accelerometry to assess the pattern of movement made by people with Parkinson's (Coe et al., 2018; van Hilten et al., 1993; Wallen et al., 2015). However, several of these studies obtained their data from larger clinical trials, such as Coe et al., (2018), thus facilitating the recruitment of greater number of people with different Parkinsonian profiles over several years. Despite the initial large sample size (n = 105), Coe et al., (2018) found that only 65 people (across the exercise intervention and control group) had complete accelerometer data, as measured over 7 days using a GENEActiv device. Complete accelerometer data was obtained for the studies reported in Chapter 3 and 4 of the current thesis, despite the smaller sample sizes. It could also be argued that the sample size for Chapter 3 is comparable to that of Delextrat et al., (2016; n = 11 people with Parkinson's.), while the sample size for Chapter 4 is in line with several studies examining the movement profiles of people with Parkinson's (Cavanaugh et al., 2015; Chastin et al., 2010; Porta, Corona, et al., 2018). Furthermore, both studies in the current thesis included an age-matched control group, a limitation of the research undertaken by Cavanaugh et al., (2015), Delextrat et al., (2016) and Porta, Corona, et al., (2018). Nonetheless, future studies investigating parameters of movement of people with Parkinson's should aim to recruit greater numbers of participants in order to a) facilitate analysis that accounts for the heterogeneity of the condition and b) aid the possibility of normal distribution for volume of movement, if using this metric.

6.4.2 Tremor

One of the limitations of the studies reported in the current thesis is that it is not known what impact tremor may have had on the acceleration data recorded by the wrist-worn device. It was intended to explore this by comparing the data from a device worn on the tremor-dominant side to the data from the less/ non-affected side. However, due to a device error it was not possible to undertake the study in full. The rest tremor that characterises Parkinson's is typically asymmetric (Kwon et al., 2016), therefore people with Parkinson's with moderate tremor (as assessed using the UPDRS-MDS) were asked to wear a GENEActiv accelerometer on each wrist. In line with the method reported in several rest tremor quantification studies (H. J. Lee et al., 2015, 2016; Scanlon et al., 2013), participants were asked to sit comfortably in a chair with their hands resting in their lap for two minutes. The participant then took a break before repeating the task twice more. Each task was timed, with the start and end time noted so that the correct data could later be extracted. As described in previous chapters the data was downloaded into Excel. Unfortunately, on inspection of the Excel sheets it became clear that the device that was worn on the right wrist by all participants was faulty, such that it recorded the movement data but all values were considerably inflated. Few participants had a left-side tremor, however Matlab was used to further process the raw acceleration data for the tremor task. Evidence suggests oscillations at a frequency of between 4-6 Hz characterise rest tremor (Salarian et al., 2007). MATLAB (version R2019b) was used to produce spectrograms for each two-minute task to visually explore whether tremor could be detected. A spectrogram is a time-frequency distribution with frequency on the vertical axis and time on the horizontal axis, see appendix 11 for an annotated example. Bands of a particular colour signal different energy at a particular frequency. These bands can be used to determine whether tremor has been detected by the wearable device. Given the error for all the data recorded by the right-side accelerometer, it was not possible to compare between tremor dominant and non-dominant side.

While the current thesis was not able to assess the impact of tremor on the movement data recorded by the accelerometers, a number of published studies using the GENEActiv device have not accounted for the possible effect of tremor (Coe et al., 2018; Delextrat et al., 2016), and Porta, Pilloni, et al., (2018) who used the ActiGraph wGT3X-BT. In line with both Coe et al., (2018) and Porta, Pilloni et al., (2018), all studies detailed in the current thesis used a 100 Hz sampling rate. As previously mentioned, rest tremor occurs at a frequency lower than 10 Hz and the power/energy is detectable at 50 Hz, however at higher frequencies the signal is down sampled. Therefore, it is likely that acceleration data recorded at a 100 Hz frequency for 60 second epochs are less impacted by rest tremor due to the reduced signal.

6.4.3 The effect of hand dominance on data

The studies reported in the current thesis were exploratory, therefore there are some possible limitations regarding the implementation of the accelerometers. It is not known what impact hand dominance had on the data recorded by the accelerometer. There is a lack of consensus in the literature regarding preferable wrist placement with several studies selecting the non-dominant wrist due to higher reported compliance rates (Porta, Corona, et al., 2018) and the data being less affected by involvement of limb in specific tasks where dominance is important (van Hilten et al., 1993). However, a large-scale UK public health study required participants to wear an accelerometer on their dominant wrist for seven consecutive days in a free-living setting (Doherty et al., 2017). Therefore, the data in the Doherty et al., (2017) study would have captured the movement associated with activities of daily living, many of which are hand-dominance related. It should also be noted that some studies do not specify wrist placement or hand dominance (Coe et al., 2018; Delextrat et al., 2016).

Due to the small sample size of the studies reported within Chapter 3 and 4 and the non-normal distribution of the svm data, hand-dominance was not controlled for in the analyses. However, there is research to indicate that svm data from both the left and right wrist are significantly associated with physiological energy expenditure (left wrist $R = 0.86$; right wrist $R = 0.83$; Esliger et al., 2011). Doherty et al., (2017) suggest that the similarity in the strength of the correlation for both locations demonstrates comparable validity for the left and right wrist. Due to equipment error the relationship between right-wrist placement with METs was not explored in Chapter 5 and no comparisons could be made to the left wrist and METs correlation. The results of the correlation between left wrist-derived svm and METs indicated a moderate association between the two variables for the walking tasks, but with a correlation coefficient substantially lower than that of Esliger et al., (2011). This discrepancy may be due to the differences in the data included in the analyses, such that Esliger et al., (2011) used the svm and $\dot{V}O_2$ data from 12 different tasks, inclusive of walking at different places and household chores (i.e. sweeping, dishwashing and shelf stacking). More research is warranted examining the relationship between physical activity outcomes and the raw svm data derived from different wrist placements within free-living settings.

6.4.4 Spiroergometry device

The study reported in Chapter 5 used a potable spiroergometry device to measure the physiological energy expenditure of participants while they undertook a variety of tasks in the sports laboratory. However, due to equipment error a battery powered unit had to be used initially until a portable unit became available. Nine participants wore the battery powered unit, which required a cable to be trailing on the floor behind the participant as they undertook each of the activities. It could be suggested that this may have resulted in these participants altering their pace, particularly when walking, sweeping and dancing. While the speed at which participants with Parkinson's walked for the slow pace task was found to be lower compared to the speeds reported in other studies (Nemanich et al., 2013; Nero et al., 2015), this was not the case for the brisk pace walking with participants walking at a faster speed compared to previous literature. Furthermore, age-matched controls walked at speeds comparable to those reported for older adults for the brisk and normal paced tasks (Eggenberger et al., 2017), and greater compared to the participants with Parkinson's. Considered together, these findings indicate that wearing the battery powered unit most likely did not have an effect on participants speed for the walking tasks. In terms of the dance and sweeping tasks it is less clear whether the cable caused any interference with undertaking the tasks in terms of effort or movement made. It should be noted that none of the participants withdrew from undertaking any of these tasks due to concerns regarding the cable. Furthermore, the dance routines used in the study required the participant to stand facing the same direction throughout the task and with mostly side-stepping movements, such that the cable was always behind the participant.

6.5 Conclusions

The main aim of the present thesis was to explore the ways in which accelerometry can be used as a research tool to extend current understanding of the benefits of dance for people with Parkinson's. Specifically, the feasibility of implementing wrist-worn accelerometers as an objective measure of the movement made by people with Parkinson's during and after participation in dance classes was demonstrated across a series of exploratory and experimental studies. Wrist-worn GENEActiv accelerometers were found to accurately track the volume and pattern of movement made by individuals with and without Parkinson's while participating in a dance class. The devices were sensitive to between-group differences in volume of movement, such that people with Parkinson's and age-matched controls were found to move less compared to young adults across a 2-hour period that included dancing and socialising. However, using volume as a summary metric to interpret the data acquired from long-term monitoring of the movement made by people with Parkinson's in the hours and days after taking part in dance class has limited real-world applicability as a stand-alone metric. Validated wrist-derived cut-points for the assessment of activity intensity levels of people with Parkinson's were developed and found to differ to values used in published studies, most of which are obtained from hip-worn accelerometers; this indicates that previous studies using these values are likely to have over or underestimated the physical activity levels of people with Parkinson's. The current thesis addressed an unmet need in the accelerometry literature by providing accurate cut-points that will, alongside the use of volume of movement, facilitate the understanding of physical activity behaviours of people with Parkinson's in future studies.

The findings presented in this thesis contributed to current knowledge about the advantages and disadvantages of wrist-worn accelerometry in the measurement of movement made by people with Parkinson's, particularly demonstrating that it is useful and feasible to use the devices to examine the effect of dance on movement in this population. These findings can be used by researchers to inform the implementation of accelerometry in such studies and deliver insight into the ways data can be interpreted depending on the research context, alongside the provision of tools to enable interpretation of movement data.

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Appendices

Appendix 1: GENEActiv Original device specifications. Figure sourced from Activinsights Ltd., (n.d.).

Physical Properties	
Size	43mm x 40mm x 13mm
Weight	16g (without strap)
Main Housing Material	PC/ABS (medical grade device)
Light Guide Material	PC (medical grade device)
Data Contact Material	Gold-plated
Fixings	20mm heavy duty spring bar
Strap	PU resin
Battery Type	Rechargeable lithium polymer
Environmental Protection	
Moisture Ingress	Water-resistant to 10m (IP67-1m 24hrs)
Material Ingress	Dust tight (IP67)
Operating Temperature	5 to 40 degrees C
Mechanical Impact	0.5 drop resistant
Measurement Capabilities	
Memory	0.5Gb non-volatile
Logging Frequencies	Selectable 10-100 Hz
Maximum Logging Frequencies	45 days at 10 Hz and 7 days at 100 Hz
Internal Clock	
Type	Quartz Real Time Clock
Frequency	32.768kHz
Accuracy	+/- 20ppm (+/- 1.7secs per day)
Acceleration Measurements	
Sensor Type	MEMS
Range	+/- 8g
Resolution	12 bit (3.9 mg)
Light Measurements	
Sensor Type	Silicon photodiode
Wavelength	400 to 1100 nm
Range	0-3000 Lux typical
Resolution	5 Lux typical
Accuracy	+/- 10% at 1000 Lux calibration
Event Logger	
Sensor Type	Mechanical membrane switch
Temperature Measurements	
Sensor Type	Linear active thermister
Range	0 to 60 degrees C
Resolution	0.25 degrees C
Accuracy	+/- 1 degrees C
Measurement Frequency	Every 30 seconds minimum
USB Connection	
Device	USB 2.0 Full Speed
Charge Cradle	Format 4 unit cradle USB 2.0 High Speed
Charge Time	90% at 2 hours, 100% at 3 hours
Data Download Time	Maximum 15 minutes for 4 concurrent units

Appendix 2: Demographics form used in Chapter 3 and 4.

General Information

Gender …… Male ☐ Female ☐

Date of birth (DD/MM/YYYY):

Handedness: ☐ Left-handed ☐ Right-handed ☐ Ambidextrous

Health Information

Have you been diagnosed with Parkinson's? Yes ☐ No ☐

If you answered yes, please answer the questions below.

At what age were you diagnosed with Parkinson's? (please write in years):

Are the Parkinson's symptoms more prominent on one side of the body compared with the other?

☐ Yes ☐ No

If yes, please could you provide more detail below about which side of the body and what symptoms you experience.

Do you have a rest tremor?

☐ Yes ☐ No

If yes, could you please provide more information below, such as which limb/s (left, right or both):

Have you undergone deep brain stimulation?

☐ Yes ☐ No

Are you taking any medication for your Parkinson's? Yes ☐ No ☐

If you answered yes, please could you provide information about each type of medication in the table on the following two pages.

Appendix 3: Modified Hoehn and Yahr staging scale (Goetz et al., 2004)

Please tick one box that you think best describes your symptoms of Parkinson's disease. The symptoms may be mild or severe or happen a lot, or not as much. Also, the time spent at each stage of the disease varies, and the skipping of stages, from Stage 1 to Stage 3, for example, is not uncommon.

❑ Stage 0: no signs of disease

❑ Stage 1: The main symptoms but very mild- tremor, muscle stiffness, slowness of movement and problems with posture- are only on one side of the body.

❑ Stage 1.5: symptoms appear only on one side of the body. Problems with balance may appear.

❑ Stage 2: symptoms appear on both sides, minor symptoms like problems with swallowing, talking and something called "facial masking" (loss of facial expression) may be noticed.

❑ Stage 2.5: symptoms appear on both sides and still mild. The same symptoms of Stage 2 are still there but may be worse now

❑ Stage 3: symptoms are mild to moderate, some postural instability occurs, but patients are physically independent

❑ Stage 4: symptoms are severe, the patient is severely debilitated and needs some assistance but can still walk or stand unassisted. The patient will need help with some or all activities of daily living.

❑ Stage 5: symptoms are very severe, the patient is typically wheelchair-bound or confined to a bed, unless aided

Appendix 4: Volume of movement made during a dance class for each of the remaining participant triads.

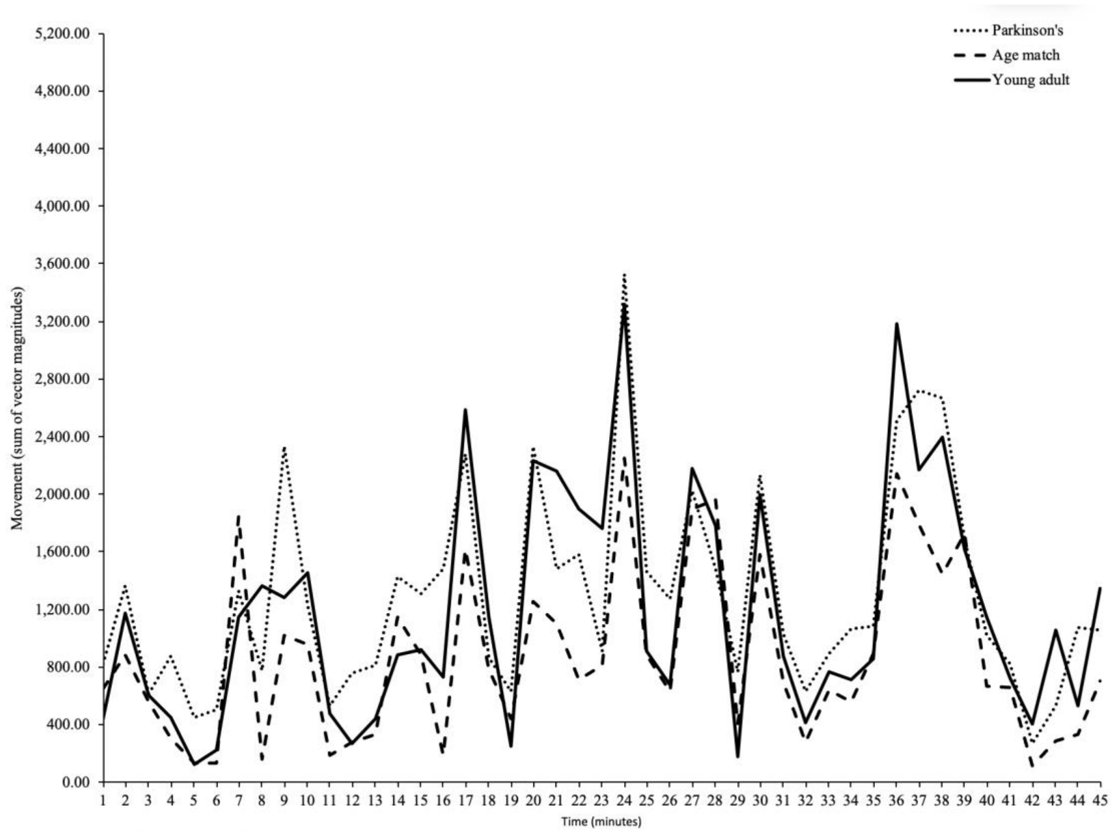

Figure 8.1 The volume of movement during a dance class made by the first participant triad.

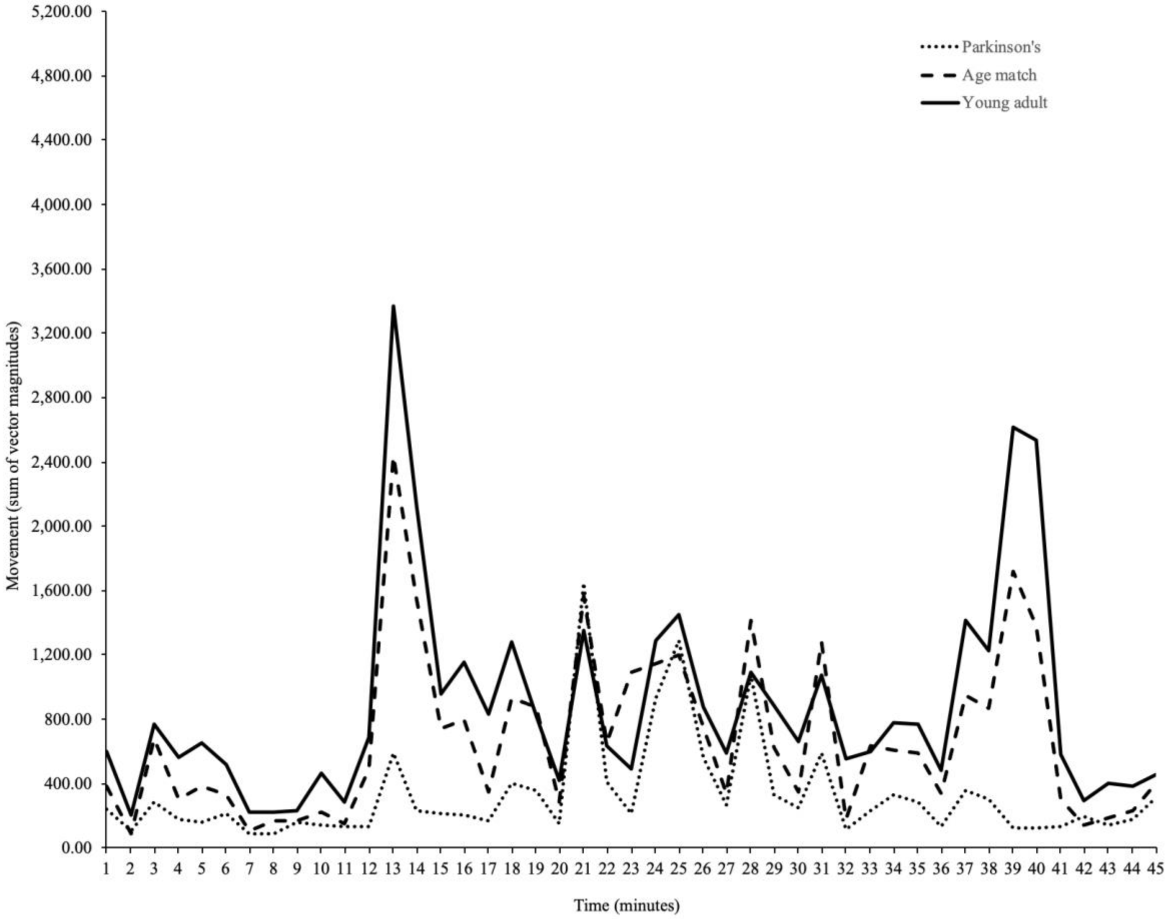

Figure 8.2 The volume of movement during a dance class made by the second participant triad.

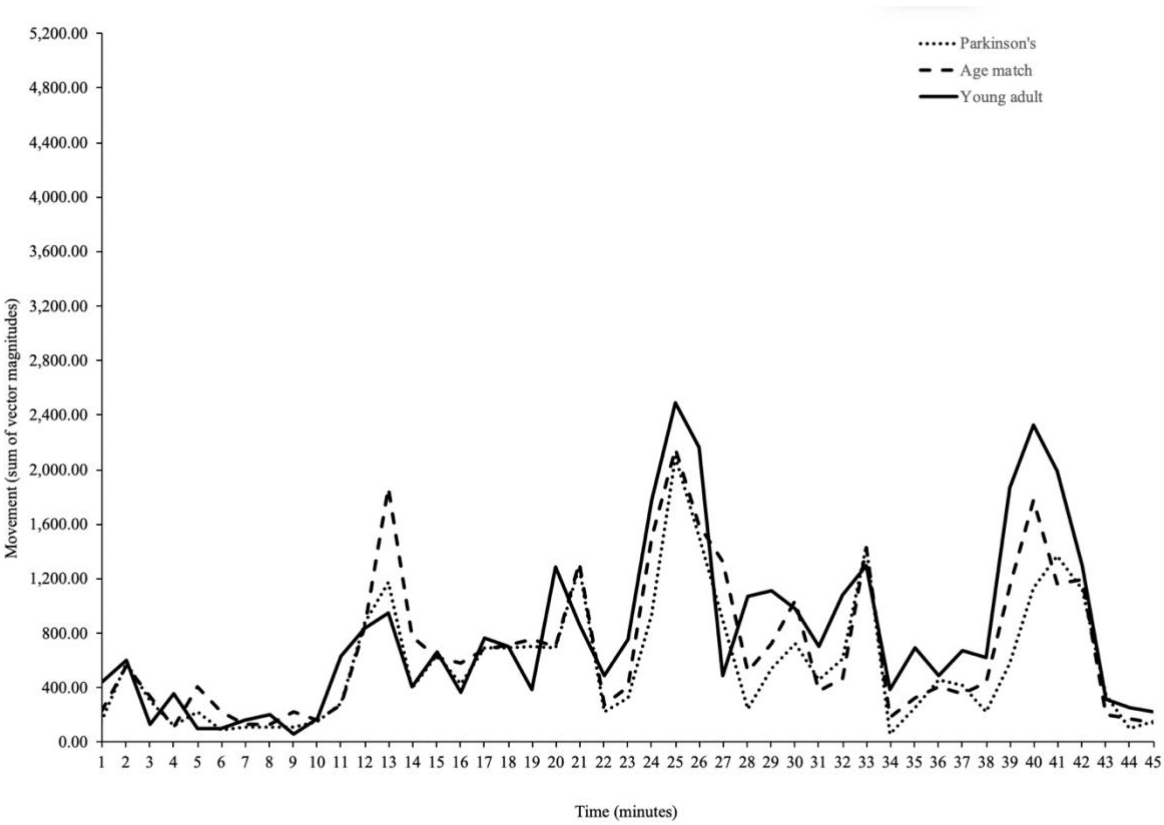

Figure 8.3 The volume of movement during a dance class made by the fourth participant triad.

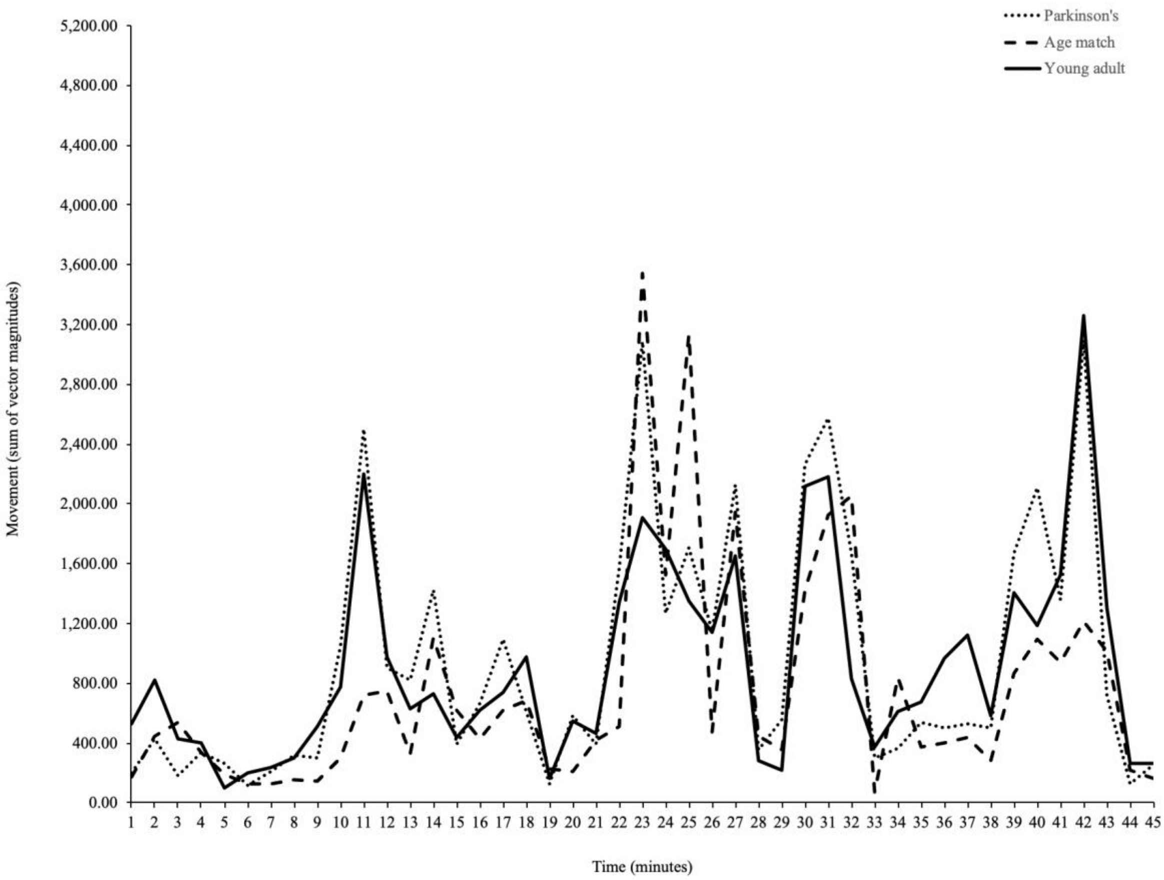

Figure 8.4 The volume of movement during a dance class made by the fifth participant triad.

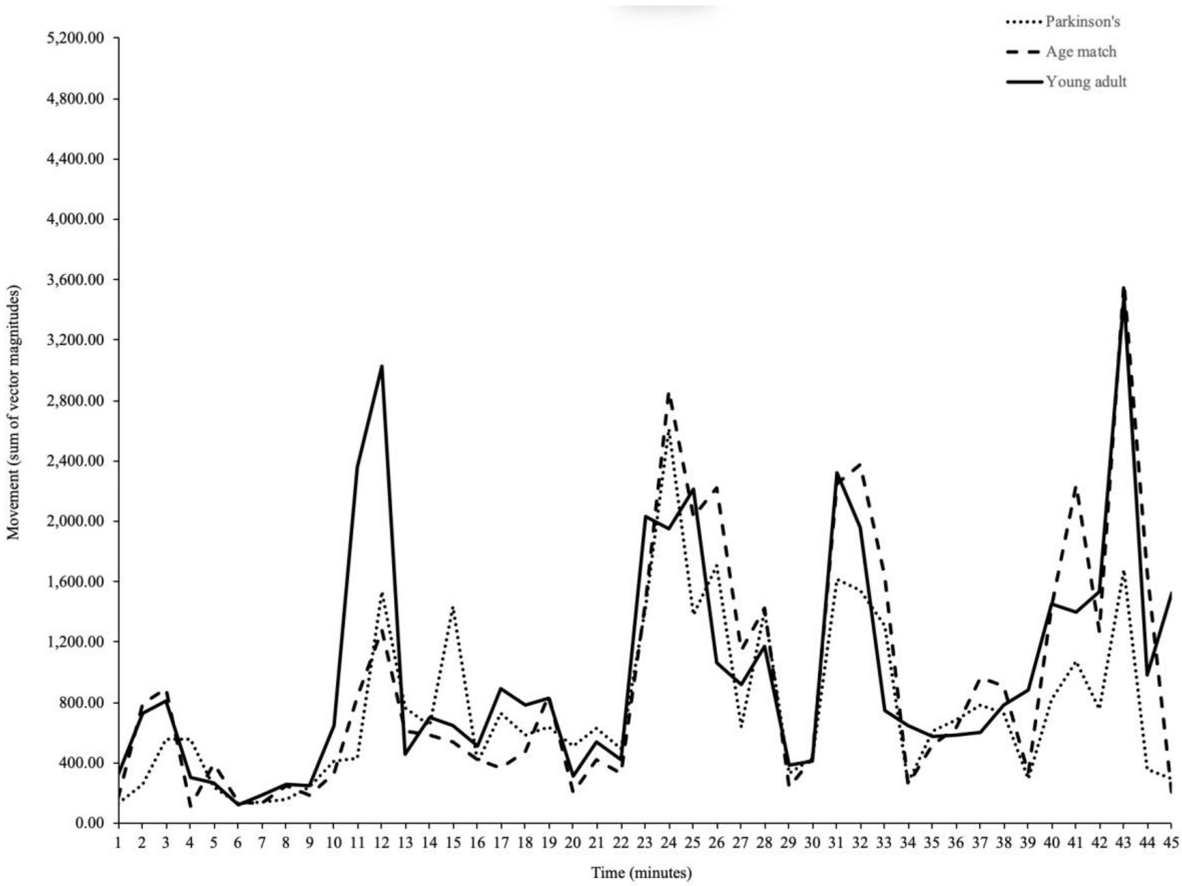

Figure 8.5 The volume of movement during a dance class made by the sixth participant triad.

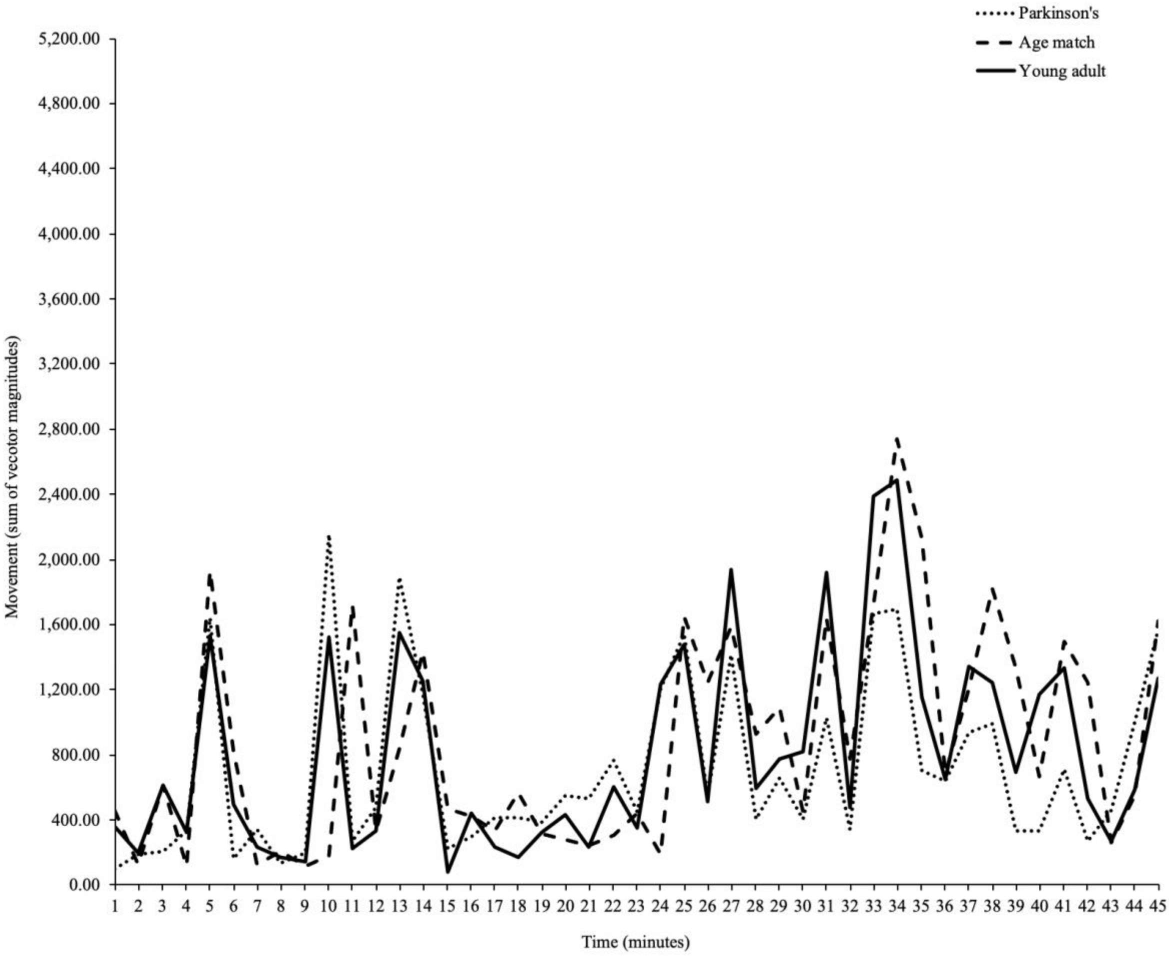

Figure 8.6 The volume of movement during a dance class made by the seventh participant triad.

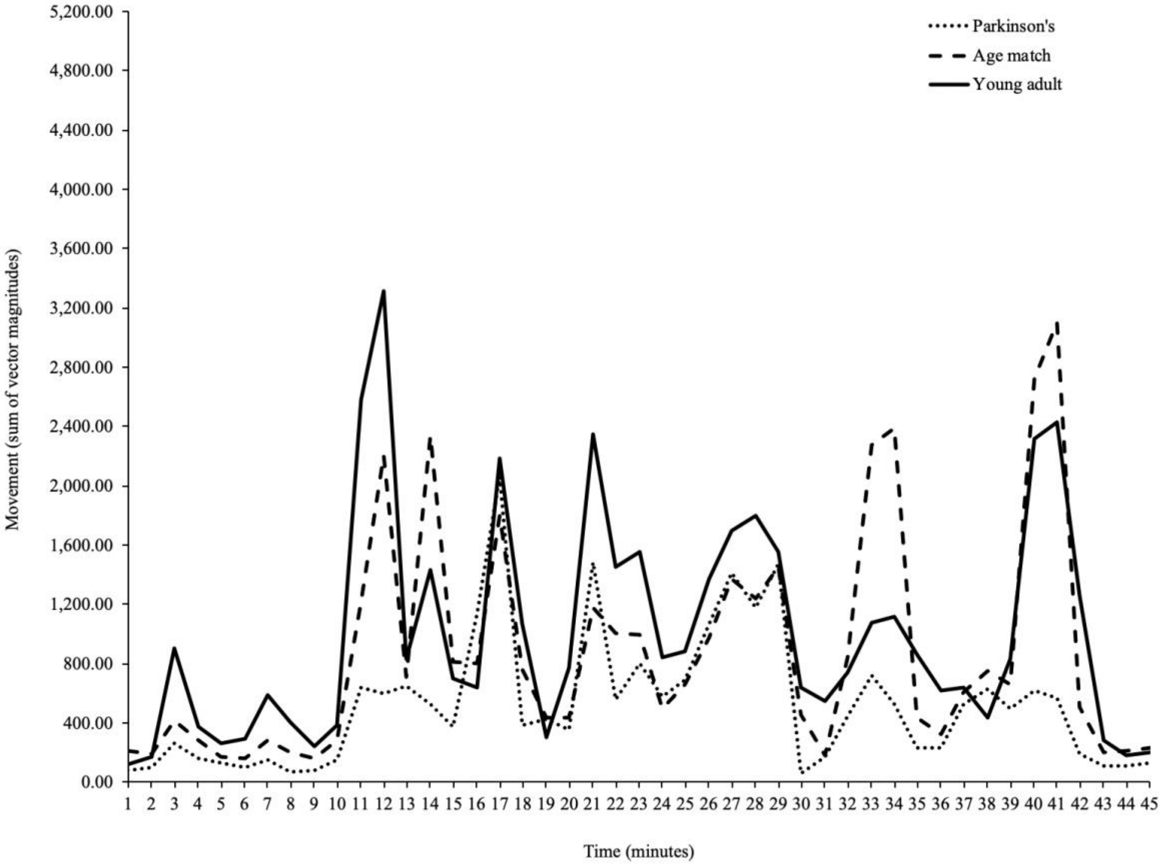

Figure 8.7 The volume of movement during a dance class made by the eighth participant triad.

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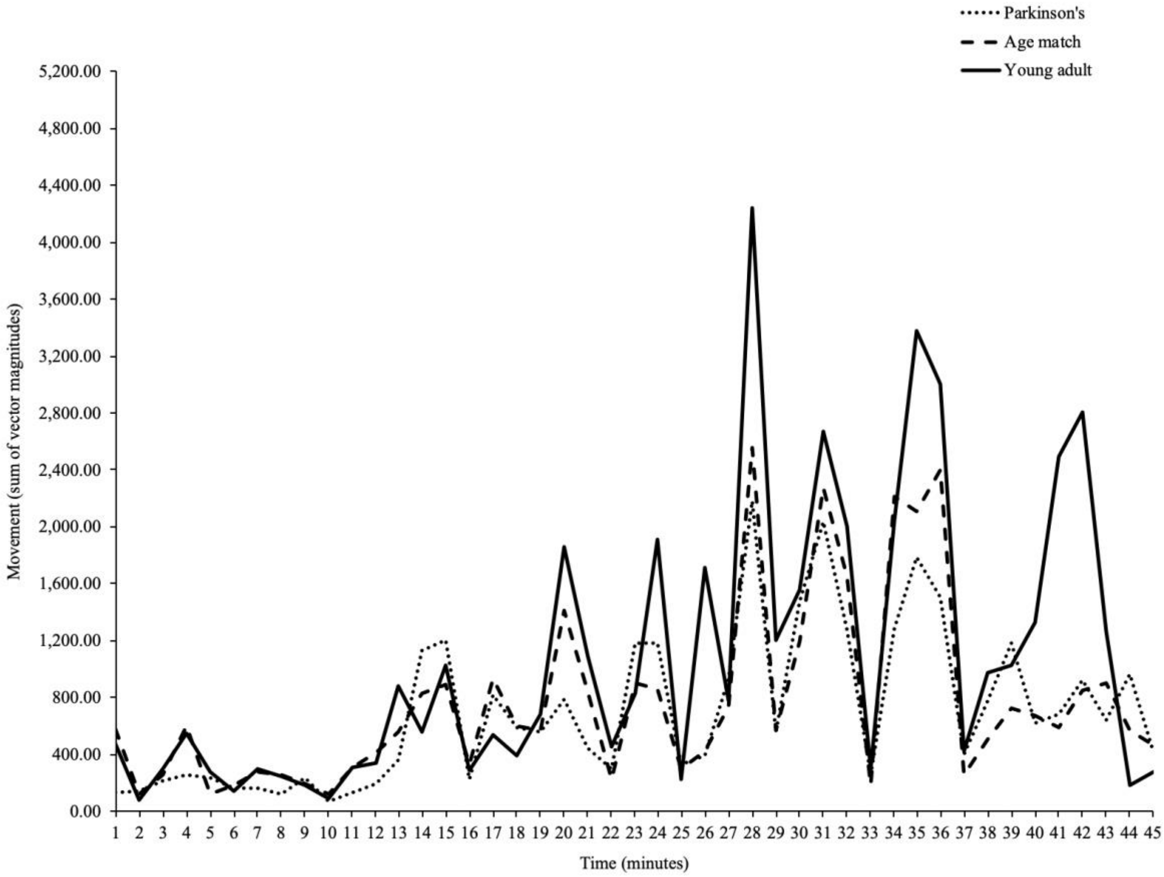

Figure 8.8 The volume of movement during a dance class made by the tenth participant triad.

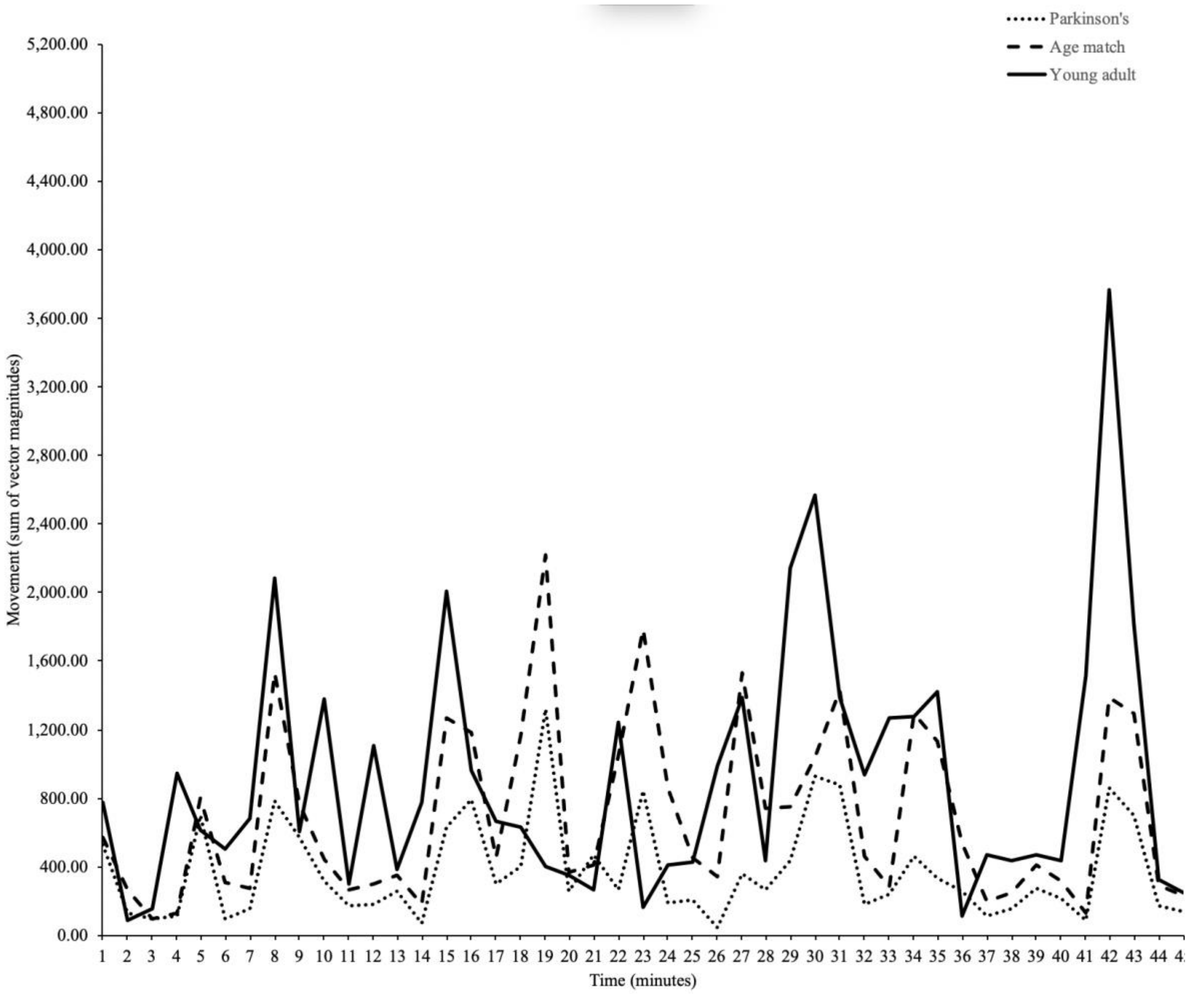

Figure 8.9 The volume of movement during a dance class made by the eleventh participant triad.

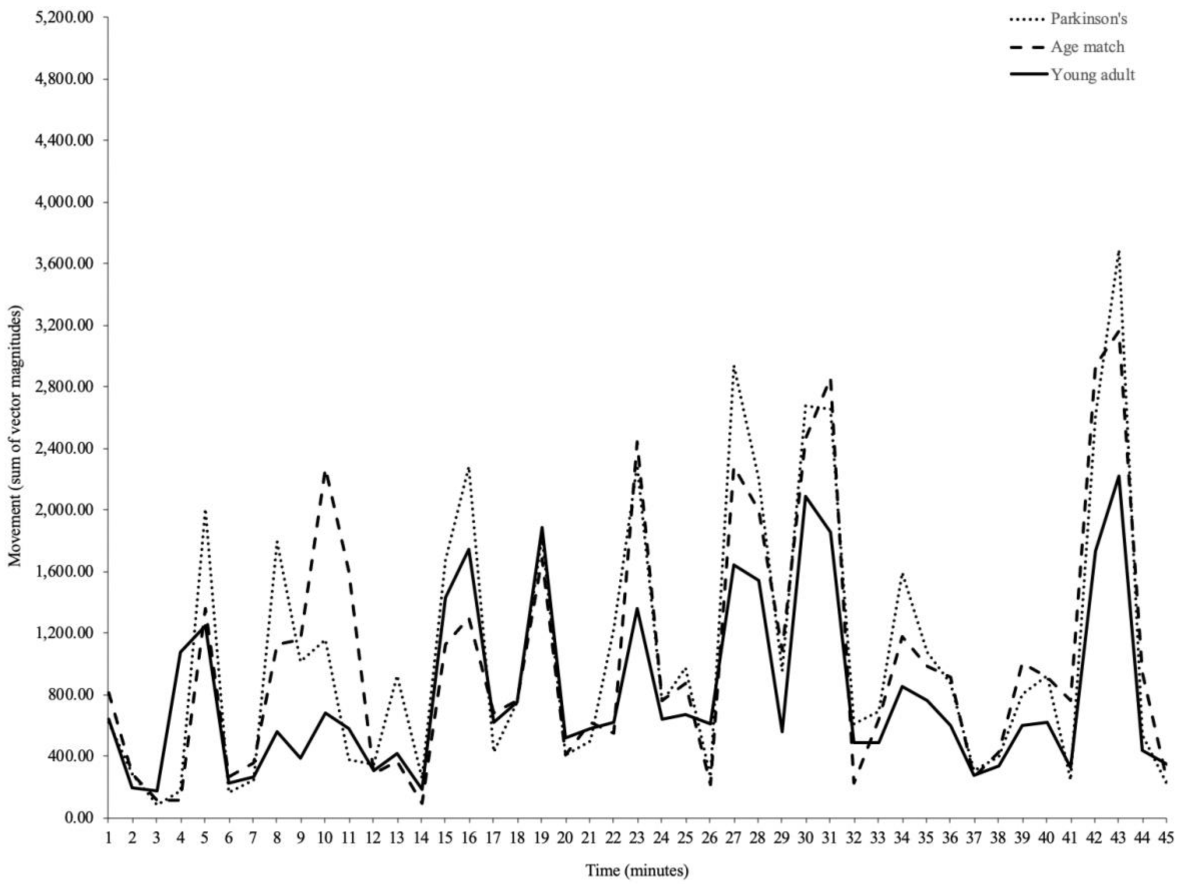

Figure 8.10 The volume of movement during a dance class made by the twelfth participant triad.

Appendix 5: Volume of movement made during a rest session for each of the remaining participant triads.

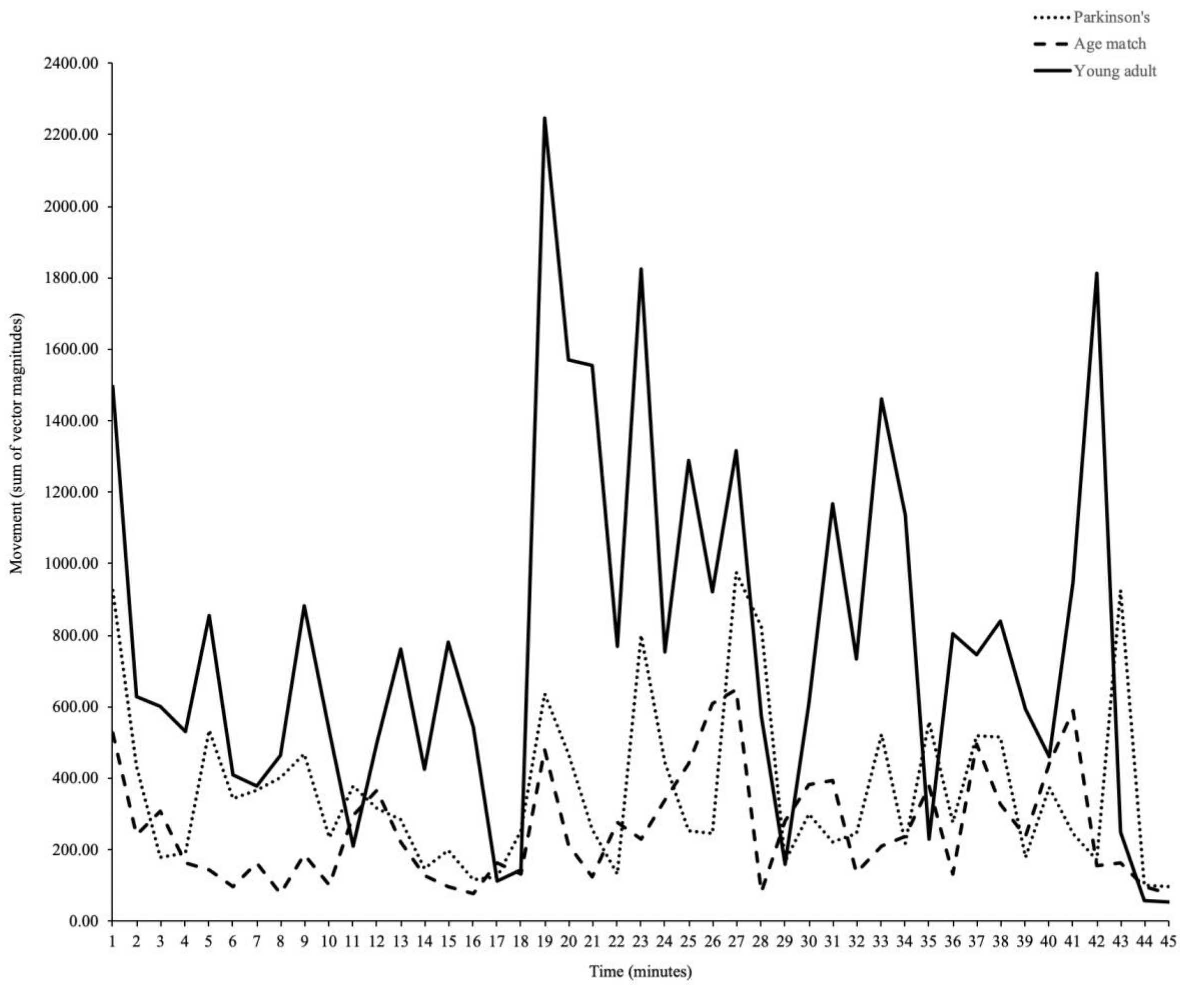

Figure 8.11 The volume of movement during a rest session made by the first participant triad.

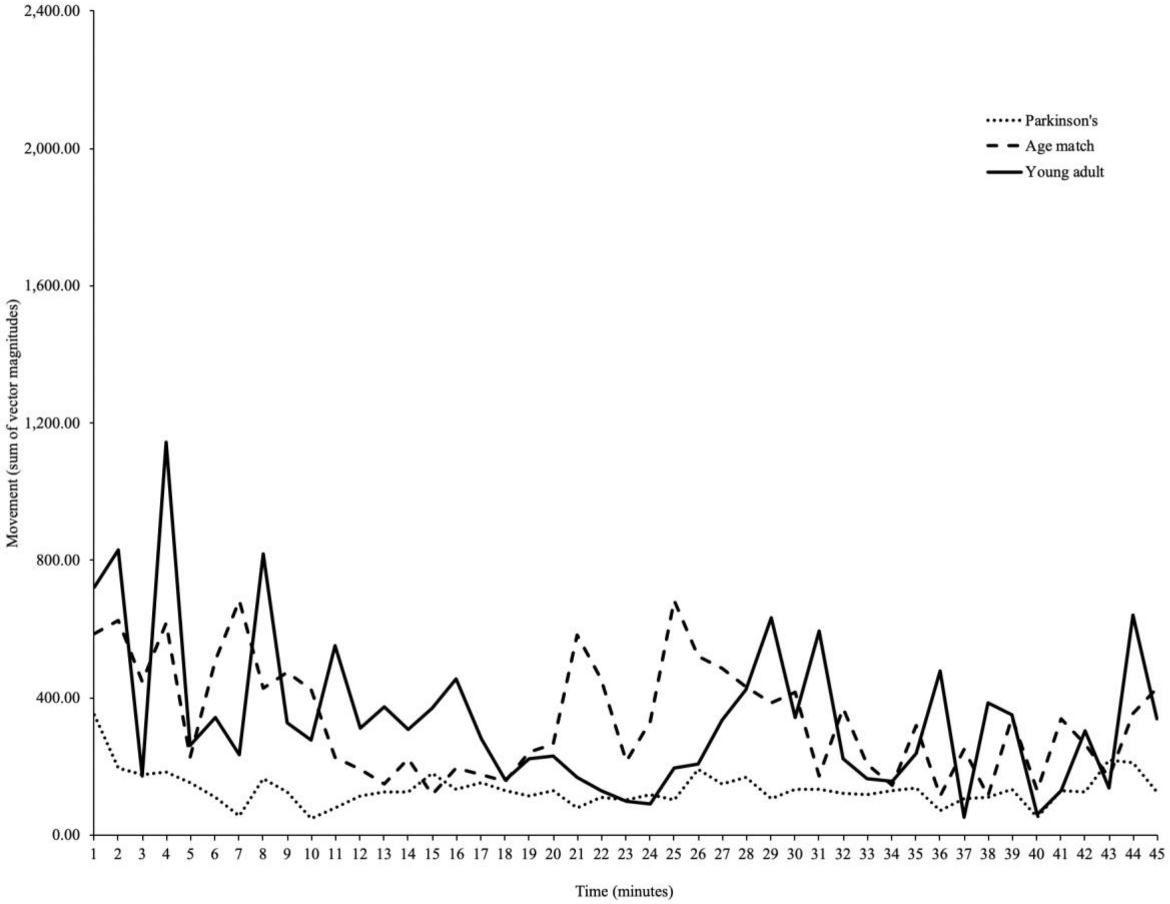

Figure 8.12 The volume of movement during a rest session made by the second participant triad.

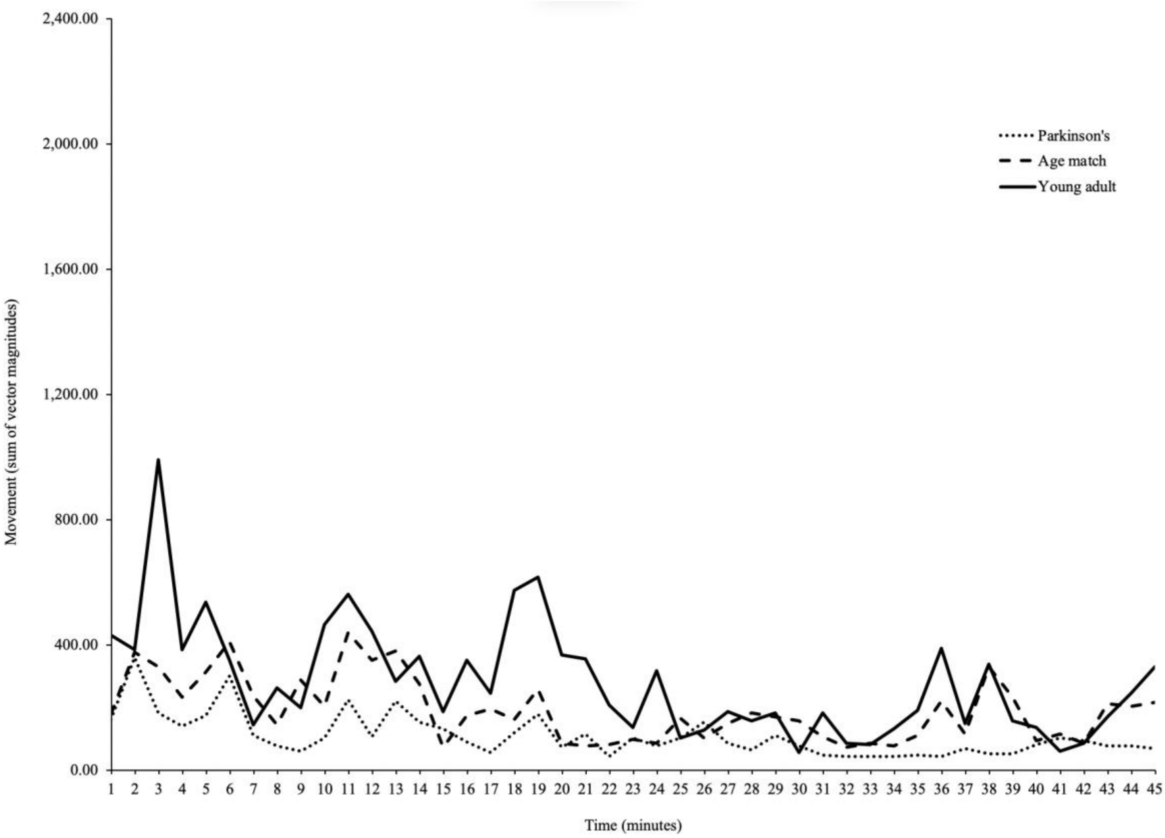

Figure 8.13 The volume of movement during a rest session made by the fourth participant triad.

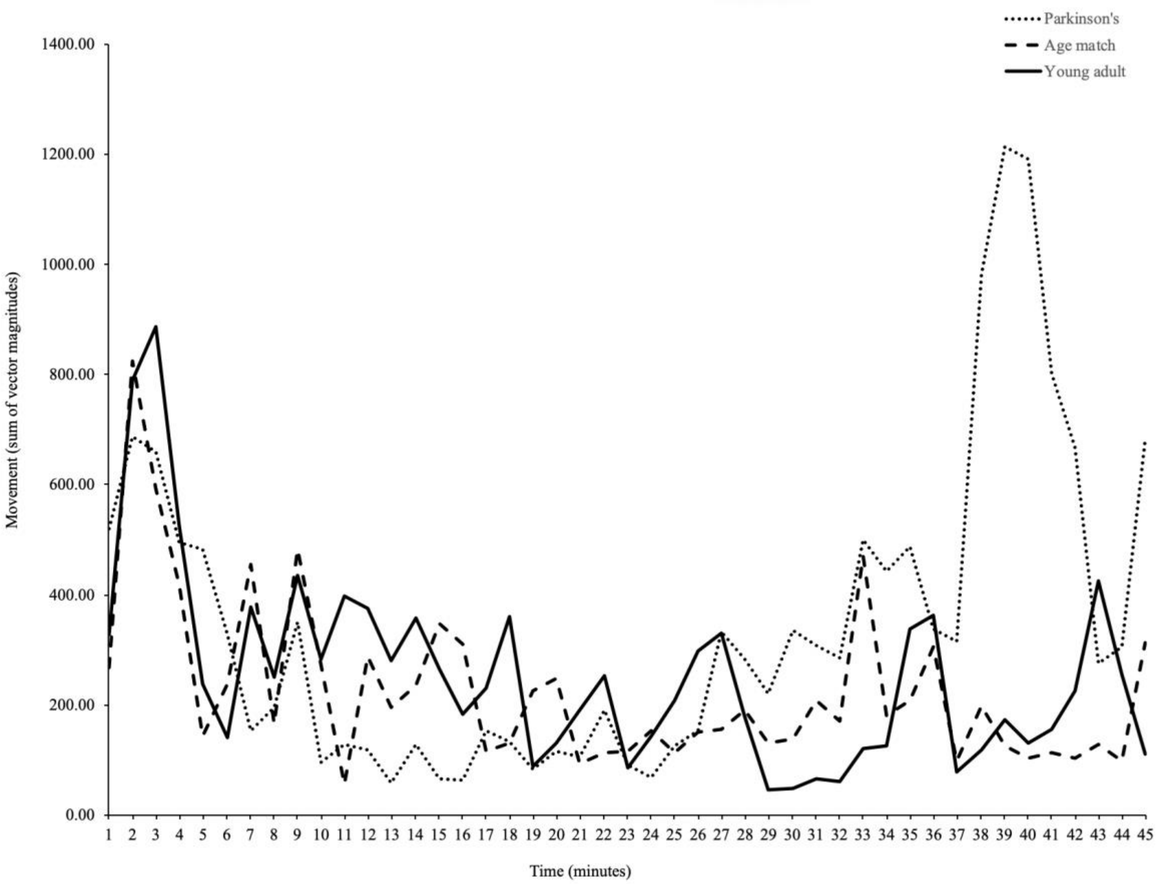

Figure 8.14 The volume of movement during a rest session made by the fifth participant triad.

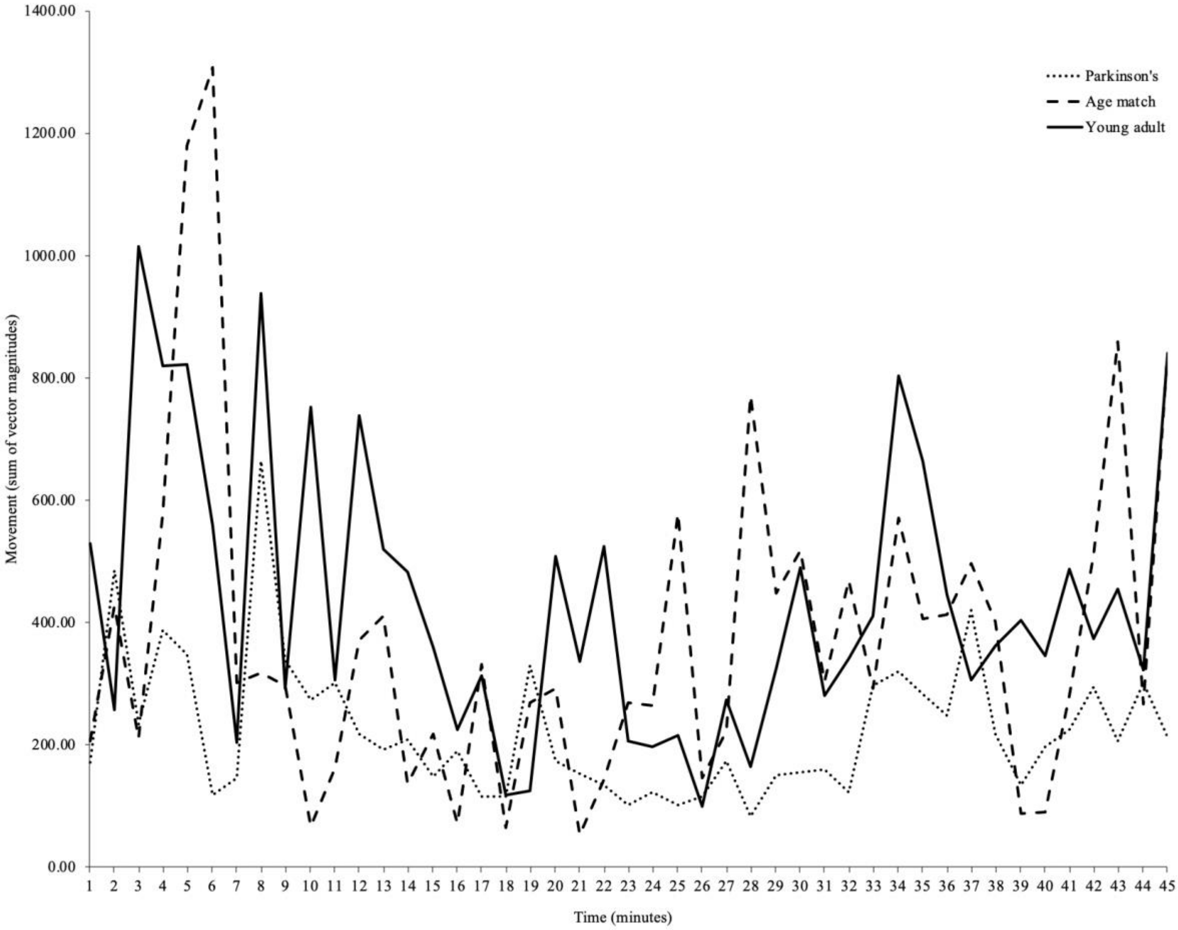

Figure 8.15 The volume of movement during a rest session made by the sixth participant triad.

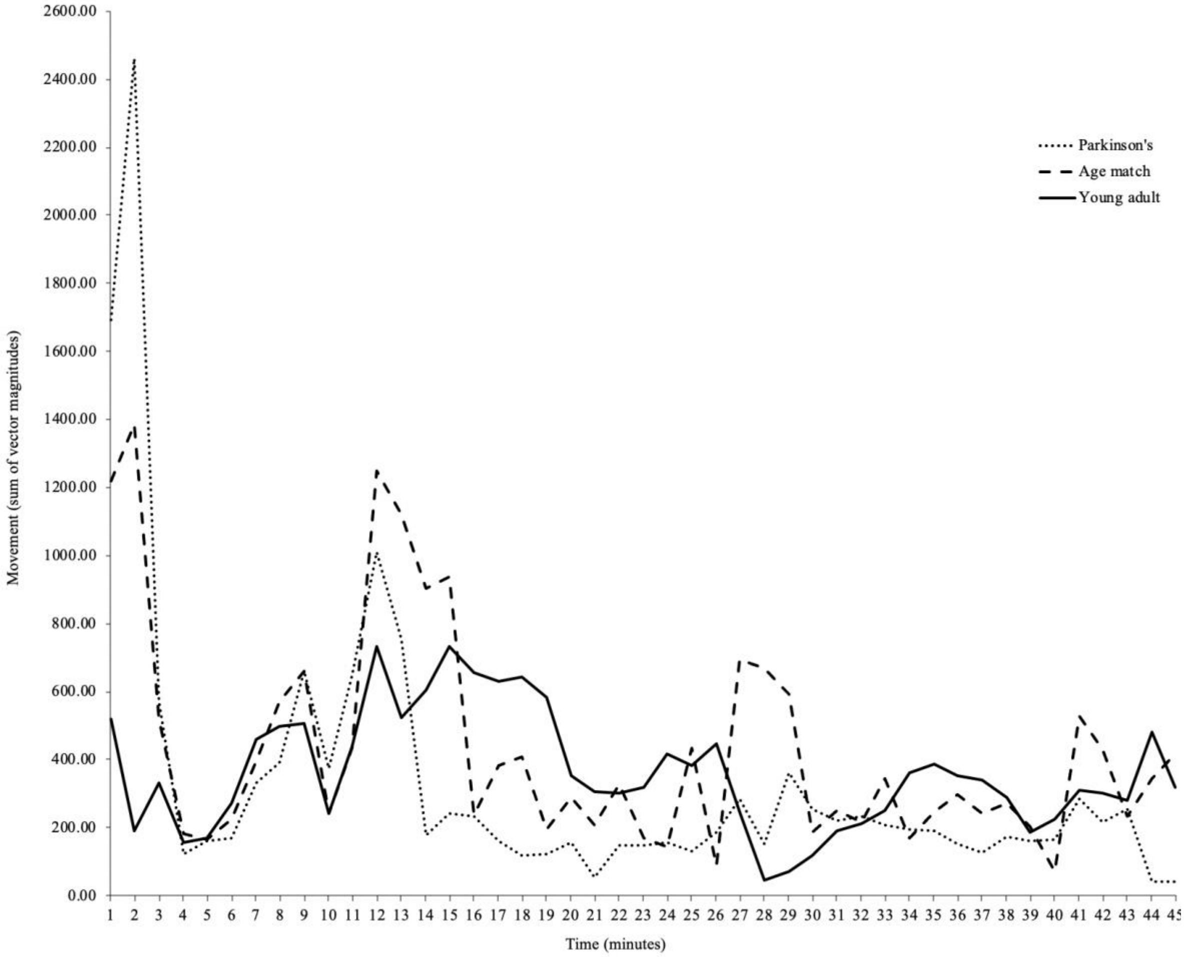

Figure 8.16 The volume of movement during a rest session made by the seventh participant triad.

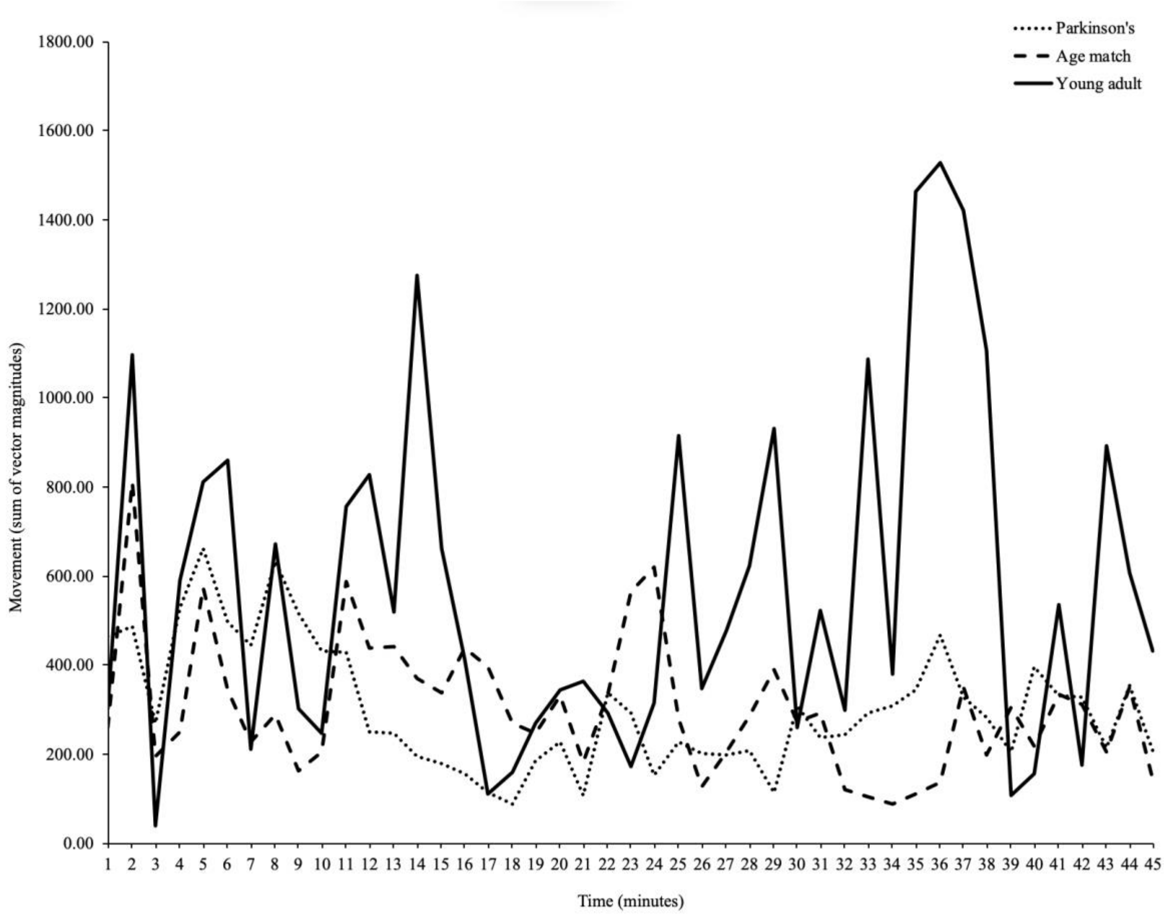

Figure 8.17 The volume of movement during a rest session made by the tenth participant triad.

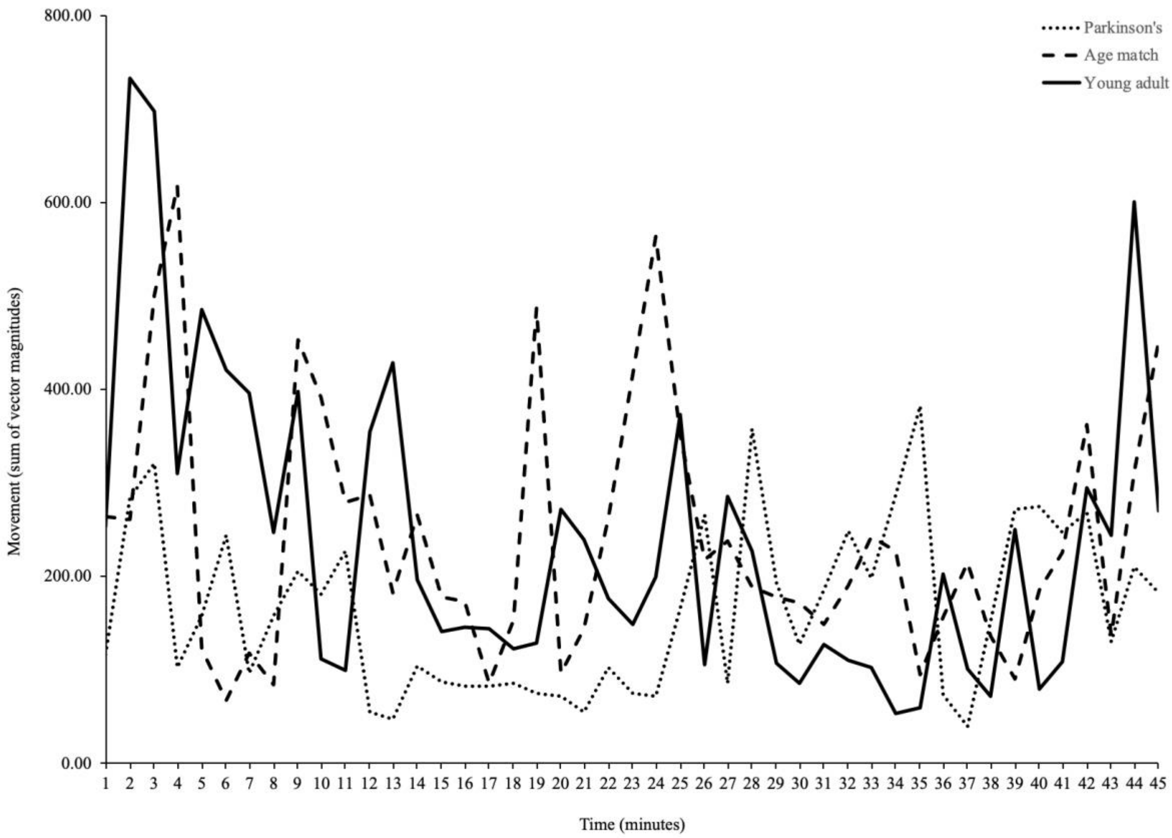

Figure 8.18 The volume of movement during a rest session made by the eleventh participant triad.

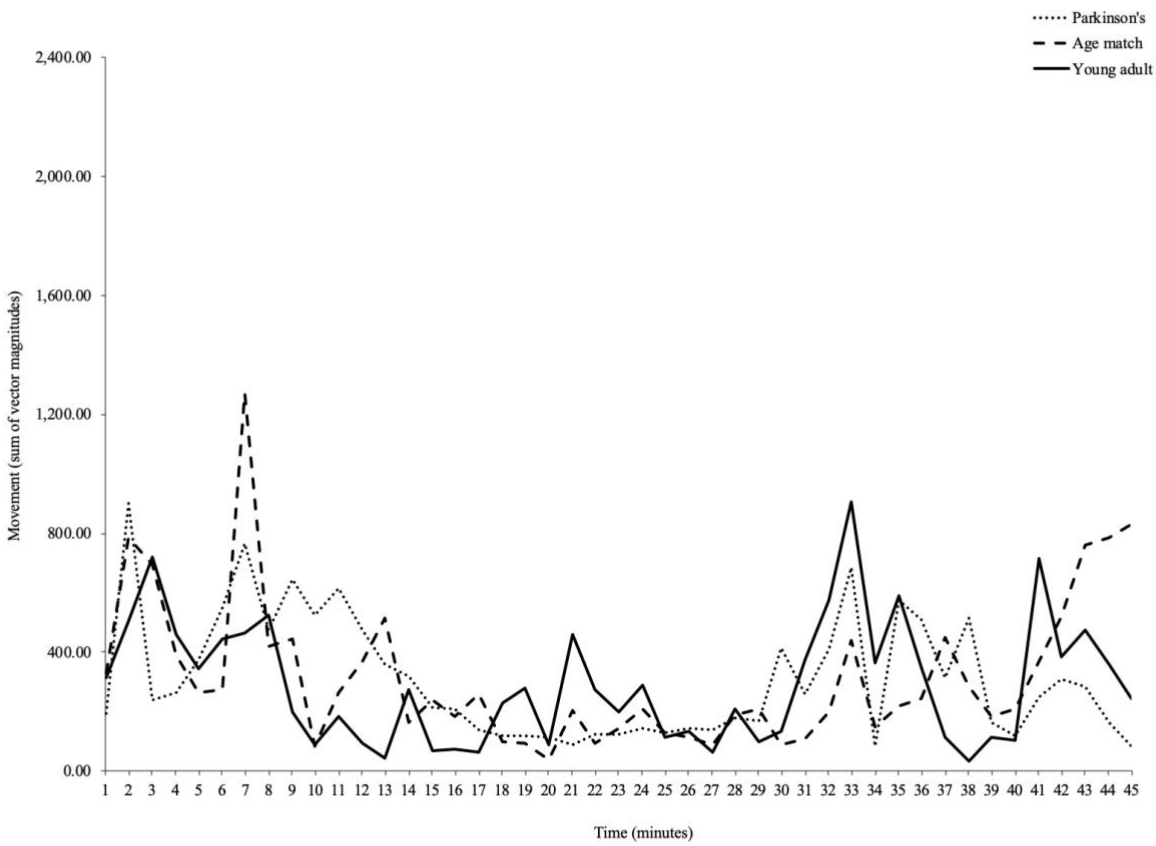

Figure 8.19 The volume of movement during a rest session made by the twelfth participant triad.

Appendix 6: Activity diary

Time of the day	Device taken off	Sleep	Activity
6am- 7am			
7am- 8am			
8am- 9am			
9am- 10am			
10am-11am			
11am-12 noon			
12 noon – 1pm			
1pm- 2pm			
2pm- 3pm			
3pm- 4pm			
4pm-5pm			
5pm- 6pm			
6pm- 7pm			
7pm- 8pm			
8pm- 9pm			
9pm- 10pm			
10pm- 11pm			
11pm- 12am			
12am-6am			

Appendix 7: Summary statistics for measures of energy expenditure

Table 0.1 Means and standard deviations for METs, heart rate and RPE by group and task.
Heart rate in beats per minute.

Task	Measures	Group	
		Parkinson's	*Age-matched*
Brisk walk	METs*	3.85 (1.22)	4.50 (1.60)
	Heart rate^	102 (16)	105 (15)
	RPE+	12.80 (1.03)	11.63 (1.72)
Normal walk	METs	3.15 (0.66)	3.22 (0.93)
	Heart rate	91 (15)	86 (8)
	RPE	10.20 (0.92)	8.50 (1.78)
Slow walk	METs	2.46 (0.55)	2.31 (0.64)
	Heart rate	83 (14)	75 (10)
	RPE	7.70 (1.48)	7.00 (1.26)
Irish dance	METs	3.05 (0.99)	3.26 (1.15)
	Heart rate	96 (21)	87 (17)
	RPE	11.70 (1.06)	10.42 (2.19)
Jai ho dance	METs	2.36 (0.66)	2.59 (0.99)
	Heart rate	93 (17)	86 (24)
	RPE	11.10 (1.45)	9.42 (1.51)
Sweeping	METs	2.66 (0.58)	3.17 (0.92)
	Heart rate	89 (15)	84 (10)
	RPE	11.75 (1.81)	9.54 (3.17)
Dish washing	METs	1.69 (0.54)	1.90 (0.54)
	Heart rate	85 (16)	76 (7)
	RPE	8.15 (1.06)	7.00 (1.46)

*10 participants per group for all tasks
+ 10 participants in the Parkinson's and 12 in the age-matched group for all tasks
^ Data missing for both Parkinson's and age-matched participants. One Parkinson's participant for the normal walk, 2 Parkinson's and age-matched participants for the slow walk, 2 Parkinson's participants for the Irish dance, 1 Parkinson's and age-matched control for Jai ho dance, 1 age-matched and 4 Parkinson's participants for sweeping and 3 age-matched and 5 Parkinson's participants for dish washing.

Appendix 8: Borg's (1982) Rating of Perceived Exertion Scale

While doing physical activity, we want you to rate your perception of exertion. This feeling should reflect how heavy and strenuous the exercise feels to you, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath but try to focus on your total feeling of exertion.

Look at the rating scale below while you are engaging in an activity; it ranges from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion." Choose the number from below that best describes your level of exertion. This will give you a good idea of the intensity level of your activity, and you can use this information to speed up or slow down your movements to reach your desired range.

Try to appraise your feeling of exertion as honestly as possible, without thinking about what the actual physical load is. Your own feeling of effort and exertion is important, not how it compares to other people's. Look at the scales and the expressions and then give a number.

#	**Level of Exertion**
6	No exertion at all
7	
7.5	Extremely light (7.5)
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Appendix 9: MDS-UPDRS motor examination. Sourced from Goetz et al., (2008).

Appendix 10: Correlation between sum of vector magnitudes and METs

Table 0.2 Pearson's correlation coefficients between svm for each device location and measured METs.

		METs	Wrist	Ankle	Hip
METs	Correlation coefficient	1.00	.31** [0.097-0.479]	.42** [0.203-0.590]	.44** [0.215-0.620]
	N	72	72	72	72
Wrist	Correlation coefficient	-	1.00	.79** [0.658-0.895]	.90** [0.834-0.945]
	N	-	72	72	72
Ankle	Correlation coefficient	-	-	1.00	.90** [0.788-0.965]
	N	-	-	72	72
Hip	Correlation coefficient	-	-	-	1.00
	N	-	-	-	72

** correlation is significant at the 0.01 level (2-tailed).

Appendix 11: Spectrogram of the raw acceleration signal with rest tremor motion artifacts present

Signal on figure below is from an accelerometer worn on the left wrist. The participant with Parkinson's reported experiencing tremor on both sides of the body, but this was greater for left upper limb. Dotted lines on figure represents the start and end time of the task. The straight line indicates the probable initiation and end of tremor period. The bright yellow horizontal band between 5-10 Hz indicates presence of rest tremor.