

**NOVEL EXPOSURE TO CONCURRENT MUSIC COMPROMISES LOCOMOTOR
PERFORMANCE IN PARKINSON'S DISEASE**

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Dedication

This thesis is dedicated to Mick.

Abstract

The effect of concurrent music on gait was investigated amongst Parkinson's disease (PD) patients and age-matched control subjects. Ten people (mean age 66.6 ± 6.5 years) with idiopathic Parkinson's disease and ten healthy age-matched (mean age 65.4 ± 6.3 years) control subjects completed steady state gait, dual task and obstacle negotiation trials in two differing test conditions; no music and whilst listening to music. Testing conditions were counterbalanced between subjects. The gait performance of PD patients was detrimentally affected by concurrently listening to music during steady state gait and obstacle negotiation, an effect that was further compounded in the dual task context. These findings imply that listening to music concurrent to gait may increase the attentional cost for PD patients. The findings of these studies have implications for patients, who may be at greater risk of falls in multi-task situations.

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Chapter 1: General Introduction

Walking (or gait) is one of the most commonly performed movements within activities of daily living, and as such is fundamental to independence and quality of life. Walking exists to safely transfer the body from one point to another (Prince, Corriveau, Hébert, & Winter, 1997), a challenging undertaking that can be further complicated by added tasks, such as maintaining a conversation whilst walking or safely negotiating an obstacle in the pathway.

Normal aging is associated with a number of changes to the gait pattern. In particular, reductions in walking speed and stride length and a concomitant increase in the duration of time that both feet are in contact with the ground (double limb support; DLS) have been consistently reported to characterise the aged gait pattern (Prince et al., 1997; Winter, Patla, Frank, & Walt, 1990). These gait changes could be considered to be a safety strategy to reduce the risk of falling through increasing the time spent in the most stable portion of the gait cycle. However, each year approximately one third of all older adults (65 years and over) will experience a fall (Blake et al., 1988; O'Loughlin, Robitaille, Boivin, & Suissa, 1993; Overstall, Exton-Smith, Imms, & Johnson, 1977). This fall rate is a serious concern for both individuals and healthcare providers alike, as in the older adult population falls are the foremost cause of injuries and injury-related death (Baker & Harvey, 1985). However, the prevalence of falls amongst neurological populations far exceeds that of the healthy community dwelling population. Parkinson's disease (PD) patients are at greatest risk of experiencing a fall, with approximately 50 percent of patients falling per annum (Stolze et al., 2004). Similar to non-neurological populations, the majority of falls in the PD population are a consequence of impaired gait

(Schaafsma et al., 2003). Gait disorders are a cardinal symptom of PD and persist despite current optimal treatment (Jankovic, 2002; Jankovic & Kapadia, 2001; Savitt, Dawson, & Dawson, 2006). As a result, alternative therapies are often used to complement existing standards of care (i.e. medications) in an attempt to address the problems associated with the unresponsive symptoms of the disease.

One form of intervention strategy that has proven to be effective in improving parkinsonian gait is the provision of periodic external spatial or temporal stimuli (cues). Cues assist patients in altering components of the gait pattern, for example increasing stride length (Morris, Iansek, Matyas, & Summers, 1994; McIntosh, Brown, Rice, & Thaut, 1997), and consequently contribute to the construction of an improved gait pattern. Common examples of spatial or visual cues are pieces of tape placed at regular intervals on the floor or a light-emitting device that projects lines on a transparent screen, both of which aim to increase step length through acting as markers for foot placement. Temporal cues are typically provided in the form of auditory stimuli, for example a simple metronome tone (rhythmic auditory stimulation; RAS; Lim et al., 2005), or an accentuated beat within an original musical piece (Lim et al., 2005; Thaut et al., 1996). Auditory cues are intended to increase walking speed through increasing the individuals step rate (cadence). Despite the benefits to parkinsonian gait that have been demonstrated with contemporary cueing techniques, there are a number of limitations associated with each of these methods. For example, visual cues may not be practical in a community setting, or may require constant vigilance for the beneficial effects to be maintained (Morris, Iansek, Matyas, & Summers, 1996). Whilst auditory cues may be a very portable method of cueing, they can be found to be repetitive in nature. For this

reason, auditory cueing may lead to habituation (Cubo, Leurgans, & Goetz, 2004). The phenomenon that music stimulates movement in both healthy and pathological (Kneafsey, 1997) populations suggests the possibility that the use of music that is both familiar to the individual and enjoyable (salient) may be an attractive alternative to current temporal cueing strategies.

The purpose of this thesis was to investigate the effect of salient music on gait amongst PD patients. The first chapter of this thesis is a general introduction, and is structured as a literature review to provide background information on PD and the biomechanics of gait. In addition, the first chapter also provides an overview of the current state of literature regarding the challenges associated with steady state gait, dual tasking and obstacle negotiation, as well as the benefits of auditory cueing in the context of gait rehabilitation. The literature review is followed by two experimental reports regarding the effect of salient music on steady state gait and dual tasking amongst healthy older adults and PD patients (Experiment 1), and the effect of salient music on obstacle negotiation amongst the same two populations (Experiment 2). The final chapter of this thesis is a general discussion, which synthesizes the research findings of the two experiments in the perspective of current literature.

1.1 Parkinson's Disease Literature

1.1.1 Epidemiology. Parkinson's disease (PD) is a chronic progressive neurodegenerative disorder that is characterized by bradykinesia (slowness of movement), rigidity (resistance to passive movement), resting tremor (involuntary shaking when relaxed), postural instability and gait disturbances. PD is the second most frequent neurodegenerative disease in today's population, affecting approximately 1.1

million individuals in North America (Chester, Turnbull, & Kozey, 2006) and up to 10 million people worldwide (Quinn, Critchley, & Marsden, 1987).

PD is associated with a dysfunction of the basal ganglia, a collection of five interconnected nuclei in the basal forebrain (Figure 1.1). The basal ganglia are involved in the control of complex voluntary movements (Middleton & Strick, 2000). In the absence of pathology, the basal ganglia provide the appropriate cues and motor responses to enable an appropriately timed motor pattern to run to completion. Pathology of the basal ganglia leads to an abnormality in the magnitude and velocity of movements, as well as an inability to initiate voluntary movements (Takakusaki, Habaguchi, Ohtinata-Sugimoto, Saitoh, & Sakamoto, 2003).

1.1.2 The basal ganglia. The main nuclei of the basal ganglia consist of the caudate, the putamen, the global pallidus, the subthalamic nucleus (STN), and the substantia nigra. However, a number of additional nuclei, such as the ventral anterior (VA) and ventral lateral (VL) thalamic nuclei also play an essential role in the functioning of the basal ganglia (Yelnik, 2002).

The basal ganglia form part of numerous complex basal ganglia-thalamocortical circuits, which serve differing functions. The most relevant of these circuits to PD is the motor circuit (Kopell, Rezai, Chang, & Vitek, 2006). The motor circuit can be described by a central processing area; the striatum (caudate and putamen), which receives afferents from the cerebral cortex (in particular the primary motor cortex, the supplementary motor area; SMA and the premotor area; PMA; Figure 1.1). The information from the striatum is then delivered via intrinsic pathways to a sequence of intermediary relay neurons, the

internal globus pallidus (GPi), the external globus pallidus (GPe), the STN and the substantia nigra pars compacta (SNc). Once the intermediate relay neurons have processed the information from the striatum it is forwarded through projections from the output structures of the basal ganglia (GPi and SNr) to the VA and VL thalamic nuclei. The thalamic nuclei then provide the basal ganglia with a connection to the motor and premotor cortices as well as the SMA. This sequence of connectivity allows the basal ganglia the opportunity to influence the regulation of ongoing movements (Purves, 1997).

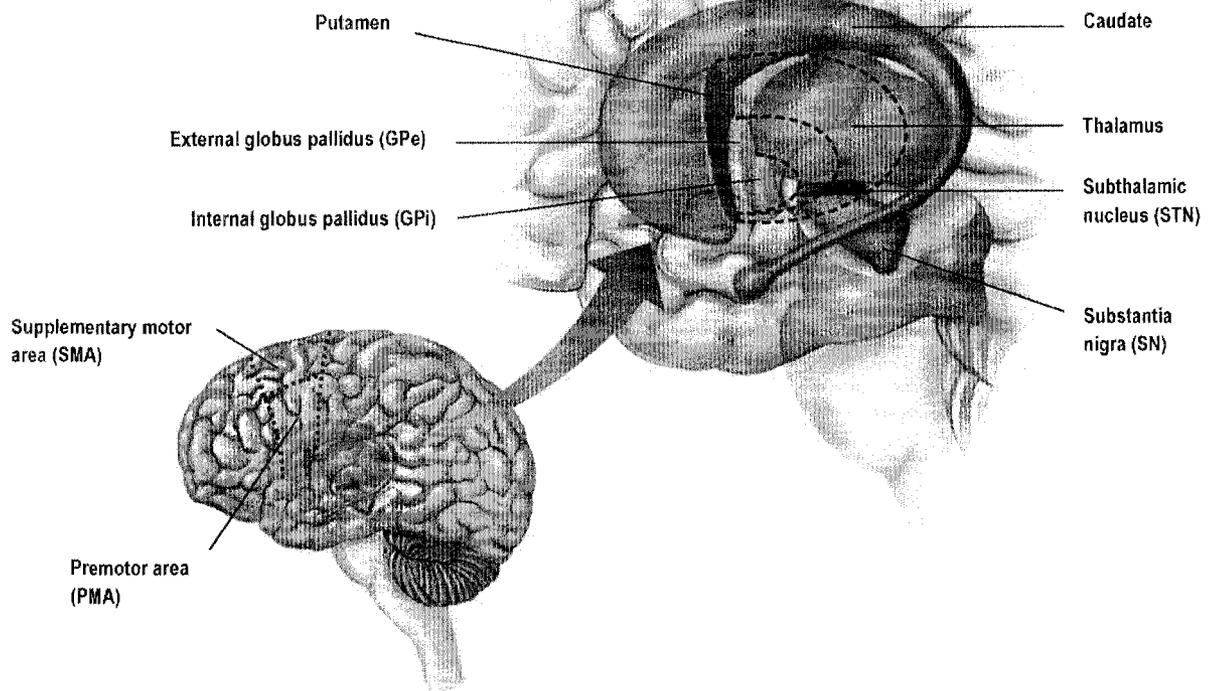


Figure 1.1 Illustration detailing the location of the basal ganglia, SMA and PMA within the human brain (adapted from <http://cti.itc.virginia.edu>).

Within the motor circuit itself, there are two main neuroanatomical pathways to the output nuclei, the direct and indirect pathways (McHaffie, Stanford, Stein, Coizet, & Redgrave, 2005). Both of these pathways function to modulate the thalamic output to the motor cortex and are governed by excitatory and inhibitory inputs.

The direct pathway is comprised of inhibitory projections from the striatum to the output structures of the basal ganglia, the GPi and SNr. Neurons in these structures send inhibitory projections directly to the VL thalamic nuclei. The thalamic nuclei in turn forward excitatory projections to the cortex (Figure 1.2). The overall effect of the direct pathway is excitatory to the thalamocortical projection. This excitability ultimately reduces the level of inhibition placed upon the motor cortex by the thalamus, therefore facilitating movement (Latash, 1998).

In contrast, the indirect pathway is comprised of inhibitory projections from the striatum to the GPe and then the STN, followed by excitatory projections to the GPi and SNr. As in the direct pathway, the output nuclei of the basal ganglia form inhibitory projections to the thalamic nuclei. Again the thalamic nuclei send excitatory projections to the cortex (Latash, 1998; Figure 1.2). The indirect pathway however, produces a net inhibitory effect on cortical neurons, thereby acting as a 'brake' to the function of the direct pathway.

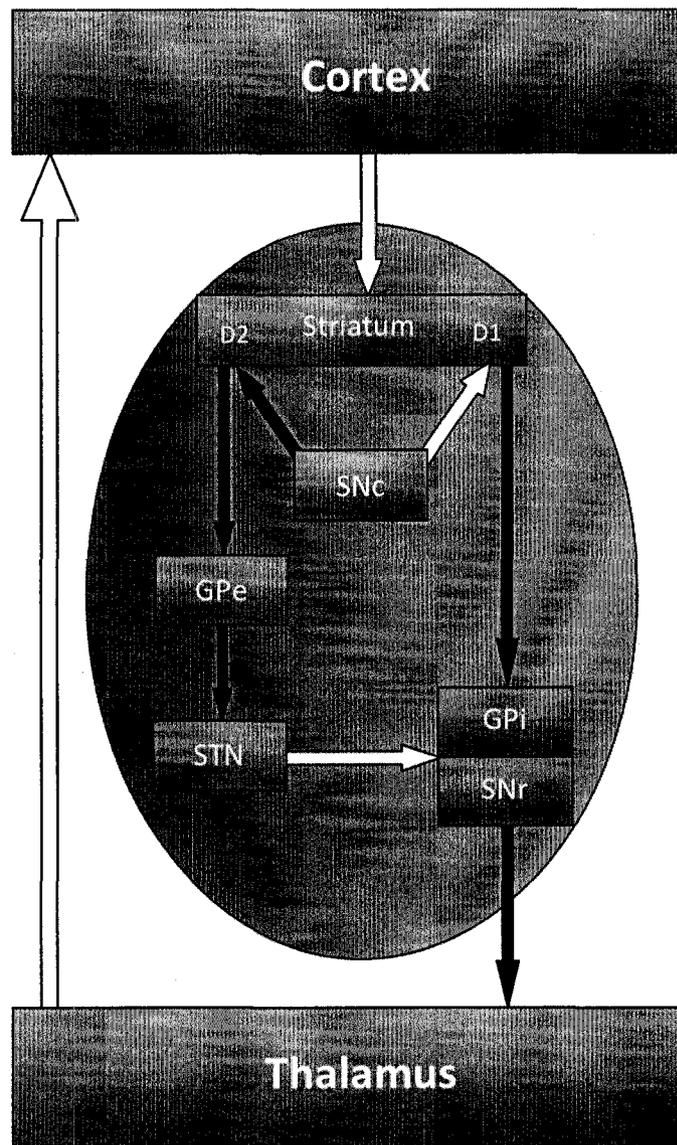


Figure 1.2 A schematic of the circuitry of the basal ganglia. Filled arrows indicate inhibitory connections, white arrows indicate excitatory connections.

A modulatory input to the neural circuit is provided to the striatal cells by the substantia nigra pars compacta (SNc) through the release of the neurotransmitter dopamine from its neuron endings (Bergman & Deuschl, 2002). The control provided by the SNc to the neural circuit is vital to the balance of activity between the direct and indirect pathways. Current perspective suggests that two different populations of dopaminergic receptors (D1 and D2) are found within the striatal neurons, and these receptors provide the basis for the direct and indirect pathways respectively (Gerfen et al., 1990). The action of dopamine on D1 receptors provides an excitatory influence to the direct pathway, while the D2 receptors produce an inhibitory effect on the indirect pathway.

Under normal conditions, dopaminergic input to the striatum result in the net effect of facilitating activity through the direct pathway over the indirect pathway (Gerfen, Keefe, & Gauda, 1995). Therefore, movement is produced by the excitatory effect that activation of the direct pathway has on the thalamocortical projections (Yelnik, 2002). PD occurs as a consequence of the degeneration of dopaminergic neurons in the SNc, leading to a decrease in the levels of dopamine in the striatum (Yelnik, 2002). This decreased level of dopamine in the striatum ultimately generates disinhibition of the output nuclei, and a consequential increased inhibition of the thalamocortical neurons (Figure 1.2). The resultant decrease in cortical activation leads to inhibition of movement, resulting in bradykinesia that is typical of PD (Yelnik, 2002).

1.1.3 Aetiology. Clinical symptoms of PD develop when approximately 80 per cent of the dopaminergic neurons in the SNc have been destroyed (Kish, Shannak, & Hornykiewicz, 1988), however, the causes of the degeneration seen in PD remain unknown. The prevailing theory is that the aetiology of the disease is multi-factorial, predominantly a combination of environmental and genetic risk factors (Gorell, Peterson, Rybicki, & Johnson, 2004). Environmental factors including extended exposure to certain metals, i.e. manganese, copper, lead, and copper and lead alloys (Gorell, Rybicki, Cole, Johnson, & Peterson, 1999), pesticides and well-water (Gorell, Johnson, Rybicki, Peterson, & Richardson, 1998) have been implicated with an increased risk of developing PD. In addition, evidence that an individual with a history of PD in a first- or second-degree relative faces an increased risk of developing PD (Rybicki, Johnson, Peterson, Kortsha, & Gorell, 1999) implies a role for genetics. Inherited forms of PD are thought to account for only a small portion of all PD cases, and as family members typically share a similar environment as well as genetics a family history of PD is not necessarily proof of heritability (Calne et al., 1987). The only unequivocal risk factor for developing PD is increasing age, with the peak onset for PD being 60 years of age (Mayeux, 2003). PD affects approximately one per cent of the North American population over the age of 65, increasing to around two per cent of the population over the age of 75 (Bennett et al., 1996).

At this time there is no permanent cure to relieve the symptoms of PD, or to replenish the depleted dopaminergic neurons. Although PD is not a direct cause of death, people suffering from PD have an increased risk (two- to five-fold) of mortality when

compared to age and gender matched general population (Fall, Saleh, Fredrickson, Olsson, & Granerus, 2003; Louis, Marder, Cote, Tang, & Mayeux, 1997).

1.1.4 Treatment. Currently, the core symptomatic treatment of PD is the use of drugs to increase the depleted dopamine levels in the striatum. Dopamine itself is unable to cross the blood-brain barrier into the central nervous system (CNS), and therefore is unsuitable as a treatment for PD. However, dopamine's precursor 3,4-dihydroxy-L-phenylalanine (levodopa) does cross the blood-brain barrier, and is presently used as the 'gold standard' treatment in PD. Once the levodopa has been metabolised it enters the CNS and is then used by the depleted dopaminergic neurons to increase dopamine concentrations at the synapse, ultimately reducing tremor, rigidity and bradykinesia (Jankovic & Kapadia, 2001).

Unfortunately, long-term use of antiparkinsonian medications can lead to a number of side effects, such as dyskinesias (involuntary movements), hallucinations, and motor fluctuations between 'on' and 'off' states, with drug resistant periods becoming more frequent and longer as the disease progresses (Burch & Sheerin, 2005). Also, a number of the symptoms of PD remain unresponsive to the antiparkinsonian medications despite optimal medication levels; these symptoms include postural instability and impairment of gait (Jankovic, 2002; Jankovic & Kapadia, 2001; Savitt, Dawson, & Dawson, 2006; van Wegen et al., 2006). Impairment of gait is often considered one of the hallmark symptoms of PD and, over time, may become one of the most incapacitating symptoms of the disease (Zijlstra, Rutgers, & Van Weerden, 1998) due to the consequential loss of independence and an increased incidence of falls (Morris et al., 1994). The resistance of gait impairments to pharmacological intervention justifies the

need to develop adjunct therapies to continue to assist PD patients in the management of this disabling symptom. Section 1.2 provides an overview of the biomechanics of gait in healthy adults, as well as the alterations that occur to the gait pattern with natural aging and the presence of PD. Sections 1.3 and 1.4 detail the interplay between cognition and the motor control of gait. Gait is rarely an autonomous task, it is often compounded by secondary tasks such as talking or carrying an object. In addition gait seldom occurs in an orderly environment, the ability to safely navigate everyday environments often requires crossing or avoiding obstacles. Both dual tasking and obstacle negotiation are functional gait activities that are reliant on the relationship between cognition and motor control.

1.2. Steady State Gait

Walking (gait) is a complex motor activity that is fundamental to independence, and critical to quality of life. It is a skill that is learned during the first year of life, reaches maturity around the ages of 7 until 60 years, and then is marked by performance deterioration in older adulthood (Prince et al., 1997). The purpose of walking is to safely and efficiently transport the body from one point to another. This is a significant challenge for the human CNS, as each step that is taken requires a voluntary fall forward to move the body's centre of gravity beyond the base of support. In this action, a fall is only averted by the safe placement of the swing foot with every step (Winter, 1995).

Non-pathological gait involves symmetrical and alternating movement sequences in which the weight of the body is supported alternately by each leg. These movement

sequences define the gait cycle, which can be differentiated into periods of single (SLS) and double limb support (DLS; Figure 1.3).

1.2.1 Age related changes in steady state gait. A number of changes to the gait pattern occur in the course of normal aging. Older adults alter their gait pattern by restricting range of motion in the hip, knee and ankle joints (Kerrigan, Todd, Della Croce, Lipsitz, & Collins, 1998). This restricted joint motion results in a decrease in walking speed through a reduction in stride length and an increase in stride time (Lockhart, Woldstad, & Smith, 2003). These modifications produce an increased time spent in the DLS phase of the gait cycle (Woo, Ho, Lau, Chan, & Yuen, 1995). Increasing the amount of time spent in DLS is generally considered to be a stabilizing strategy, as it reflects more time spent in a stable stance with both feet in contact with the ground. Yet, an alternative consequence of increased DLS duration is a reduction in the ability of the body to progress forward (Cromwell, Newton, & Forrest, 2002; Winter et al., 1990). Because of this reduced forward progression, suggestion is made that gait efficiency is compromised.

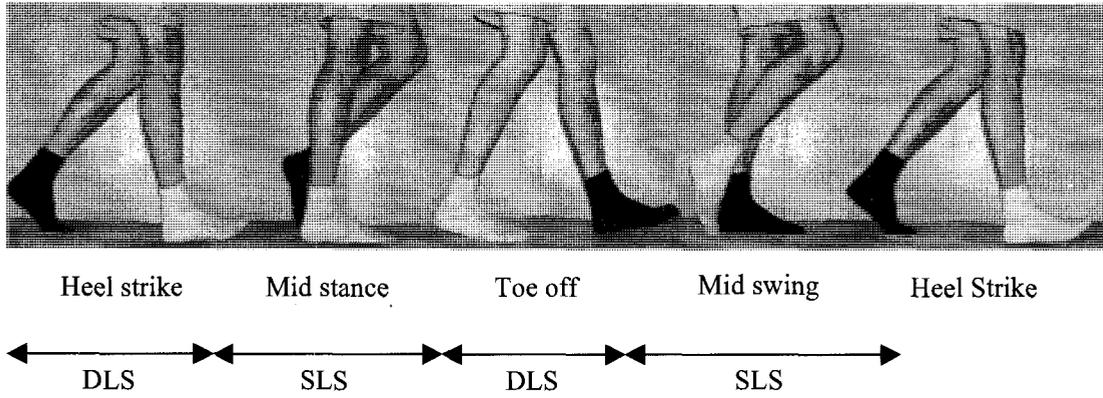


Figure 1.3 An illustration of the events and support phases of the gait cycle (as indicated by the white (right) foot).

1.2.2 Steady state gait in PD. Parkinsonian gait is characterized by a ‘stooped posture’, with the trunk, head and neck inclined forward (Figure 1.4). The patient generally holds his/her arms flexed, with the hands carried in front of the body. Arm swing is typically reduced, while reduced knee and ankle flexion (Knutsson, 1972) and less marked heel strike (Kimmeskamp & Hennig, 2001) are observed in the lower limbs. These characteristics tend to lead to PD patients who walk with small shuffling steps and a general slowness of movement (Hanakawa et al., 1999; Knutsson, 1972). When compared to the healthy older adult population, PD patients walk with a further reduced gait velocity. This reduction in gait velocity is allied with a reduced stride length, increased cadence and a resulting increased time spent in DLS (Blin et al., 1991; Knutsson, 1972; Morris et al., 1994).

It is not yet fully understood how the dysfunctional basal ganglia contribute to the slower walking patterns of PD patients. In the absence of pathology it has been hypothesised that the basal ganglia in conjunction with the SMA in the cortex aid in initiating each sequential sub-movement in a well-learned motor sequence such as locomotion (Brotchie, Iansek, & Horne, 1991). The basal ganglia initially provides an internal cue to interact with the pre-motor activity of the SMA (Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004) thereby allowing repetitive, rhythmic movements to be completed while leaving the cortex free to control other tasks that require attention (Bond & Morris, 2000). Phasic output from the basal ganglia during a movement sequence indirectly acts to inhibit the SMA; this controls the increase in cortical activation that is required for movement execution, as well as the decrease in cortical activity that ensures the timely termination of a movement (Brotchie et al., 1991).

The basal ganglia is also theorised to contribute to the cortical 'motor set', preparing and maintaining motor plans, thereby allowing movements to be completed with appropriate timing and amplitude (Robertson & Flowers, 1990). It is theorised that in PD patients there is a disruption in the internal cueing process (Morris et al., 1994) as well as a disturbance of the interaction between the basal ganglia and the SMA (Cunnington, Iansek, Bradshaw, & Phillips, 1995), resulting in movements of reduced amplitude and speed (Morris, 2000) and increased variability in the timing of the gait pattern (Frenkel-Toledo et al., 2005).

A.



B.



Figure 1.4 An example of posture during gait for a A) healthy older adult and B) Parkinson's patient.

Gait has traditionally been considered a relatively automatic task controlled by subcortical structures (Bloem, Grimbergen, van Dijk, & Munneke, 2006), therefore requiring the use of minimal attentional resources. However, extensive research in both healthy (Dubost et al., 2006; Hollman, Kovash, Kubik, & Linbo, 2007; Lajoie, Teasdale, Bard, & Fleury, 1993; Lindenberger, Marsiske, & Baltes, 2000; Lundin-Olsson, Nyberg, & Gustafson, 1997; van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007; Verghese et al., 2007) and pathological (Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001; Bond & Morris, 2000; Camicioli, Oken, Sexton, Kaye, & Nutt, 1998; Canning, 2005; Morris et al., 1996; O'Shea, Morris, & Iansek, 2002; Rochester et al., 2004; Yogev et al., 2005) populations has confirmed that gait is dependent upon cognitive resources. Also of relevance is that the cognitive demands associated with this motor task vary with age and the health of the individual (Woollacott & Shumway-Cook, 2002) as well as anxiety levels (Brown, Doan, McKenzie, & Cooper, 2006; Gage, Sleik, Polych, McKenzie, & Brown, 2003; McKenzie & Brown, 2004) and task complexity (Bond & Morris, 2000).

It has been suggested (Ble et al., 2005) that increasing the cognitive demands of a gait related task increases the likelihood of a fall occurring. Falls are prevalent amongst community dwelling older adults, with approximately one third of adults 65 years or older falling each year (Blake et al., 1988; O'Loughlin et al., 1993). However, within the neurological population of a similar age this fall rate is doubled (Bohannon, 1989), with PD patients most at risk of experiencing falling (Stolze et al., 2004). Seventy percent of PD patients are reported to fall annually, with fifty percent of patients experiencing multiple falls each year (Bloem, Hausdorff, Visser, & Giladi, 2004; Wood, Bilclough, Bowron, & Walker, 2002). Falls are a major cause of injury in the both the older adult

(Englander, Hodson, & Terregrossa, 1996) and PD populations (Wielinski, Erickson-Davis, Wichmann, Walde-Douglas, & Parashos, 2005), and can result in a debilitating fear of falling (Adkin, Frank, & Jog, 2003; Bloem, Grimbergen, Cramer, Willemsen, & Zwinderman, 2001; Tinetti, Speechley, & Ginter, 1988) and loss of independence (Murphy & Isaacs, 1982; Wenning et al., 1999).

Aside from the considerable physical and emotional cost of falling there is also a high health cost associated with the high fall rate. It has been estimated that the cost of fall-related injuries will exceed \$32 billion per annum in 2020 in the United States alone, with the proportion of the population over the age of 65 expected to double by this time (Englander et al., 1996). As such, substantial research has been directed towards identifying the risk factors associated with falls in both the non-neurological older adult and PD populations. Within the multitude of intrinsic (host) and extrinsic (environmental) risk factors that have been identified multitasking and impaired obstacle negotiation are two complex situations that are attentionally demanding and have frequently been associated with fall incidents in both populations (Bloem et al., 2004; Stolze et al., 2004; Tinetti & Speechley, 1989).

1.3. Cognitive Contributions to Gait

1.3.1 Attention and executive function. The motor control and cognitive control of gait are of equal relevance to this thesis. The understanding that gait is in fact an attentionally demanding task has led to an increased understanding of the interaction between cognition and the motor control of gait. In particular, we now know (Ble et al., 2005) that executive function is critical in successful gait, whether steady state gait or a

complex gait related task (i.e. dual tasking or obstacle negotiation). Executive function refers to a collection of cognitive processes that are thought to control the planning, initiating and guiding of goal-directed actions (Royall et al., 2002). Impairments of executive function are associated with damage or disruption to the frontal lobe or the associated basal ganglia-thalamocortical circuit (Royall et al., 2002). Disordered executive function has been related with a number of disorders and diseases including; schizophrenia (Heinrichs & Zakzanis, 1998), major depression (Degl'Innocenti, Agren, & Backman, 1998), Alzheimer's disease (Baddeley, Baddeley, Bucks, & Wilcock, 2001; Buckner, 2004, Perry & Hodges, 1999), Huntington's disease (Delval et al., 2008) and PD (Dalrymple-Alford, Kalders, Jones & Watson, 1994) amongst many others. In addition, it has been found that executive function deteriorates with normal aging (Buckner, 2004).

Attention is one component of the cognitive processes encompassed by executive function (Lezak, 1995). More specifically, attention can be described as attending to a single aspect of the environment at the expense of all others (Johnston & Wilson, 1980), and further can be subdivided into a number of distinct subcategories i.e. focused, sustained, selective, alternating and divided attention (Sohlberg & Mateer, 1989). Of these subcategories, divided attention, which is often described as the ability to perform two or more tasks simultaneously, has been heavily studied using dual task paradigms. In the investigation of human movement, dual task paradigms are often used to infer the level of automaticity of the primary motor task (Abernethy, 1988) when a secondary motor or cognitive task is acting as a distracter. Attentional resources are considered to be limited in capacity for each individual (Kahneman, 1973) and it is thought that all

tasks require a fraction of these resources. When the capacity of attentional resources is exceeded impairment in at least one of the tasks being performed will be observed, for example when walking and talking an individual may slow or even stop their walking in order to maintain the conversation.

Three prominent neuropsychological models have been developed to explain the observed dual task interference; capacity-sharing, bottleneck and cross-talk (Pashler, 1994). The capacity-sharing theory postulates that people share attentional resources amongst tasks, the available resources are finite, and therefore when tasks are executed concurrently there are fewer resources available for each task, and the performance of one or more of the tasks is compromised. An assumption of this model is that individuals have voluntary control over the allocation of attention to the tasks (Pashler, 1994). Alternatively, according to the bottleneck theory of attention, tasks are processed in series as opposed to in parallel (as in the capacity-sharing model). Therefore, when two or more tasks are carried out simultaneously and compete for use of a single pathway; one or both tasks will be either delayed or impaired due to the bottleneck created (Pashler, 1994). A third possibility is that dual task interference may be dependent on task similarity, as proposed by the cross-talk model. It is thought that common resources will be used to process similar information/tasks, which will result in increased efficiency of processing (Pashler, 1994). Currently, there is no consensus on which theory of dual-task interference best explains the observed dual task decrement or whether a combination of the theories could explain the dual task effect.

1.3.2 Age related changes in dual tasking. It has long been considered that attentional resource capacity may diminish with increasing age (Craik & Byrd, 1982; McDowd & Shaw, 2000), and as such it could be expected that older adults would experience greater difficulty than younger adults with successfully performing dual tasks even when the secondary task is relatively simple. In older adults increased difficulty in performing dual-tasks has been associated with a greater risk of falls (Chen et al., 1996; Faulkner et al., 2007; Woollacott & Shumway-Cook, 2002), and accordingly the relationship between attention, gait control and aging has received considerable interest. An influential publication by Lundin-Olsson and colleagues (1997) described an incapability to simultaneously walk and talk among a group of frail elderly, a relationship that proved to be a strong predictor of falls in the subsequent six months. This study provides foundation for the theory that gait requires attentional resources, and additionally indicates that the attentional costs incurred by older adults are indeed greater than those experienced by healthy young adults. More recent research supports the finding that gait performance is compromised in older adults when performed concurrently to a secondary cognitive task (Dubost et al., 2006; Hollman et al., 2007; Lajoie et al., 1993; Lindenberger et al., 2000; Verghese et al., 2007). It has been argued (Bloem et al., 2003; Springer et al., 2006) that the observed reductions in gait speed and in some cases stride length may be a conscious adaptation to a 'safer' gait strategy, for example a mindful prioritisation of gait over the secondary task. However, this notion would appear to be contradicted by the finding that gait stability is also compromised in older adults during motor-cognitive coupled tasks (Dubost et al., 2006; Hollman et al., 2007; van Iersel et al., 2007) suggestive of a higher risk of falls (Hausdorff, Rios,

Edelberg, 2001). It is important to note that it is not only motor-cognitive dual task paradigms that lead to a detriment to gait performance in older adults; paradigms that incorporate two motor tasks similarly produce dual task interference. Interestingly however, experimental designs utilising a motor-motor paradigm do not produce a significantly greater deterioration in gait performance for the older adults than younger adults (Shkuratova, Morris, & Huxham, 2004), suggestive that the motor-cognitive coupling provides greater challenge to the attentional resources of older adults than motor-motor coupling.

1.3.3 Dual tasking in PD. Difficulty performing concurrent tasks is a common and sometimes disabling problem that has frequently been reported in PD literature (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; Canning, 2005; Morris et al., 1996). The gait impairments exhibited by PD patients during steady state walking are typically exaggerated during dual task performance regardless of whether the secondary task is motor or cognitive in nature (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; Canning, 2005; Morris et al., 1996; O'Shea, Morris & Iansak, 2002; Rochester et al., 2005). Indeed, PD patients who have mild to moderate disease severity experience significant decreases in gait speed (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; O'Shea et al., 2002; Rochester et al., 2005), stride length (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; O'Shea et al., 2002; Rochester et al., 2005) and an increase in double limb support time (O'Shea et al., 2002) when challenged by a consecutive cognitive task whilst walking. Moreover, these decreases in gait performance are significantly greater than those demonstrated by healthy older adults.

This finding has been mirrored in studies using a motor task such as walking with a tray of glasses (Bond & Morris, 2000; Canning, 2005; Rochester et al., 2005) or transferring coins from pocket to pocket (O'Shea et al., 2002).

It is theorised that the basal ganglia dysfunction found in PD reduces the automaticity of movement control for repetitive well-learned sequences (Brown & Marsden, 1988; Georgiou et al., 1993) and subsequently increases cortical involvement during motor execution (Samuel et al., 1997). The lack of movement automaticity requires PD patients to direct a considerable amount of limited attentional resources to the primary task of walking, thereby significantly diminishing the residual attentional resources available for concurrent tasks. Compounding the reduction in available resources for simultaneous tasks is the decrement in executive function that is present in varying degrees amongst PD patients (Dalrymple-Alford et al., 1994). Executive function has been identified as being critical to the ability to appropriately allocate attentional resources (Bloem, Valkenburg et al., 2001; Rochester et al., 2004). In dual or multitask situations where one of the task involves ambulation, the safest and therefore most sensible strategy would be to prioritise the primary gait related task over the secondary and tertiary tasks (Bloem, Grimbergen et al., 2001). However, PD patients endeavour to execute all tasks concurrently, seemingly unable to adopt a 'posture first' strategy (Bloem, Grimbergen et al., 2001). This 'posture second' strategy, in combination with the gait and cognitive deficits prevalent in the PD population results in the deterioration of all tasks (Bloem, Grimbergen et al., 2001). This multitasking impairment that is characteristic of the PD population is associated with an increased risk of falls (Willemsen, Grimbergen, Slabbekoorn, & Bloem, 2000).

1.4 Obstacle Negotiation

Complex gait related tasks such as obstacle negotiation are often implicated in epidemiological studies related to falls. Indeed, within the multitude of intrinsic and extrinsic risk factors that have been identified for falls, tripping has been identified as a contributing factor in approximately 50 percent of cases in older adults (Blake et al., 1988; Lord, Ward, Williams, & Anstey, 1993), with trips frequently being associated with unsuccessful obstacle crossing (Overstall et al., 1977; Tinetti et al., 1988). Tripping on an obstacle has also been implicated as a leading cause of falls in neurological patients (Stolze et al., 2004).

Successful negotiation of an obstacle is attention demanding (Chen et al., 1996; Kim & Brunt, 2007; Schrod, Mercer, Giuliani, & Hartman, 2004; Siu et al., 2008; Weerdesteijn, Schillings, van Galen, & Duysens, 2003), requiring ‘on-line’ adjustments of a motor pattern, a demand that may be increased by age (Chen, Ashton-Miller, Alexander, & Schultz, 1991; Lowrey, Watson, & Vallis, 2007; Patla, Prentice, Rietdyk, Allard, & Martin, 1999; Weerdesteijn, Nienhuis, & Duysens, 2005), neurological disorders (Den Otter, Geurts, de Haart, Mulder, & Duysens, 2005; Doan et al., in review; Petrarca, Di Rosa, Cappa, & Patane, 2006; Said, Goldie, Patla, & Sparrow, 2001; Said, Goldie, Patla, Sparrow, & Martin, 1999) and environmental context (Brown et al., 2006; Brown, McKenzie, & Doan, 2005; McKenzie & Brown, 2004).

1.4.1 Age related changes in obstacle negotiation. Deterioration of cognitive and sensorimotor systems are known to occur with normal aging, predisposing older adults to compromised balance and an increased likelihood of falls (Alexander, 1991).

When the challenges to maintaining balance are further exacerbated in situations such as obstacle negotiation (Chou, Kaufman, Brey, & Draganich, 2001) it has been found that older adults adopt a more cautious gait strategy (Chen et al., 1991). In particular, older adults negotiate an obstacle contingency by decreasing the crossing step length (Figure 1.5) and crossing velocity when compared to younger adults (Chen et al., 1991; Lowrey et al., 2007; Patla, Prentice, Robinson, & Neufeld, 1991). It is considered that these adjustments would reduce the likelihood of a fall if contact was made with the obstacle (Patla et al., 1991). In the case of a shorter crossing step, there is less time spent in the SLS phase of the gait cycle where there is a limited base of support. Therefore, in the event of obstacle contact the reduced forward momentum would allow for greater opportunity to regain balance (Patla et al., 1991). It has also been found, however, that older adults commence the adaptations to the gait pattern that are necessary for safe obstacle negotiation at least one step earlier in the approach phase than younger adults (Chen, Ashton-Miller, Alexander, & Schultz, 1994). This finding implies that older adults may experience difficulty in adapting their gait pattern in a time critical condition, increasing the risk of obstacle contact (Chen et al., 1994).

Direction of progression

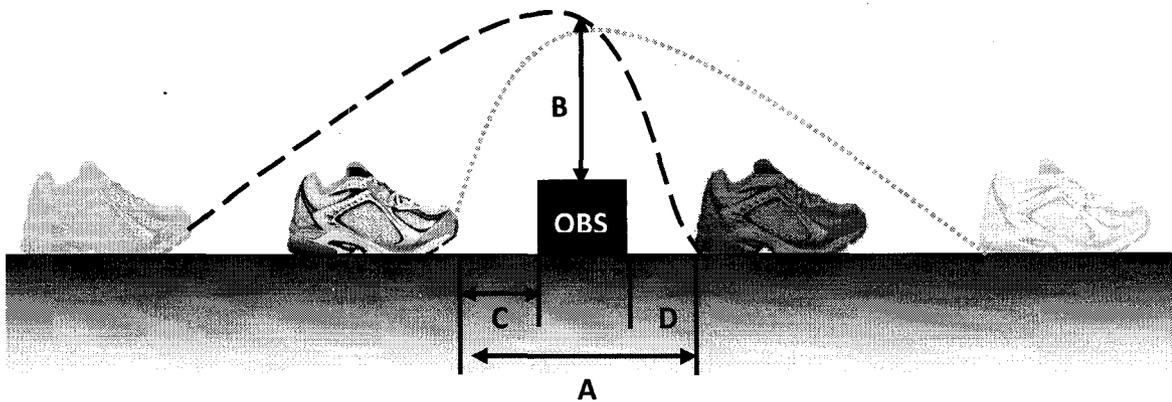


Figure 1.5 A diagram indicating the spatial measures of obstacle negotiation. Grey fill indicates lead limb foot; light fill indicates trail limb foot. Dark dashed line indicates approximate trajectory of lead limb foot; light dotted line indicates approximate trajectory of trail limb foot. Obstacle is denoted by OBS. Measures shown are (A) step length; (B) step height; (C) toe-obstacle distance; (D) heel-obstacle distance.

Another consistent finding is that older adults place the heel of the lead foot closer to the back edge of the obstacle (heel-obstacle distance; Figure 1.5) during the crossing step (Chen et al., 1991; Lowrey et al., 2007; McFadyen & Prince, 2002; Weerdesteyn et al., 2005). This finding has been interpreted as a 'risky' strategy (McFadyen & Prince, 2002; Weerdesteyn et al., 2005) with a reduced heel-obstacle distance suggested to increase the risk of contacting the obstacle on foot placement. However, heel contact with an obstacle is perceived to impose a low risk of falling, instead being associated with a recoverable stumble (Chen et al., 1991). Many other kinematic parameters of obstacle crossing have produced contrary findings. The distance between the trail toe and the front edge of the obstacle (toe-obstacle distance; Figure 1.5) has been reported as being longer in the older adults when compared to younger adults (Patla, Prentice, & Gobbi, 1996) or not significantly different (Chen et al., 1991; Draganich & Kuo, 2004; Lowrey et al., 2007). In addition, the crossing step height (Figure 1.5) documented amongst older adult has been described as both lower (McFadyen & Prince, 2002) and higher (Patla et al., 1996; Watanabe, 1994) than younger adults. Current speculation indicates that the inconsistent findings for age-related gait changes in some kinematic crossing parameters may be due to a lack of challenge presented by the experimental design; the low number of obstacle contacts largely confirms this suggestion (Weerdesteyn et al., 2005). In an effort to address the inconsistencies in the literature more challenging experimental designs are being utilized, including obstacle crossing under time-critical conditions (Weerdesteyn et al., 2005), dual tasking during obstacle negotiation (Chen et al., 1996), as well as obstacle crossing in environmental contexts that impose threat to postural control (Brown et al., 2006; McKenzie & Brown, 2004).

1.4.2 Obstacle negotiation in PD. Despite the challenges associated with obstacle negotiation amongst the non-neurological population and the identification of tripping as a major cause of falls there is a lack of literature available on the motor patterning or success rates of obstacle crossing amongst PD patients. The presence of bradykinesia, balance impairments and attentional deficits (Dalrymple-Alford et al., 1994) amongst the PD population is suggestive that PD patients would experience greater difficulty than healthy older adults in successfully negotiating both expected and unexpected obstacle contingencies. In particular, based on steady state unobstructed gait it may be hypothesised that the foot clearance height over the obstacle may be reduced, that the crossing step length would be shorter and that the crossing velocity would likely be slower than in healthy older adults. Any of these stepping characteristics could increase the risk of tripping on an obstacle and therefore increase the likelihood of a fall. A recent study by Doan and colleagues (in review) confirms that PD patients do indeed demonstrate decreased crossing step length as a result of shorter pre- and post-obstacle horizontal distance, and that further decrements in crossing parameters and crossing success were exhibited when anxiety levels were heightened in a situational context that threatened stability.

Complex gait tasks such as obstacle negotiation and dual tasking are frequently encountered during activities of daily living, such as safely navigating cluttered environments or walking whilst talking. As such, it is necessary that the development of intervention strategies for the management of PD gait deficits extend beyond the relative simplicity of steady state gait to encompass functional gait activities such as obstacle

negotiation. Targeting functional gait in this way will allow patients the opportunity to maintain their independence.

1.5. Current Therapies

1.5.1 Auditory cueing in steady state gait. One form of rehabilitation therapy that has penetrated the field of gait rehabilitation is the effect of music on movement. In human culture one of the fundamental functions of music has been to stimulate movement (Merriam, 1964). Music has also historically been a part of healing rituals in many cultures (Merriam, 1964). Within the multitude of acoustic rehabilitation therapies that are currently available, rhythmic auditory stimulation (RAS) is increasingly being used in the treatment of patients suffering from movement disorders. RAS is a neurological technique in which rhythmic cues are provided ‘free field’ via a metronome or embedded as an accentuated beat within a complex musical piece to enhance the control of movements that are intrinsically rhythmical (Thaut, 2005).

Within activities of daily living, walking is the most regularly performed inherently rhythmical movement (Roth & Wisser, 2004) and as a result effective and efficient gait is necessary for an individual to maintain their functional independence. An extensive body of research has demonstrated the effectiveness of RAS as a rehabilitation tool for patients suffering from impaired gait function. Significant improvements in gait parameters have been shown following the use of RAS in patients suffering from brain injury (Hurt, Rice, McIntosh, & Thaut, 1998; Kenyon & Thaut, 2000), Huntington’s disease (Thaut, Miltner, Lange, Hurt, & Hoemberg, 1999), stroke (Ford, Wagenaar, & Newell, 2007; Mauritz, 2002; Thaut et al., 2007; Thaut, McIntosh, & Rice, 1997) as well

as PD (del Olmo & Cudeiro, 2005; Freedland et al., 2002; Hausdorff et al., 2007; Howe, Lovgreen, Cody, Ashton, & Oldham, 2003; McIntosh et al., 1997; Miller, Thaut, McIntosh, & Rice, 1996; Suteerawattananon et al., 2004; Thaut et al., 1996).

RAS is thought to work through rhythmic entrainment in which the RAS acts as an external timekeeper, which in the case of PD patients may replace the faulty timekeeping of the dysfunctional basal ganglia. It is theorised that auditory rhythm acts as a physiological attractor and acts to entrain timing functions in motor control. This theory has been substantiated by the research of Thaut and Kenyon (2003), which demonstrated that even when rhythmic auditory patterns were provided at levels below conscious perception, a steady and stable coupling between motor responses and the rhythmic cue could be achieved almost immediately. The early work of Rossignol and Melville Jones (1976) also demonstrated the ability of auditory rhythm to entrain muscle activation patterns, which can be utilized during locomotion. A number of more recent studies have also provided evidence for audiospinal motor facilitation. These studies (Miller et al., 1996; Thaut et al., 1996) have demonstrated that rhythmical cueing produces invariable EMG for the medial gastrocnemius and tibialis anterior muscles, suggesting that auditory cueing facilitates the stable recruitment of motor units during gait thereby improving gait performance.

In view of the gait disorders associated with PD, the use of music therapy and in particular RAS is especially attractive. Indeed, single session studies with rhythmic auditory cues have been associated with improvements in both the temporal and spatial characteristics of the continuous gait of PD patients, with increased gait speed (Howe et al., 2003; McIntosh et al., 1997; Suteerawattananon et al., 2004), stride length (McIntosh

et al., 1997), and cadence (Freedland et al., 2002; Howe et al., 2003; McIntosh et al., 1997; Suteerawattananon et al., 2004) when compared to walking without cueing. It has also been found that following a period of training (a minimum of three weeks) with RAS, PD patients can experience increases in gait speed, stride length, cadence (Thaut et al., 1996) and decreased step-to-step variability (del Olmo & Cudeiro, 2005; Miller et al., 1996), which are generally maintained following the cessation of regular training (del Olmo & Cudeiro, 2005; Miller et al., 1996; Thaut et al., 1996). Ultimately, providing an external acoustic cue at an appropriate rhythm improves and stabilizes the temporal, spatial and force production elements (Thaut, 2005) of gait whether through immediate entrainment or from training through ongoing learning, by allowing the dysfunctional movement pathways in the basal ganglia of PD patients to be bypassed (Morris et al., 1996).

1.5.2 Auditory cueing in dual tasking. Recent investigations of cueing and dual tasking have demonstrated that cueing may also be an effective tool in reducing dual-task interference amongst PD patients (Baker, Rochester, & Nieuwboer, 2007, 2008; Canning, 2005; Rochester et al., 2005; Rochester et al., 2007). Indeed, both attentional (Baker et al., 2007; Canning, 2005), rhythmical auditory (Rochester et al., 2005; Rochester et al., 2007) and combination (Baker et al., 2007, 2008) cueing strategies have produced significant improvements in gait performance when gait was coupled with a secondary motor task. It has been suggested that this finding may simply be a by-product of increased arousal in the PD patients due to the nature of the task (i.e. more interesting than simply walking; (Rochester et al., 2007). An alternative explanation that has been forwarded is that cues may reduce the attentional requirements of dual tasking by

improving the distribution of attentional resources (Behrman, Teitelbaum, & Cauraugh, 1998). It is thought that in the case of rhythmic or combination cues, the cueing strategy may reduce the need to pre-plan movement sequences through providing an external temporal stimulus at appropriate intervals (Rochester et al., 2007).

Although significant work to date has demonstrated the effectiveness of RAS in the gait rehabilitation of PD patients, there are a number of potential limitations that have been associated with the strategy. Specifically, RAS whether provided as a simple metronome tone, or as an accentuated beat imbedded in a complex musical piece can tend towards repetitiveness, and therefore presents the potential for habituation (Cubo et al., 2004). Whilst this issue has not been evidenced in the studies completed thus far, these studies have been relatively short in duration. It is conceivable that with the long-term use of a RAS strategy the lack of salience could be an issue that leads to compromised vigilance and a discontinuation of use. Therefore, it appears that there is a necessity for the development of a gait rehabilitation strategy that retains the effectiveness and portability of RAS, but that also incorporates a level of salience. An attractive alternative to a simple metronome tone that may address the concern of salience is the use of music that is both familiar and pleasant for the individual. Indeed, not only is music considered to have the ability to evoke a physical response (Janata & Grafton, 2003; Kneafsey, 1997), anecdotal reports abound of music helping PD patients to move in situations where they encounter freezing of gait.

1.6 Summary

The debilitating gait impairments experienced by PD patients remain resistant to conventional medications (Jankovic, 2002; Jankovic & Kapadia, 2001; Savitt et al., 2006), and moreover become exacerbated in challenging situations such as dual tasking (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; Canning, 2005; Morris et al., 1996; O'Shea, Morris & Iansak, 2002; Rochester et al., 2005) or obstacle negotiation (Doan et al., in review), increasing the already high fall risk of this population. Consequently, impairments of gait can threaten the patients' functional independence and quality of life. As such, adjunct rehabilitation therapies have become a major and necessary focus of research in recent years. Auditory cueing is one strategy that has been established to be effective in improving parkinsonian gait in a variety of situations (Rochester et al., 2005; Rochester et al., 2007); however, there are a number of limitations associated with this rehabilitation strategy including the lack of salience to the individual. In light of this evidence, there is a definitive need to develop a sustainable gait training tool for PD patients that is both salient to the patient and practical for use in situations of daily living. Given the potential for music to facilitate movement in pathological populations (McIntosh et al., 1996; Thaut et al., 1997, Thaut et al. 1999; Thaut et al., 2007), salient music could pose an attractive alternative to current cueing strategies. The experiments presented in this thesis represent the initial step towards a long-term goal of developing a suitable and sustainable gait training tool.

Chapter 2: Objective of Thesis

2.1 Theory

Music has a potent ability to evoke movement, which is considered to be due to a coupling between the motor and auditory systems (Thaut et al., 1997).

2.2 Objective

Based on this theory the objective of this thesis was to investigate the effect of concurrent music on gait performance in PD patients under a number of different task contexts. Two experiments were conducted to accomplish this objective: Experiment 1 investigated the effect of music on spatiotemporal measures of gait in single (steady state gait) and dual task contexts whilst Experiment 2 examined the effect of music on gait kinematics during obstacle negotiation.

2.3 Hypotheses

2.3.1 Experiment 1: The effects of concurrent music on gait in single and dual task contexts. Based on the commonly reported phenomenon that music stimulates movement in both healthy (Bernatzky, Bernatzky, Hesse, Staffen, & Ladurner, 2004; Copeland & Franks, 1991) and pathological (McIntosh et al., 1997; Thaut et al., 1996) populations I hypothesised that the music would effectively ‘activate’ the PD patients, resulting in an improvement in overall gait performance. More specifically, I expected to see an increase in gait velocity and stride length, and a decrease in DLS duration in Experiment 1.

2.3.2 Experiment 2: The effects of concurrent music on obstacle negotiation.

In accordance with the known gait deficits suffered by PD patients (Kimmeskamp & Hennig, 2001; Knutsson, 1972), I expected that the PD group would exhibit impaired obstacle crossing strategies in the baseline (no music) condition of Experiment 2 when compared to the CTRL subjects. However, I expected to see an increase in obstacle crossing velocities, obstacle clearance height and obstacle crossing step length (as a result of increased pre- and post- obstacle distances) during concurrent music trials for both groups.

Chapter 3: Experiment 1 - Novel Challenges to Gait in Parkinson's Disease: The Effect of Concurrent Music in Single and Dual Task Contexts

3.1 Abstract

Anecdotal reports abound of the ability of music to facilitate movement in both healthy and pathological populations. This study examined the effects of concurrent music on parkinsonian gait in single and dual task contexts. Ten patients with idiopathic Parkinson's disease and 10 healthy age matched control subjects walked at a self selected pace along an unobstructed walkway in four differing test conditions. Test conditions were differentiated by the presence of music accompaniment (no music/music) and the presence of a secondary cognitive task (single/dual). Music was self-selected by subjects based on music preferences. Repeated-Measure Analyses of Variance were used to determine the effect of task, music and group on the spatiotemporal measures of gait (velocity, stride length and the percentage of the gait cycle spent in double limb support). Gait amongst the Parkinson's disease patients was adversely affected by concurrent music, in contrast gait performance in the control subjects showed no significant difference between no music and music conditions. The added requirement of the cognitive task differentially influenced gait performance in Parkinson's disease patients and control subjects, with Parkinson's disease patients displaying a further decrease in spatiotemporal parameters of gait and control subjects a marginal improvement. The findings of this study suggest that gait impairments associated with Parkinson's disease are exacerbated by the presence of concurrent music; an effect that is further exaggerated by the addition of a cognitive task. These results have implications for patient safety in multitasking situations.

3.2 Introduction

Parkinsonian gait is typically characterised by reduced gait velocity, decreased stride length and an increased cadence (Knutsson, 1972). Despite the overall effectiveness of dopaminergic drugs in the symptomatic treatment of Parkinson's disease, a number of gait deficits often remain resistant (Blin et al., 1991), over time becoming one of the most incapacitating symptoms of this disease. The persistence of gait impairments has necessitated the exploration of rehabilitation therapies that could potentially complement pharmacologic therapies and assist in the management of gait difficulties. One therapy, established to be effective in facilitating parkinsonian gait, is the provision of external spatial or temporal stimuli that serve to cue the gait cycle. Immediate beneficial effects, with improvements in spatiotemporal parameters of gait have been demonstrated using a variety of cue modalities such as visual (Martin, 1967; Morris et al., 1994; Morris et al., 1996), auditory (Freedland et al., 2002; Lim et al., 2005; McIntosh et al., 1997; Thaut et al., 1996), and attentional cues (Behrman et al., 1998; Canning, 2005; Morris et al., 1996). Indeed, the effects of visual cues were reported as early as 1967 in a classic study by Martin who demonstrated that PD patients used longer strides and an increased gait velocity when walking over transverse lines on the walking surface, a finding that has been successfully replicated in a number of subsequent studies (Morris et al., 1994; Morris et al., 1996), and provided foundation for application of other cue modalities. Contemporary cueing strategies include auditory cues such as a rhythmic metronome tone or an accentuated beat within a musical piece, as well as attentional strategies such as using instructional sets (i.e. "big steps"). The use of auditory cues has been shown to produce significant improvements in gait velocity, cadence and stride length (Freedland et al., 2002; Lim et al., 2005; McIntosh et al., 1997; Thaut et al., 1996),

whilst attentional cues have also been shown to improve velocity and cadence (Behrman et al., 1998; Canning, 2005; Morris et al., 1996).

The prevailing theory of external stimulation of movement in PD is that a cue can serve to facilitate gait by preferential activation of motor pathways that circumvent the dysfunctional basal ganglia (Morris et al., 1996). Whilst this strategy results in improved gait performance, the resulting motor output requires increased conscious control and consequentially restricts the availability of attentional resources for concurrent tasks. Intuitively, the restricted accessibility of attentional resources may limit the efficacy and subsequent practicality of cueing in task contexts that necessitate dedicated attention, such as dual tasking (Bloem et al., 2006; Bond & Morris, 2000). Interestingly though, recent studies (Baker et al., 2007; Baker et al., 2008; Canning, 2005; Rochester et al., 2004) have demonstrated that the magnitude of dual task interference is alleviated by the presence of cues, a finding that has provided the basis for speculation that external cues may act to facilitate the process of appropriately distributing attentional resources (Rochester et al., 2005).

Although there is considerable work to date demonstrating the success of a number of cue modalities in facilitating parkinsonian gait both in single and dual task conditions, there are a number of limitations presented by contemporary cueing strategies. For example, visual cueing tools can lack portability (van Wegen et al., 2006), whilst auditory cues can tend towards repetitiveness and a potential for habituation (Cubo et al., 2004); disadvantages that are likely to compromise vigilance and may lead to discontinuation of use. One practical solution to overcome these limitations is to implement cueing techniques that provide essential spatial or temporal stimuli while

incorporating some level of salience to the individual. An alternative to a simple auditory tone that may address the issue of salience is the use of music that is both familiar and enjoyable to the individual. It is commonly considered that music has the ability to induce a physical response. Indeed, music has been extensively shown to encourage movement in the healthy population, whether it be increased endurance during exercise (Copeland & Franks, 1991) or simply getting out of bed in the morning (Bernatzky et al., 2004). Moreover, anecdotal reports indicate that music can help stimulate movement in PD patients in situations where they experience freezing. In addition, previous studies (McIntosh et al., 1997; Thaut et al., 1996) have utilised original musical pieces with an accentuated beat to significantly improve gait velocity, stride length and cadence amongst PD patients. In accordance with these observations, our research program is currently investigating the possibility of incorporating salient music as a viable cueing strategy for parkinsonian gait. As a starting point in exploring this possibility, we compared the consequences of music accompaniment on spatiotemporal parameters of gait on PD and age-matched control subjects in single and dual task conditions. Based on the phenomenon that music can stimulate movement in both healthy and pathological populations, I hypothesised that the music would be ‘activating’ to movement and that I would therefore observe improved gait performance in the concurrent music trials.

3.3 Methods

3.3.1 Subjects. Ten patients with idiopathic PD (PD: $M_{\text{age}} = 66.6 \pm 6.5$ yrs; range = 58-76 yrs; 5 females; clinical characteristics in Table 3.1) and ten healthy age-matched control subjects (CTRL: $M_{\text{age}} = 65.4 \pm 6.3$ yrs; range = 57-75 yrs; 8 females) participated in this study. The Human Research Ethics committee of the University of

Lethbridge granted ethical approval of the study. All subjects were informed of the nature of the study and gave their informed written consent prior to the commencement of testing. PD patients were recruited through local neurologists and PD support groups. Inclusion criteria were diagnosis of idiopathic PD (by a consultant neurologist), mild to moderate disease severity (stage II to III on the Hoehn and Yahr scale; Hoehn & Yahr, 1967), stable antiparkinsonian medication regimen (for at least one month prior to testing), independently mobile without use of a walking aid, and adequate hearing. Patients were excluded if their disease duration was less than one year, they scored less than 26 on the Mini-Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975), they suffered from any neurological condition or comorbidity likely to affect gait and/or if they were already walking to music. Medical history and medication usage (Table 3.1) were ascertained prior to testing through a comprehensive interview. The impairment status of PD patients was assessed using the motor subsection of the United Parkinson's Disease Rating Scale (UPDRS; Fahn & Elton, 1987). All subjects in the CTRL group were recruited from the local community, were self-declared to be free from any neurological disorders or any other medical conditions that may affect gait function, and had adequate hearing.

3.3.2 Protocol. The testing protocol for this study represented test conditions to assess the effect of concurrent music on gait in single and dual task conditions, as well as the effect of music on gait performance in a complex walking task (obstacle negotiation). Obstacle negotiation trials will be addressed in a separate paper due to the differences in motor patterns used between steady state and obstructed walking.

Table 3.1 *Clinical Characteristics of Parkinson's Disease Patients*

Subject	Age (yr)	Disease Duration (yr)	Hoehn & Yahr	UPDRS (III)	Medications
PD 1	71	3	2.0	24	Levodopa
PD 2	76	4	3.0	26	Levodopa
PD 3	73	9	2.0	30	Levodopa
PD 4	62	1	2.0	30	Pramipexole
PD 5	74	8	2.5	26	Levodopa
PD 6	65	2	2.0	30	Levodopa
PD 7	58	12	2.5	26	Levodopa
PD 8	61	13	2.0	30	Levodopa, Amantadine
PD 9	66	10	2.5	30	Levodopa, Amantadine
PD 10	60	2	2.5	30	Levodopa

Note. Hoehn and Yahr and UPDRS (III) scores were measured in the ON condition.

Subjects were asked to walk the length of a 10m walkway at a self-selected pace. Test conditions were differentiated by the presence of music accompaniment (no music/music), and the requirement to perform a concurrent secondary cognitive task (no task/cognitive task).

Condition 1 (no music, no task, no obstacle, NM_{SINGLE})

Walking the length of the unobstructed walkway in the absence of music.

Condition 2 (music, no task, no obstacle, M_{SINGLE})

Walking the length of the unobstructed walkway whilst listening to music.

Condition 3 (no music, cognitive task, no obstacle, NM_{DUAL})

Walking the length of the unobstructed walkway whilst carrying out a cognitive task in the absence of music.

Condition 4 (music, cognitive task, no obstacle, M_{DUAL})

Walking the length of the unobstructed walkway whilst listening to music and carrying out the cognitive task.

Music (hereafter referred to as salient music) had previously been selected based upon the subjects indicated genre or artist preferences during a prior telephone interview. The cognitive task consisted of serially subtracting three's (aloud) from a random three-digit number. A new starting number was provided for each trial in the dual task conditions immediately prior to the commencement of the trial. Subjects were not provided with specific instructions regarding task prioritisation.

Subjects performed a total of six trials in each of the conditions (for a total of 24 trials). Order and practice effects were controlled for by randomising the order of task

(no task, cognitive task) presentation. Trials were blocked by the presence of music (NM/M), the blocks were counterbalanced between subjects. One practice trial was performed at the start of the testing session. All subjects with PD were tested ON medication (minimum of one hour post medication). Patients were shadowed by a trained researcher to ensure safety.

3.3.3 Apparatus. Three-dimensional (3D) kinematic data were collected at 120Hz using a six camera motion analysis system (Peak Performance Technologies and Vicon Motus 9.0 software, Englewood, CO, USA). Retro-reflective markers were placed on the sternal notch and bilaterally on the acromion process, lateral humeral epicondyle, ulnar styloid process, greater trochanter, lateral femoral condyle, lateral malleolus, the dorsal aspect of the foot between the first and second metatarsal, and on the calcaneus. A microphone headset and computer with an integrated audio card were used to capture the participant's verbalisations during the dual task trials (8000 Hz; Microsoft® Sound Recorder, Version 5.1). An iPod© Nano (Apple Inc, Cupertino, CA, USA) with headphones was attached to the subjects waistband to provide the subjects with music at a self-selected volume during trials in the music condition. Additionally, digital video cameras were used to capture frontal and sagittal digital video.

3.3.4 Data processing. Custom written algorithms were created in MATLAB® (Version R2007a; The Mathworks, Natick, MA, USA) to process raw marker data and calculate spatiotemporal parameters of gait. Raw marker data was filtered at 10Hz (low pass fourth-order Butterworth filter). Whole body centre of mass (COM) in the anterior-posterior (AP) dimension was calculated with a seven segment model using pre-

determined anthropometric values (Winter, 1990). The finite differences method was used to calculate AP COM velocity.

The event of right heel contact was used to crop kinematic data into gait cycles. Spatiotemporal parameters of gait consisted of: (1) AP COM velocity (gait velocity), (2) stride length, and (3) percentage of the gait cycle duration spent in double limb support (% DLS) as per previous studies in this area (Morris et al., 1996; O'Shea et al., 2002). Mean values were calculated across gait cycles and within each condition for all measures.

Cognitive task data were scored manually to determine the total number of verbalisations per trial, as well as the number of incorrect responses and the relative performance score (% errors) for each trial. Mean values were calculated across each DUAL condition for each measure.

3.3.5 Statistical analysis. Demographic data were summarised descriptively and compared between groups using independent t-tests. The properties (tempo and lyrical content) of music selections were quantified, between group differences were compared using independent t-tests. Cognitive data were entered into separate, mixed 2-factor [Group (CTRL/PD) x Music (NM/M)] Repeated-Measure Analyses of Variance (RM ANOVA). Gait measures were entered into separate mixed 3-factor [Group (CTRL/PD) x Music (NM/M) x Task (SINGLE/DUAL)] RM ANOVA to determine the effect of task, music and group on the spatiotemporal measures of gait specified in this study. Paired or independent t-tests were used to compare within and between group differences when the

RM ANOVA test established statistical significance. Statistical significance was set at 0.05.

3.4 Results

Descriptive statistics and summary statistical findings are provided in Tables 3.2 and 3.3 respectively. The mean tempo of the playlists selected for the music condition did not differ significantly ($p > 0.05$) between the CTRL and PD groups (Figure 3.1). The CTRL group tended to opt for music selections which had higher lyrical content than those of the PD group, however, this difference did not reach significance ($p > 0.05$; Figure 3.2).

During the cognitive task PD patients showed a tendency to articulate more numbers than the CTRL group across both no-music and music conditions, however, this difference did not reach significance ($p > 0.05$; Figure 3.3A). In addition, the PD group tended to demonstrate a higher percentage of errors in verbalisations during the cognitive secondary task than the CTRL group across both the no-music and music conditions. The PD group had a tendency to produce more errors during the concurrent music trials, whilst the CTRL group tended towards fewer errors in the music condition, however this differential effect was not significant ($p > 0.05$; Figure 3.3B).

Table 3.2 *Summary of descriptive statistics for gait parameters in the PD and CTRL groups [mean (SD)].*

Parameter	CTRL				PD			
	Single Task		Dual Task		Single Task		Dual Task	
	NM	M	NM	M	NM	M	NM	M
COM velocity (m/s)	1.41(0.11)	1.41(0.10)	1.28(0.13)	1.31(0.13)	1.29(0.15)	1.27(0.16)	1.03(0.39)	0.99(0.41)
Stride length (m)	1.41(0.05)	1.43(0.06)	1.34(0.07)	1.36(0.08)	1.35(0.09)	1.34(0.12)	1.27(0.16)	1.23(0.19)
DLS (%)	23.7(1.26)	23.8(0.83)	25.9(0.78)	24.5(0.98)	26.1(5.35)	29.1(5.73)	29.2(3.22)	31.5(2.69)

Table 3.3 *Summary of statistical findings. Univariate RM ANOVA result (G group, M music, T task).*

Parameter	G	M	T	MxG	TxG	MxT	TxMxG
COM velocity (m/s)	*		**	0.078			*
Stride length (m)	0.073		***	0.084			0.074
DLS (%)	0.069		*	**			

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

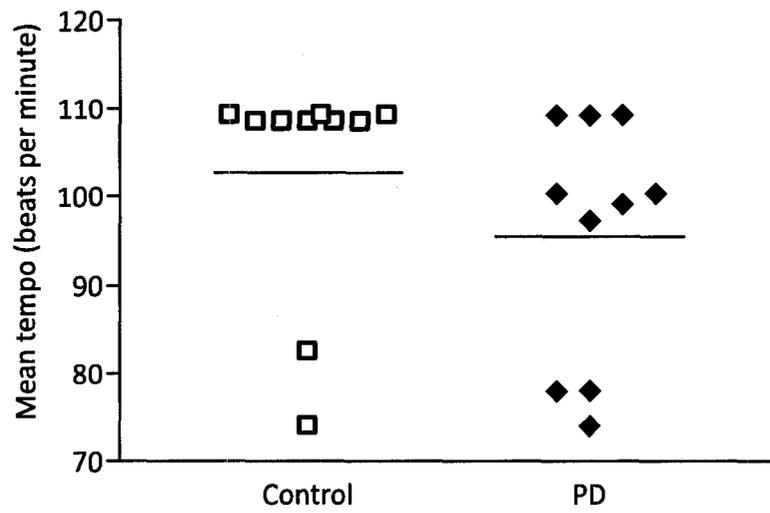


Figure 3.1 The mean tempo of individualised playlists provided to subjects during the music condition. Group means are indicated by horizontal lines.

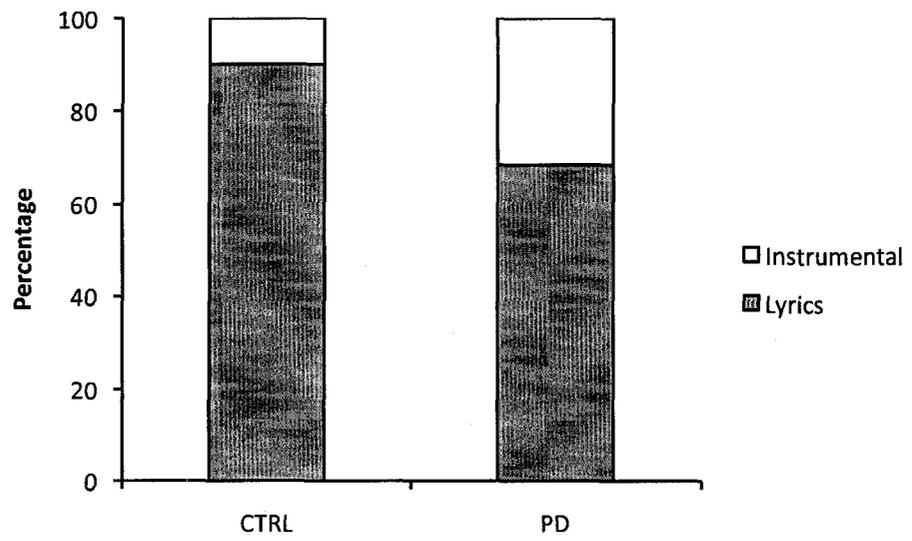


Figure 3.2 The distribution of playlist selections, between instrumental and lyrical music.

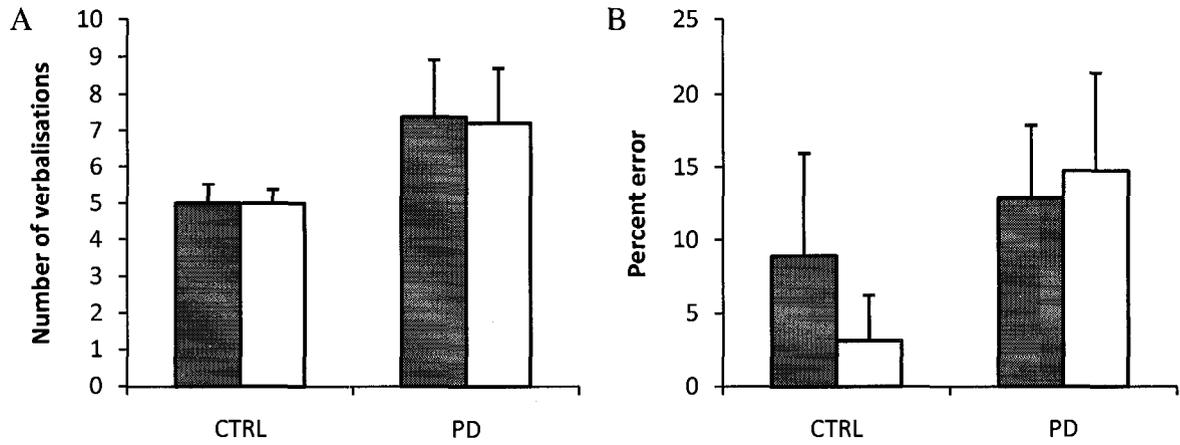


Figure 3.3 The effect of concurrent music on (A) the number of verbalizations and (B) the percentage of errors made during a secondary cognitive task (serial 3's). Dark bars represent no music trials, whilst light bars represent music trials. Data presented are means and standard errors of means.

PD patients consistently walked significantly slower [$F(1,18) = 5.359, p = 0.033$] with a tendency towards shorter strides [$F(1,18) = 3.623, p = 0.073$] and a longer double limb support phase [$F(1,18) = 3.784, p = 0.068$] across all conditions when compared to the CTRL group. Follow-up comparisons of means for baseline gait (no task, no-music) confirmed that gait velocity was significantly reduced amongst the PD subjects when compared to the CTRL subjects ($t(18) = 2.18, p = 0.043$; PD = 1.29m/s; CTRL = 1.41m/s). In addition, the PD group walked with considerably shorter strides ($t(18) = 2.08, p = 0.052$; PD = 1.35m; CTRL = 1.41m) than the CTRL group, however no significant difference was observed for the double limb support phase (PD = 26.1%; CTRL = 23.7%) in the baseline condition.

Listening to music whilst walking had a differential effect on gait performance amongst PD patients when compared to CTRL subjects, as confirmed by a significant interaction between music and group for % DLS [$F(1,18) = 10.528, p = 0.004$] and strong interactions for gait velocity [$F(1,18) = 3.503, p = 0.078$] and stride length [$F(1,18) = 3.342, p = 0.084$]. In particular, PD patients walked 2.2% slower, with a shorter stride length (1.9%) and a longer duration in the double limb support phase of the gait cycle (9.7%) in the concurrent music trials. In contrast, the CTRL group showed marginal improvements to gait patterns in music trials, increasing walking velocity (1%), and stride length (1%) and decreasing the duration of the double limb support phase by approximately 2.8% when compared to no-music conditions.

When challenged by a concurrent cognitive task, both the PD subjects and CTRL subjects adjusted their gait patterns to walk slower [$F(1,18) = 16.443, p = 0.001$; PD = 21% change; CTRL = 8% change], with shorter strides [$F(1,18) = 29.811, p < 0.001$; PD

= 7% change; CTRL = 5% change], and a longer double limb support duration [$F(1,18) = 4.251, p = 0.054$; PD = 10% change and CTRL = 6% change]. However, the task by group interactions failed to reach significance.

As confirmed by a significant three-way (task x music x group) interaction, the added requirement of concurrent music in the dual task context differentially influenced walking velocity [$F(1,18) = 4.653, p = 0.045$] between PD patients and CTRL subjects. Specifically, PD patients showed a further 4% decrease in walking velocity, beyond the 20% decrease imposed by the dual task, when required to perform the dual task in the concurrent music condition. Conversely, the noted detrimental dual task effect was less pronounced amongst the CTRL group in the concurrent music condition with healthy control subjects demonstrating a 3% increase in velocity when compared to the baseline dual task condition (no music; Figure 3.4A). The same pattern of differential effect was noted for both stride length (Figure 3.4B) and double limb support duration (Fig. 9C); however, these interactions did not reach significance ($p > 0.05$). Indeed, of noteworthy mention is the striking effect of concurrent music in the dual task context amongst PD patients when compared to CTRL subjects for the measure of double limb support. As illustrated in Figure 3.4C, the gait pattern of the PD patients included a further prolonged DLS phase (8%) for the dual task trials that were performed with concurrent music compared to the no music dual task trials. Again, the opposite was observed in the CTRL group who decreased the duration of the DLS phase by 3% when performing the dual task with concurrent music.

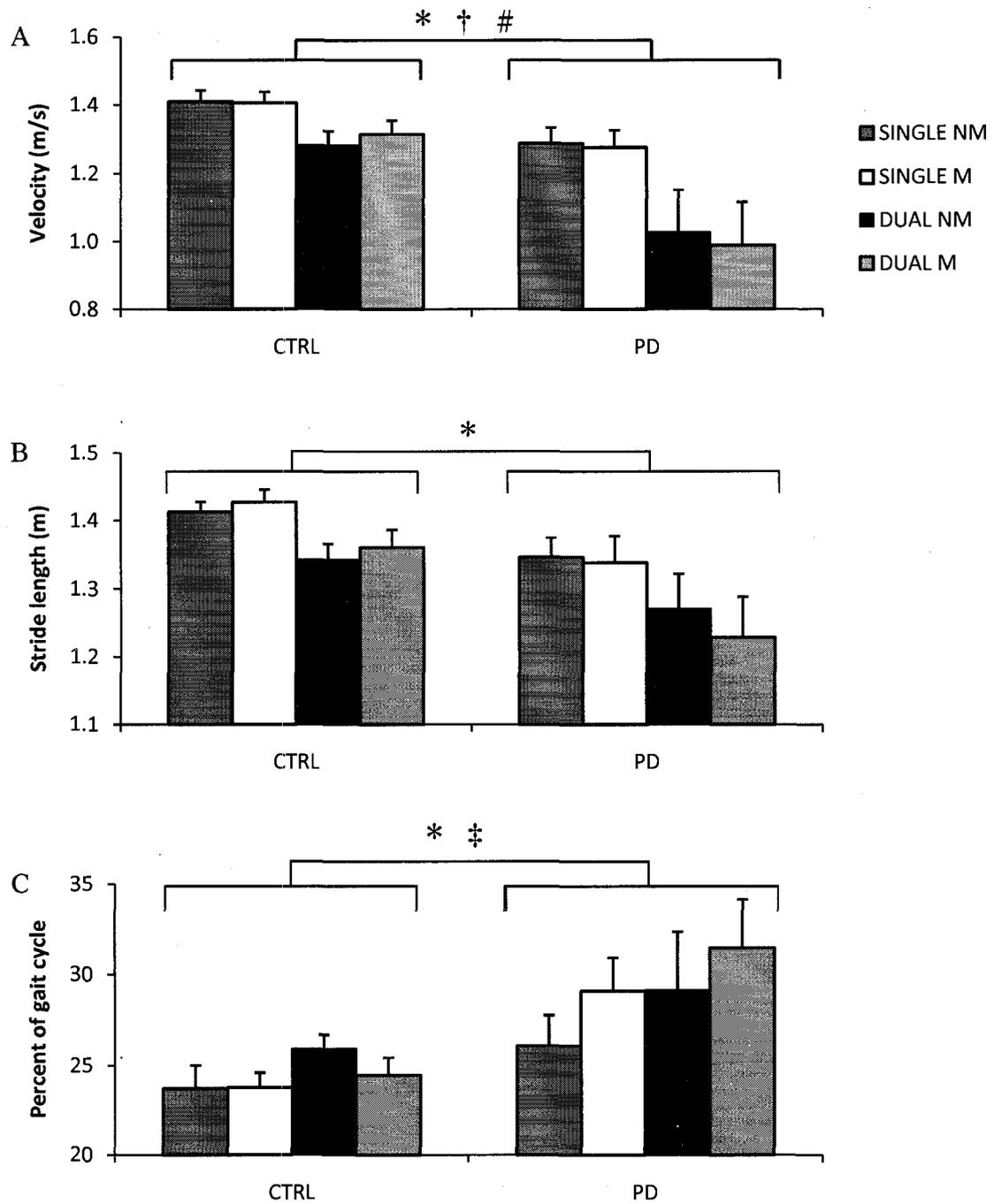


Figure 3.4 The effect of concurrent music and dual task on (A) gait velocity, (B) stride length, and (C) % of gait cycle spent in DLS in CTRL and PD subjects. Data presented are means and standard errors of means. * Significant effect of task, † significant effect of group, ‡ significant music x group interaction, # significant task x music x group interaction.

3.5 Discussion

Music is a powerful stimulus, with a well-documented ability to evoke movements (Janata & Grafton, 2003; Kneafsey, 1997) and strong emotions (Blood, Zatorre, Bermudez, & Evans, 1999; Panksepp & Bernatzky, 2002). Previous research has demonstrated a facilitatory effect of original instrumental music on the gait patterns of PD patients (McIntosh et al., 1997; Thaut et al., 1996). My purpose in this study was to investigate whether parkinsonian gait is altered by the presence of concurrent salient music in single and dual task contexts. Two questions were addressed: (1) does concurrent music influence gait kinematics in non-neurological and parkinsonian populations and (2) is the dual task effect, known to be present in both populations (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; Ebersbach, Dimitrijevic, & Poewe, 1995; Lundin-Olsson et al., 1997; Morris et al., 1996; O'Shea et al., 2002; Woollacott & Shumway-Cook, 2002), influenced by concurrent music? These questions were motivated by my interest in identifying alternate therapies that can translate into functionally appropriate and ecologically relevant choices for patients with PD. My findings show that gait patterns in the PD patients were altered in the concurrent music trials, interestingly in a manner similar to the dual task effect imposed by performing a secondary cognitive task. Consequently, I was not surprised by the observation that the dual task effect was exacerbated for PD patients but not for the control subjects in the concurrent music trials. The similarity observed between the gait interference exacted by concurrent music to the phenomenon of dual task decrement implies possibility that concurrent music imposes added cognitive demands that may interfere with attentional control of gait in the PD population. Previous research

investigating the influence of music on cognitive performance in non-neurological populations similarly suggests that music adds to the cognitive load, acting as a distraction from the primary task (Furnham & Strbac, 2002; Parente, 1976). Although this theory points caution for patients who may enjoy listening to music whilst walking, it also opens the possibility to use concurrent music as a viable method to impose added cognitive demand in gait training programs that target improvement in dual task performance as a measure of functional outcome.

3.5.1 Group differences in gait in single and dual task contexts. Consistent with prior reports on parkinsonian gait (Knutsson, 1972; Morris et al., 1994), the PD patients in this study walked with reduced gait velocity and stride length and an increased duration of the gait cycle in double limb support when compared to the healthy control subjects in the baseline condition (no-task, no-music). These group differences persisted across all four experimental conditions. As would be expected, simultaneously performing the arithmetic task of counting backwards and walking resulted in decreased walking speed and stride length and an increased duration of double limb support, when compared to simply walking alone. This finding is suggestive that the cognitive task interfered with the primary task of walking to impose a dual task effect (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Morris et al., 1996; O'Shea et al., 2002; Rochester et al., 2004). Yet, contrary to my expectation, the dual task effect was comparable between groups. It has previously been determined that the complexity (Bond & Morris, 2000) and type (Galletly & Brauer, 2005) of secondary task performed affects the allocation of attention between simultaneous tasks for PD patients. One possibility is that the motor-cognitive task pairing used in this study did not provide a

sufficient challenge to tax the attentional capacity or the ability to distribute attentional resources of the PD patients to a greater extent than the control group. Indeed, the dual task impairment that is typically demonstrated by PD patients has been attributed to the impairment in executive function that has been associated with the disease (Dalrymple-Alford et al., 1994). The level of executive function of the patients used in this study was not determined, but it is plausible that the patient population that we worked with in this study, who had mild to moderate disease severity, had levels of executive function that were within normal limits. Given the known exacerbation of dual task interference when cognitive task complexity increases (Bond & Morris, 2000) it is conceivable that a concurrent task of greater complexity than “serial three’s” may therefore be required for the exacerbated dual task effect of the PD group to occur.

3.5.2 Effect of concurrent music on gait in single and dual task contexts. My results revealed that the gait of PD patients’ was detrimentally affected by concurrent music, while the gait of CTRL subjects remained largely unchanged. More specifically, control subjects did not demonstrate an effect of music in the walking only condition, but marginal increases in gait velocity, stride length and a decrease in the duration spent in double limb support were observed in control subjects for the dual task trials with concurrent music. Moreover, the improvements observed in the spatiotemporal measures of gait did not occur at the expense of cognitive performance. Conversely, PD patients demonstrated a significantly longer proportion of the gait cycle spent in double limb support whilst listening to music in the walking only condition, while gait speed and stride length remained unaffected. When the patients were required to also perform the arithmetic task, the increase in double limb support duration was further exacerbated and

patients demonstrated slower gait speed and shorter strides. Additionally, the PD group made considerably more errors during the cognitive task when simultaneously listening to music. In combination these results imply that concurrently listening to music is imposing added cognitive demand for the patients, as displayed by a poorer performance on both the primary task of walking and the secondary cognitive task. It is possible that the demonstrated alterations in gait patterning are an accommodation to the additional attentional load imposed by the concurrent music. The adjustments may serve to increase stability by decreasing the duration of the dynamic single limb support phase of the gait cycle, potentially reducing the risk of a fall. I suggest, therefore, that concurrent music effectively imposes a tertiary cognitive load, thereby creating a multi-task scenario that is especially difficult for PD patients to manage (Bloem, Valkenburg et al., 2001). This proposal is supported by the findings of previous studies that indicate that the general resource capacity of PD patients is diminished and that PD patients experience greater difficulty appropriately allocating their attentional resources when task complexity increases (Bond & Morris, 2000).

The results for my study contrast those of previous studies, which have reported the facilitatory effect of music on parkinsonian gait performance (McIntosh et al., 1997; Thaut et al., 1996). However, one possibility for explanation is that the music used in these previous studies was typically original instrumental tracks with an accentuated beat (McIntosh et al., 1997; Thaut et al., 1996) at a tempo that exceeded the natural cadence of the subject. The close synchronization between the subjects' steps and the rhythm of the music resulted in improved walking velocity (McIntosh et al., 1997; Thaut et al., 1996) as an outcome of increased cadence, in addition to a reduction in gait variability (Thaut et

al., 1996). In my study, the music selections were suggested by the subjects. Therefore the tempo of the music was not controlled, nor was it matched to cadence. My intention in this study was to explore the consequences of concurrent music on gait using music selections that bear meaning to the listener rather than replicate the known effect of tempo-cadence synchronization. It is a distinct possibility that the wide tempo range within each group music playlist (Figure 3.1) may partially explain the exacerbation of gait deficits that were demonstrated by the PD group in the presence of music. Current research being carried out in the Balance Research Laboratory aims to more clearly elucidate the effect of the salience of the music on observed gait changes by examining the potential effect of training with salient music that has a restricted tempo range.

An alternative explanation may be that the group-dependent differences in gait performance reflect differing effects of affective arousal produced by the music selections. Music playlists were self-selected by the subjects, making it probable that music choices were selected for emotional and/or motivational reasons. The music selections for both groups were highly complex, including lyrics in 90 percent of cases for the control group and 70 percent of cases for the PD group, likely increasing affective arousal (Panksepp & Bernatzky, 2002). Whilst it is expected that both groups actively attended to the music, it would appear that the attentional demands did not exceed the resource capacity of the control subjects. In contrast, attending to gait whilst simultaneously listening to music appeared to exceed the PD patients' available resource capacity, resulting in deterioration in gait performance, a deterioration that was compounded with the further addition of the cognitive task.

3.5.3 Future directions. The known decrement in parkinsonian walking performance that occurs in the presence of a concurrent cognitive task has provided foundation for an emergence of studies aimed at improving dual and multi-task performance (Bedeschi et al., 2008; Canning et al., 2008; Piemonte, Okamoto, Richi, & Valle, 2008). The promise of these training protocols is to enhance functionality through improved ability to perform tasks concurrent to walking. Increased automaticity of motor control processes and improved attentional control strategies can be achieved in PD patients through regular gait training whilst performing a simultaneous cognitive task (Bedeschi et al., 2008). My findings indicate that walking whilst listening to concurrent salient music was attentionally demanding; however, it was less so than the cognitive task in isolation. I therefore suggest that listening to concurrent salient music would be an attractive secondary task in the early stages of dual and multi-task training. Conceivably, dual task impairment will be greatest early in the training regimen; therefore incrementally increasing the difficulty of the secondary task as improvements in dual tasking are observed will reduce the risks to patient safety associated with dual task interference.

3.6 Conclusion

The work presented indicates that listening to music is an attention-demanding activity for PD patients. The gait performance of PD patients was detrimentally affected by concurrently listening to salient music whilst walking in the single task situation, an effect that was further compounded in the dual task context.

The findings of my study substantiate the available information on the multi-task limitations exhibited by PD patients. It is apparent that gait patterning is adversely

affected by attending to simultaneous tasks, a result of decreased available resource capacity and/or increased difficulty in appropriately allocating attentional resources. These results have serious implications for patients, who may be at greater risk of falls in multi-task situations such as walking whilst talking in a complex environment. Therapists are addressing this issue by moving towards multi-task training, an area of rehabilitation where the use of concurrent salient music may be beneficial, both in terms of attentional loading and compliance.

Chapter 4: Experiment 2 - Concurrent Music Compromises Obstacle Negotiation in Parkinson's Disease

4.1 Abstract

Multitasking situations exacerbate gait impairments and increase the risk of falling amongst the Parkinson's disease population. This study examined kinematic parameters of obstacle negotiation amongst 10 Parkinson's disease patients and 10 age-matched control subjects in two test conditions, differentiated by the presence of music (no music/music). Music had previously been self-selected by the subjects. Subjects completed six trials in each testing condition, walking the length of a 10m walkway at a self-selected pace and crossing a 0.15m obstacle placed at the midpoint of the walkway. Whilst obstacle crossing was successful for all subjects the results indicate that concurrent music differentially altered obstacle crossing strategies for the Parkinson's disease and control groups. Parkinson's disease patients' decreased crossing speeds and crossing step length in concurrent music trials, in contrast control subjects maintained crossing speeds and increased crossing step length. The findings of this study suggest that the presence of auditory distracters during obstacle crossing may increase the attentional cost of obstacle negotiation for PD patients. The alterations to crossing strategies observed amongst Parkinson's disease patients suggest the possibility of an increased risk of falls in complex environments for this population.

4.2 Introduction

The prevalence of falls amongst neurological patients has been found to be twice as high as among those of a similar age who do not suffer neurological impairment (Bohannon, 1989). Within the neurological population Parkinson's disease (PD) patients

are most at risk of falling (Stolze et al., 2004), with seventy percent of PD patients reported to fall annually and fifty percent of patients experiencing multiple falls each year (Bloem et al., 2004; Wood et al., 2002). Falls are a major cause of injury in the PD population (Wielinski et al., 2005), and can result in a debilitating fear of falling (Adkin et al., 2003; Bloem, Grimbergen et al., 2001). In addition, falls can significantly increase the possibility of nursing home (Hely et al., 1999) or hospital (Temlett & Thompson, 2006) admission amongst PD patients.

Falls have a multifactorial aetiology; a significant body of work has been dedicated to identifying intrinsic (patient-oriented) and extrinsic (environmental) risk factors associated with falls amongst PD patients (Robinson et al., 2005). Recent research (Ashburn, Stack, Pickering & Ward, 2001; Robinson et al., 2005) has recognized balance impairments and cognitive deficits to be leading independent intrinsic risk factors for falls in the PD population. However, current contributions documenting the interdependence of cognition and motor performance substantiate the increased fall risk amongst PD patients in dual task contexts, such as talking or carrying an item whilst walking (Willemsen et al., 2000). In fact, multitasking has been implicated in almost fifty per cent of falls amongst PD patients (Bloem et al., 2006). In the traditional context, the dual task paradigm is defined by simultaneous performance of a cognitive task (Camicioli et al., 1998; Hausdorff, Balash, & Giladi, 2003; Yogev et al., 2005; Yogev et al., 2007) whilst walking. Recognition of the contextual validity of gait as a task that is often compounded by secondary motor tasks, however, has led to the emergence of research studies that investigate how ecologically relevant secondary tasks such as transferring coins from one pocket to another (O'Shea et al., 2002) or carrying a tray of

glasses (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Canning, 2005; Rochester et al., 2005) influence walking. The decrement observed when PD patients execute multiple tasks simultaneously and the implied risk to safety has recently resulted in the development of multitask training protocols (Bedeschi et al., 2008; Canning et al., 2008; Piemonte et al., 2008). Multitask training protocols aim to increase functionality through improving the capacity to perform additional tasks concurrent to walking.

Currently, I am exploring the effects of concurrent music on parkinsonian gait. My motivation for this work is an interest in developing an alternative therapy for PD patients that while meaningful to the patient, is also ecologically valid and functionally relevant. My previous study presented in this thesis indicated that PD patients walk differently when listening to music. Specifically, my primary finding was that steady state gait performance was compromised in concurrent music trials, a finding that I attributed to the attentional load imposed by the novelty of the task. Nevertheless, I do recognise that the motor and attentional demands of locomotion in complex everyday environments exceed those of steady state gait (Siu et al., 2008). Indeed, the ability to safely navigate a cluttered environment may require obstacle negotiation that has been identified as an attentionally demanding task (Chen et al., 1996; Schrodt et al., 2004; Weerdesteyn, et al., 2003). In this study, I extended my investigation to explore whether concurrent music influences the kinematics of obstacle negotiation in PD patients. In the non-pathological population, dual task paradigms (obstacle negotiation and secondary cognitive task) have been used to determine the attentional demands of successful obstacle negotiation. Impaired obstacle crossing in the presence of the secondary task (Chen et al., 1996; Kim & Brunt, 2007; Schrodt, Mercer, Giuliani, & Hartman, 2004; Siu

et al., 2008; Weerdesteyn et al., 2003) implies dual task interference, a characteristic finding when the finite attentional resource capacity of the individual has been exceeded by multiple task demands (Kahneman, 1973). Based on known gait, balance (Koller, 1989) and attentional deficits (Dalrymple-Alford et al., 1994) experienced by the PD population, I hypothesised that PD patients would experience greater difficulty than age-matched control subjects in successfully negotiating an obstacle and that decrement in obstacle negotiation kinematics would be exacerbated when patients concurrently listened to music.

Thus, the purpose of the current study was to define obstacle negotiation kinematics of PD patients whilst crossing a three-dimensional obstacle. To achieve this goal standard kinematic parameters of obstacle negotiation patterns were investigated. A second goal of the study was to explore whether the obstacle negotiation patterns characteristic to non-pathological and PD populations were differentially altered by the addition of concurrent music.

4.3 Methods

4.3.1 Subjects. A total of twenty subjects were included in this study; ten patients with idiopathic PD ($M_{\text{age}} = 66.6 \pm 6.5$ yrs; range = 58-76 yrs; $M_{\text{height}} = 1.68 \pm 0.08$ m; 5 females; clinical characteristics in Table 4.1) and ten age-matched healthy adults (CTRL: $M_{\text{age}} = 65.4 \pm 6.3$ yrs; range = 57-75 yrs; $M_{\text{height}} = 1.66 \pm 0.07$ m; 8 females). The Human Research Ethics Committee of the University of Lethbridge provided ethical approval of the study. All subjects were recruited from the local community, with PD patients being recruited through local support groups and

neurologists. Subjects provided their informed consent prior to testing. Patients were included if they had been diagnosed with idiopathic PD by a consultant neurologist, had mild to moderate disease severity as determined by the Hoehn and Yahr scale (Stage II to III; Hoehn & Yahr, 1967), had a stable medication regimen (a minimum of 1 month prior to commencement of testing) and the ability to ambulate independently without using a walking aid. Exclusion criteria for the PD group were disease duration of less than 1 year, the presence of a neurological disorder or comorbidity likely to affect gait, a score of 26 or lower on the Mini-Mental Status Examination (MMSE; Folstein et al., 1975), the presence of a hearing deficit or already walking to music. CTRL subjects were included if they did not have a hearing deficit, could ambulate independently without the use of a walking aid and did not have a neurological disorder or comorbidity that would affect gait.

4.3.2 Protocol. Subjects walked the length of a 10m walkway at a self-selected pace, crossing over a dense foam obstacle that was placed at the midpoint of the walkway. Six obstacle negotiation trials were performed in two different testing conditions, differentiated by the presence of musical accompaniment (no music/music). Music (henceforward referred to as salient music) was selected based upon the genre and artist preferences of the subject, which were previously determined through a telephone interview. The test conditions were counterbalanced between subjects. A practice trial was performed prior to the start of data collection. PD subjects were tested a minimum of one hour post medication. A trained researcher walking behind each subject ensured safety.

Table 4.1 *Clinical characteristics of Parkinson's disease patients*

Subject	Age (yr)	Disease Duration (yr)	Hoehn & Yahr	UPDRS (III)	Medications
PC 1	71	3	2.0	24	Levodopa
PD 2	76	4	3.0	26	Levodopa
PD 3	73	9	2.0	30	Levodopa
PD 4	62	1	2.0	30	Pramipexole
PD 5	74	8	2.5	26	Levodopa
PD 6	65	2	2.0	30	Levodopa
PD 7	58	12	2.5	26	Levodopa
PD 8	61	13	2.0	30	Levodopa, Amantadine
PD 9	66	10	2.5	30	Levodopa, Amantadine
PD 10	60	2	2.5	30	Levodopa

Note. Hoehn and Yahr and UPDRS (III) scores were measured in the ON condition.

4.3.3 Apparatus. Reflective markers were placed on the sternal notch and bilaterally on the acromion process, lateral humeral epicondyle, ulnar styloid process, greater trochanter, lateral femoral condyle, lateral malleolus, the dorsal aspect of the foot between the first and second metatarsal, and the calcaneus. Three-dimensional (3D) kinematic data were collected using a six camera motion analysis system (Peak Performance Technologies and Vicon Motus 9.0 software, Englewood, CO, USA) which collected marker positions at a sampling frequency of 120Hz. The obstacle was a dense foam block (0.225m high x 0.155m deep x 0.60m wide) placed in the centre of the walkway and was visible from trial onset. In the music testing condition salient music was played at a self-selected volume via an iPod Nano® (Apple Inc, Cupertino, CA, USA) with headphones, which was attached to the participant's waistband. Frontal and sagittal video was captured using digital video cameras.

4.3.4 Data processing. The frequency of obstacle contact was determined from video records. Raw marker data were filtered at 10Hz using a low pass fourth-order Butterworth filter. Filtered marker data were processed and spatiotemporal parameters of gait were calculated using custom written algorithms (Matlab® Version R2007a; The Mathworks, Natick, MA, USA). Relevant measures used to assess kinematics of obstacle crossing are defined fully in Table 4.2 and illustrated in Figure 1.5. For the purposes of this study the lead limb was designated as the first leg to cross the obstacle, whilst the second leg to cross the obstacle was identified as the trail limb. For each subject, mean values across trials were calculated for all measures and used for analysis.

4.3.5 Statistical analysis. Demographic data were summarised descriptively and were compared between groups using independent t-tests. All spatiotemporal parameters of gait were normalised to leg length to control for anthropometrical differences between subjects (Chen et al., 1991; Chen et al., 1994). The effect of music and group on normalized spatiotemporal parameters of obstacle negotiation kinematics and obstacle contact data were analyzed using separate mixed 2-factor [Group (CTRL/PD) x Music (NM/M)] Repeated-Measures Analyses of Variance (RM ANOVA). Post-hoc t-tests were used to compare within and between group differences when the RM-ANOVA test established statistical significance. Statistical significance was set at 0.05.

4.4 Results

Descriptive statistics and summary statistical findings are provided in Table 4.3. The incidence of obstacle contacts did not differ between groups or conditions, with zero obstacle contacts recorded for each group.

Table 4.2 *Summary of measures of obstacle negotiation kinematic definitions.*

Parameter	Abbreviation	Definition
Step length (m)	SL	Length of step taken to cross obstacle defined as horizontal distance from trail foot toe-off position to lead foot heel-contact position.
Step height (m)	SH	Vertical distance between lead foot toe and centre of top surface of obstacle during obstacle crossing step.
Toe-obstacle distance (m)	TO	Horizontal distance between trail foot toe-off position and front edge of obstacle prior to obstacle crossing.
Heel-obstacle distance (m)	HO	Horizontal distance between rear edge of obstacle and lead foot heel-contact position following obstacle crossing.
Velocity of lead limb (m/s)	CV _{Lead}	Mean horizontal linear velocity of lead limb during obstacle crossing step.
Velocity of trail limb (m/s)	CV _{Trail}	Mean horizontal linear velocity of trail limb during obstacle crossing step.

Table 4.3 Summary of descriptive statistics and statistical findings for normalized gait parameters in the PD and CTRL groups [mean (SD)]. RM ANOVA result (G group, M music).

Parameter	CTRL		PD		G	M	MxG
	NM	M	NM	M			
Step length	0.737(0.04)	0.791(0.05)	0.786(0.04)	0.724(0.04)			
Step height	0.230(0.04)	0.227(0.06)	0.232(0.02)	0.233(0.03)			
Toe-obstacle distance	0.320(0.12)	0.376(0.13)	0.407(0.07)	0.347(0.12)			0.082
Heel obstacle distance	0.224(0.01)	0.225(0.02)	0.183(0.02)	0.187(0.02)			
Lead limb crossing velocity (s ⁻¹)	2.793(0.31)	2.803(0.28)	2.573(0.46)	2.322(0.47)	*	0.083	0.064
Trail limb crossing velocity (s ⁻¹)	2.581(0.46)	2.609(0.42)	2.593(0.61)	2.207(0.39)		*	**

* $p < 0.05$; ** $p < 0.001$

The movement patterns used to cross the obstacle differed between groups. PD patients adopted a crossing strategy that was defined by a significantly slower lead limb velocity compared to the CTRL group [CV_{Lead} ; $F(1,18) = 4.723$, $p = 0.043$]. This group difference persisted for both testing conditions (no music/music). The PD group also had a tendency to place the heel of their lead foot closer to the obstacle (HO) during the crossing step than the CTRL group across both conditions, however, this group effect was not significant ($p > 0.05$). Trail limb velocity (CV_{Trail}), toe-obstacle distance (TO), step height (SH) and step length (SL) did not differ significantly between the two groups ($p > 0.05$) across the no music and music conditions. Follow-up comparisons of means for significant measures in the baseline condition (no music) did not establish any statistically significant differences between groups.

Listening to music whilst walking had a differential effect on obstacle crossing kinematics amongst PD patients when compared to CTRL subjects, as confirmed by a significant interaction between music and group for trail limb velocity [$F(1,18) = 10.919$, $p = 0.004$; Figure 4.1B] and strong interactions for lead limb velocity [$F(1,18) = 3.900$, $p = 0.064$; Figure 4.1A] and toe-obstacle distance [$F(1,18) = 3.395$, $p = 0.082$; Figure 4.2C]. More specifically, in the music trials PD patients used obstacle crossing movement patterns defined by slower crossing velocities of the lead (9.8%) and trail (14.7%) limbs. In addition, PD patients placed their trail foot considerably closer to the front of the obstacle (14.7%) than in the no music condition. In contrast, CTRL subjects crossed the obstacle with minimal change to trail and lead limb velocities (1.1% and 0.4% increase respectively) and a greater distance between the trail foot and the front of the obstacle (17.5%) in the concurrent music trails. A similar pattern of differential effect

was observed for step length with PD patients decreasing step length (6.2%) whilst CTRL subjects increased step length by 9.4% in the music condition, however this interaction did not reach significance ($p > 0.05$; Figure 4.2A). Step height (Figure 4.2B) and heel-obstacle distance (Figure 4.2D) remained largely unchanged between no music and concurrent music trials for both CTRL and PD subjects.

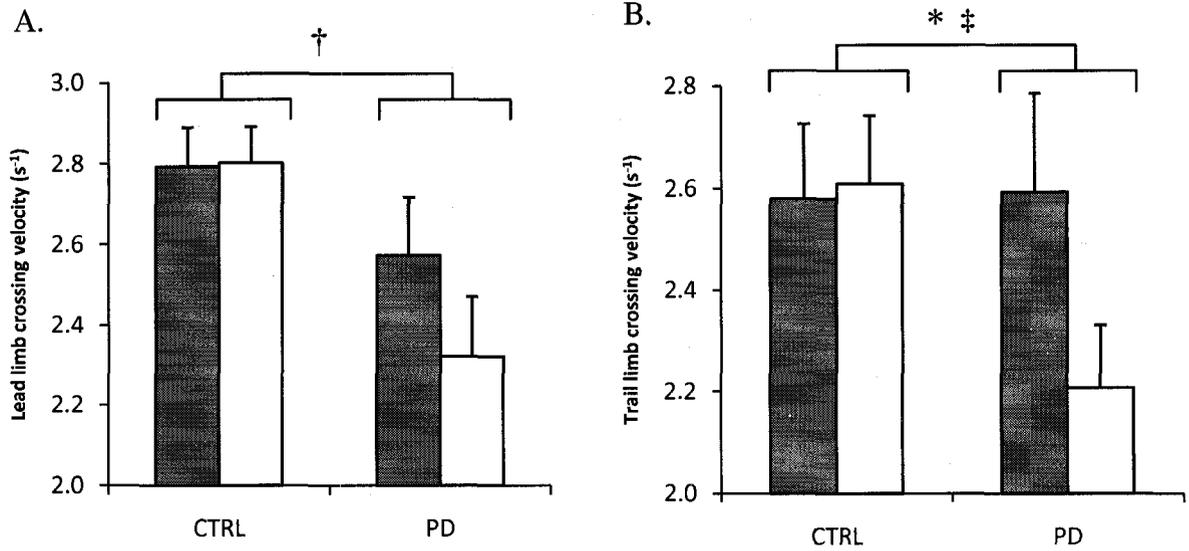


Figure 4.1 The effect of concurrent music on normalized crossing velocity of (A) lead limb and (B) trail limb in CTRL and PD subjects. Dark bars represent NM trials, whilst light bars represent M trials. Data presented are means and standard errors of means. * Significant effect of music, † significant effect of group, ‡ significant music x group interaction.

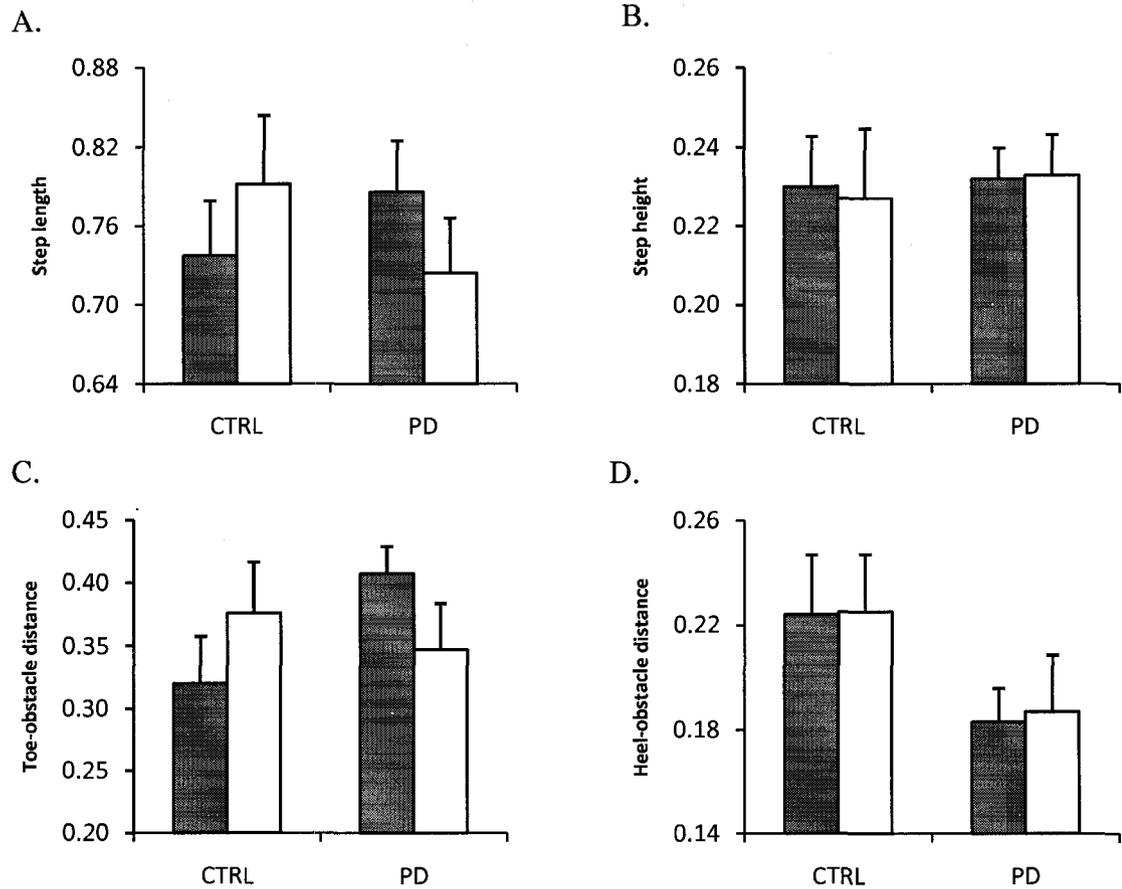


Figure 4.2 The effect of concurrent music on normalized (A) step length, (B) step height, (C) toe-obstacle distance, and (D) heel-obstacle distance in CTRL and PD subjects. Dark bars represent NM trials, whilst light bars represent M trials. Data presented are means and standard errors of means.

4.5 Discussion

PD patients are at a considerably greater risk of experiencing a fall than the non-neurological older adult population (Stolze et al., 2004), with impaired obstacle negotiation having been identified as one of the principal causes of falls in the population (Stolze et al., 2004). In the present study our purpose was twofold: to define the obstacle crossing kinematics of PD patients and to explore whether listening to concurrent salient music whilst walking influenced the crossing kinematics of non-neurological and PD subjects. Our findings indicated that PD patients and healthy age-matched control subjects cross a three-dimensional obstacle differently. Based on existing evidence we have interpreted these differences to imply that PD patients adopted a more conservative crossing strategy when compared to CTRL subjects. In the concurrent music trials, however, PD patients altered their crossing strategy in a fashion that could be considered to be more hazardous. Whilst a lack of obstacle contacts indicates that subject safety was not compromised, the adaptations to obstacle crossing kinematics observed are suggestive that the presence of concurrent music could add to the cognitive load of an already attentionally demanding task.

4.5.1 Obstacle crossing kinematics: PD vs. CTRL. Whilst PD patients and CTRL subjects were equally able in avoiding obstacle contact during crossing, PD patients adopted a differing strategy to the CTRL subjects in order to safely negotiate the obstruction. More specifically, PD patients crossed the obstacle with slower lead limb velocity and similar trail limb velocity when compared to the CTRL group. Decreased obstacle crossing speed has previously been reported to be a safety strategy, reducing the risk of falling in the event of obstacle contact due to reduced forward momentum,

allowing greater time for recovery (Patla et al., 1991). Contrary to our expectations PD patients did not step as close to the front edge of the obstacle as CTRL subjects during the crossing step. However, PD patients did land closer to the obstacle than the CTRL group following crossing. The result of the combined foot placement was a longer crossing step length amongst the PD patients when compared to CTRL subjects. This obstacle crossing behaviour has been described as a safety strategy (Chen et al., 1991; Chou & Draganich, 1998). Larger toe-obstacle distances combined with longer step length has been associated with a lower risk of tripping on an obstacle. The increased time available to reach a suitable crossing height reduces the likelihood of contacting the obstacle with the toe of the trail limb during crossing (Chen et al., 1991; Chou & Draganich, 1998). However, landing closer to the obstacle following crossing is suggestive of an increased risk of heel contact with the obstacle (Chen et al., 1991). Whilst this foot placement strategy increases the possibility of a stumble, it may be preferable to land closer to the back of the obstacle than step closer to the front of the obstacle (Chen et al., 1991). Heel contact with an obstacle may be easier to recover from than a trip caused by toe contact (Chou & Draganich, 1997). Alternatively, the short post obstacle distance may also be a conscious strategy by the PD patients to increase safety. The combination of decreased crossing velocity and increased step length observed amongst the PD group results in increased time spent in the unstable single limb support phase of the gait cycle. This contrasts the behaviour of PD patients during unobstructed walking, which is defined by a longer duration of double limb support. It is feasible that PD patients shorten the post-obstacle distance in order to reduce the duration of time spent in single-limb support and consequently revert to the more stable double limb

support phase of the gait cycle following obstacle crossing (McKenzie & Brown, 2004). Double-limb support offers a larger base of support, increasing stability and decreasing the likelihood of loss of balance.

Consideration is warranted regarding the factors influencing the differences observed in obstacle crossing strategy between PD patients and CTRL subjects. A possibility is that the PD patients perceived increased risks that are presented by obstacle negotiation, and accordingly adjusted their gait to offset the apparent risks. Said and colleagues (2001) offered a similar suggestion upon observing comparable modifications to obstacle crossing strategies in hemiplegic stroke patients.

4.5.2 Effects of concurrent music on obstacle crossing kinematics. Whilst the absolute success rate of obstacle avoidance was maintained, the addition of salient music to the task of obstacle negotiation resulted in differing alterations to spatiotemporal gait parameters for PD and CTRL subjects. More specifically, CTRL subjects' maintained crossing velocity for both the lead and trail limb, whilst slightly increasing the crossing step length by stepping further from the front edge of the obstacle prior to obstacle crossing. In contrast, PD patients further reduced the crossing velocity of both the lead and trail crossing legs. PD patients also demonstrated a considerably shorter crossing step length, which resulted from stepping considerably closer to the front edge of the obstacle prior to crossing. Both the PD and CTRL group largely maintained the step height and landing distance during the concurrent music trials. I note that the alterations in crossing strategies demonstrated by the PD patients whilst listening to music are similar in nature to those observed amongst healthy control subjects in obstacle negotiation studies incorporating a secondary cognitive task (Schrodt et al., 2004;

Weerdesteyn et al., 2003). The resemblance of the alterations to the crossing strategy with the addition of music amongst PD patients to that displayed during dual task obstacle crossing provides support for my previous finding that concurrent music may be adding to the cognitive load of the patients. The suggestion that music can be attentionally demanding is supported by previous research (Furnham & Strbac, 2002; Parente, 1976) examining the effect of concurrent music on cognitive performance in non-neurological adults. Studies have found that the concurrent music acted as a distracter from the principle task, effectively acting as an additional task and reducing residual attentional resources. It would appear that in this study, the attentional resources of the CTRL subjects were not exceeded by the demands of simultaneously crossing an obstacle and listening to music, as illustrated by the maintenance or improvement in obstacle crossing parameters. In contrast, concurrently attending to the demands of obstacle negotiation and listening to music appeared to provide challenge for the PD patients. Whilst the lack of obstacle contact implied that the resulting alterations to obstacle crossing parameter were not particularly hazardous, the alterations do imply the possibility of further decrements with increased cognitive demand.

4.6 Conclusion

The work presented indicates that PD patients adopt a differing obstacle crossing strategy compared to healthy control subjects when negotiating a three-dimensional obstacle. Based on current evidence, I have interpreted these alterations to crossing kinematics to represent an adaptation to a safer crossing strategy. The addition of concurrent music to the obstacle negotiation task produced differing adaptations to crossing strategies for the CTRL and PD groups. Specifically, PD patients reduced

obstacle-crossing velocities, stepped closer to the front of the obstacle and consequently adopted a shorter crossing step whilst the control group increased crossing step length and maintained crossing velocities. The findings of this study imply that listening to music may impose an additional attentional load for PD patients. In addition, the results also support the possibility that the adaptations to obstacle crossing patterns observed in concurrent music trials are an accommodation to this attentional load. These findings imply that PD patients may be at greater risk of falling in complex environments that involve obstacle negotiation and auditory distracters.

Chapter 5: General Discussion

Disordered gait is one of the most disabling features of Parkinson's disease (PD), frequently associated with falls (Stolze et al., 2004), loss of functional independence (Murphy & Isaacs, 1982; Wenning et al., 1999) and reduction in quality of life (Lyons, Pahwa, Troster, & Koller, 1997). It is well documented that cueing can be effective in allowing patients to achieve functional gait patterns in both single (del Olmo & Cudeiro, 2005; Freedland et al., 2002; Hausdorff et al., 2007; Howe et al., 2003; McIntosh et al., 1997; Suteerawattananon et al., 2004; Thaut et al., 1996) and dual task (Baker et al., 2007, 2008; Canning, 2005; Morris et al., 1996; Rochester et al., 2004; Rochester et al., 2007) contexts. More specifically, auditory cues can bring about immediate improvements in gait velocity (Howe et al., 2003; McIntosh et al., 1997; Suteerawattananon et al., 2004), stride length (McIntosh et al., 1997), and cadence (Freedland et al., 2002; Howe et al., 2003; McIntosh et al., 1997; Suteerawattananon et al., 2004) in single task situations, and in combination with attentional strategies, can significantly improve dual task gait performance (Baker et al., 2007, 2008). However, auditory cueing could be considered to lack salience and be monotonous, the latter being a trait which may lead to habituation (Cubo et al., 2004) and ultimately a loss of effectiveness or discontinuation of use. In an attempt to address the issues of salience and monotony associated with contemporary auditory cueing strategies, there is a need to identify an alternative therapy that not only provides the necessary temporal stimuli, but is also meaningful to the individual. Given the ability of music to facilitate movement in both healthy (Bernatzky et al., 2004; Copeland & Franks, 1991) and pathological (McIntosh et al., 1996; Thaut et al., 1997, Thaut et al. 1999; Thaut et al., 2007)

populations the experiments presented in this thesis sought to determine the effect of salient music on gait performance amongst patients with PD. This thesis represents the first step towards a long-term goal of developing an alternative therapy that whilst functionally and ecologically relevant is also significant to the individual.

5.1 Effects of Salient Music on Steady State Gait and Dual Tasking

The first experiment presented in this thesis investigated the effect of salient music on single (steady state) and dual task gait performance in both non-neurological and PD patients. My hypothesis for this experiment based on the phenomenon that music can stimulate movement was that concurrent music trials would improve bradykinesia in the PD patients across both single and dual task contexts, as demonstrated by an increase in overall gait speed and stride length and a decrease in the time spent in double limb support (DLS).

In accordance with previous studies (Knutsson, 1972) the gait of PD subjects was found to be bradykinetic when compared to CTRL subjects in the baseline condition (no task, no music). Specifically, the PD group demonstrated a slower gait velocity, decreased stride length and an increased proportion of time spent in DLS. These group differences were maintained across all four testing conditions. Also consistent with earlier research (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; Canning, 2005; Dubost et al., 2006; Hollman et al., 2007; Lajoie et al., 1993; Lindenberger et al., 2000; Lundin-Olsson et al., 1997; Morris et al., 1996; O'Shea et al., 2002; Rochester et al., 2005; Verghese et al., 2007), a decrease in gait performance accompanied dual task trials for both the CTRL and PD subjects when compared to single task situations. I found that the PD group tended towards

articulating more verbalisations and producing a greater percentage of errors than the CTRL group during the dual task. However, interestingly and contrary to my expectations, the dual task decrement in gait was not significantly greater for PD patients than for CTRL subjects. The lack of exacerbated dual task gait performance in the PD group could be indicative that the motor-cognitive task combination was not of sufficient difficulty to impose demands on the attentional capacity or the ability to adequately allocate attentional resources that exceeded those of the CTRL subjects. This would be in agreement with the work of Galletly and Brauer (2005) who found that the dual task decrement demonstrated between PD and CTRL subjects was equivalent when the secondary task was relatively simple. An alternative explanation for the comparable dual task decrement was that PD patients were correctly prioritizing their gait over the accurate completion of the secondary cognitive task; this would contrast the results of previous studies that have indicated that PD patients typically incorrectly prioritize the secondary task (Bloem et al., 2006). This would allow PD patients to maintain a stable, safe gait pattern at the expense of accurately completing the cognitive task. However, it is also plausible that the PD group experienced greater difficulty in completing the cognitive task than the control group due to the impairments in executive function that are associated with PD (Dalrymple-Alford et al., 1994; Rochester et al., 2005; Yogev et al., 2005).

The findings indicated that concurrent salient music produced differential results between the PD and CTRL group. Whilst these results were supportive of the theory that there is direct coupling between the auditory and motor systems, the findings were contrary to my hypothesis. Specifically, in the single task context PD patients

demonstrated a marginal decrease in gait performance when listening to concurrent music, gait alterations that were very similar in nature to those produced by the dual task effect when performing a secondary cognitive task. The detrimental effect of music that was seen in the PD patients was further exacerbated in the dual task context. In contrast, the gait performance of the CTRL subjects remained largely unchanged with concurrent music in the single task condition, with a marginal increase in gait performance observed during the dual task trials with concurrent music. The number of verbalisation articulated by the PD and CTRL groups was unchanged by the presence of concurrent music, however, the number of errors in verbalisations tended to increase for the PD group and decrease for the CTRL group with concurrent music. The fact that my study found an increased detriment in the ongoing performance of both the motor and cognitive tasks for PD patients in the dual task trials with concurrent music was indicative that concurrent salient music could be increasing cognitive demands for the PD patients, which in turn may affect the attentional control of gait. It was interesting that the detrimental effects of concurrent music to gait in the PD group were mainly confined to the measure of double limb support. It is possible that the PD patients were actively accommodating the additional cognitive demand of the concurrent music, increasing stability by reducing the amount of time spent in the unstable single limb support phase of the gait cycle.

The findings presented in this thesis are in contrast to previous studies (McIntosh et al., 1997; Thaut et al., 1996) that found music to be facilitatory to parkinsonian gait. However, previous researchers used original instrumental pieces that had an accentuated beat and had been specifically written to enable the subject to synchronize their stepping

pattern to the tempo of the music (McIntosh et al., 1997; Thaut et al., 1996). The synchronization between cadence and the music tempo resulted in significantly reduced gait variability (Thaut et al., 1996) and increased gait velocity (McIntosh et al., 1997; Thaut et al., 1996). In the experiments presented in this thesis the tempo of the music was not determined prior to testing, the important quality of the music being considered to be the salience to the individual. So, whilst the opportunity existed for subjects to match their cadence to the tempo of the music and this could potentially be the cause of decreases in gait velocity, this was not our intention. Subjects were not instructed to synchronize their walking to the music; they were simply instructed to listen to the music whilst carrying out the single and dual tasks. Music tempos were determined post-testing and the tempo ranges were found to be wide-ranging, however these differences were not significantly different between the two groups. Overall, the results from this experiment provide further evidence for multitasking limitations faced by PD patients (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Morris et al., 1996; O'Shea et al., 2002; Rochester et al., 2004).

5.2 Effects of Salient Music on Obstacle Negotiation

The second experiment presented in this thesis explored both the crossing strategy of the PD group and the effect of concurrent music on obstacle negotiation in both non-neurological and PD subjects. I hypothesised that PD patients would demonstrate characteristics consistent with bradykinetic gait when obstacle crossing. More specifically, I expected that obstacle crossing velocities, obstacle clearance heights and crossing step lengths would be reduced amongst PD patients when compared to CTRL subjects. Based on the findings of Experiment 1, I hypothesised that concurrent music

trials would produce a decrement in spatiotemporal parameters of obstacle negotiation for PD subjects. A decrement would specifically be considered to be a considerable decrease in obstacle crossing velocities, obstacle clearance height, and crossing step length. Any or all of these alterations to obstacle crossing kinematics could be associated with an increased risk of obstacle contact and therefore a more hazardous obstacle crossing strategy (Chen et al., 1991).

Contrary to my hypothesis, but in agreement with previous research investigating obstacle-crossing strategies in neurological populations (Said et al., 2001) the PD group demonstrated an increased crossing step length (as a result of a stepping considerably further from the front of the obstacle) when compared to the CTRL subjects in the no music condition. However, consistent with my hypothesis the PD group crossed the obstacle considerably slower with the lead limb when compared to the CTRL group in the no music condition. It has previously been suggested (Chen et al., 1991; Chou & Draganich, 1998) that increased crossing step height and length is an indication of a 'safer' crossing strategy, as it reduces the risk of contacting the obstacle during crossing. In addition a reduced crossing velocity could also be considered a safety strategy, with the associated reduction in forward momentum reducing the risk of falling in the event of obstacle contact (Chou et al., 2001; Pai & Patton, 1997). Conversely, slower obstacle crossing velocities could be deemed to be 'risky' due to the increased length of time that would be spent in the unstable single limb support phase of the gait cycle. It is possible that the PD patients made a conscious decision to adopt a safer obstacle crossing strategy due to an awareness of the increased difficulty that they may encounter due to gait and attentional limitations (Dalrymple-Alford et al., 1994;

Koller, 1989). A similar explanation was posited by Said and colleagues (2001) who suggested that the increase in clearance height and crossing step length witnessed in hemiplegic stroke patients was a conscious adaptation of a safer strategy in order to compensate for known gait deficits.

The addition of concurrent music to obstacle negotiation trials resulted in differential alterations to obstacle crossing kinematics between the CTRL and PD group. The obstacle crossing kinematics of the CTRL subjects displayed a slight increase in crossing velocities (lead and trail limbs) and placed their trail limb further from the front of the obstacle (resulting in a longer step length) during the concurrent music trials. In contrast, the PD patients further reduced the crossing velocities of the lead and trail limbs, and decreased the crossing step length through stepping closer to the front edge of the obstacle. Crossing step height and the distances between the lead heel and the rear of the obstacle were largely unaffected by the presence of concurrent music in both groups. These alterations to obstacle crossing kinematics amongst PD patients are comparable to those reported in the dual task literature (Chen et al., 1996; Schrodt et al., 2004; Weerdesteyn et al., 2003), where a secondary cognitive task was coupled with obstacle negotiation. This supports the findings reported for the first experiment, and substantiates the possibility that concurrent music imposes an additional cognitive load.

5.3 Implications of Results

The alterations to steady state gait and obstacle negotiation kinematics observed with the addition of concurrent music in the studies presented in this thesis are

comparable to those reported in the dual task literature (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; Chen et al., 1996; Schrodt et al., 2004; Weerdesteyn et al., 2003), in which behaviour changes imparted by a concurrent cognitive task confirm an interplay between cognitive and motor systems. The differential effect of music on motor performance between CTRL and PD subjects substantiates the theory posited by Thaut and colleagues (1997) that music has the ability to evoke movement through the coupling of the motor and auditory systems. Nonetheless, the differential effect of music on motor performance warrants further investigation. One possibility for the explanation of the gait deficits observed for the PD patients in the concurrent music trials is based on our previous suggestion that listening to salient music added to the cognitive load of the patients, effectively acting as an additional task. It is well documented (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; Canning, 2005; Morris et al., 1996; O'Shea et al., 2002; Rochester et al., 2004; Yogev et al., 2005) that individuals suffering from PD are required to assign greater attentional resources to the control of gait when compared to the non-neurological population; in part due to disruption in the automaticity of movement control (Brown & Marsden, 1988; Georgiou et al., 1993). It is considered that the conscious motor control utilised by the PD patients enables the movement to be redirected away from movement pathways through the dysfunctional basal ganglia (Cunnington, Iansek & Bradshaw, 1999), resulting in successful movement execution but diminished residual attentional resources. Therefore, if concurrent music is also imposing a cognitive load, residual attentional resources will be further reduced. This

scenario increases the opportunity for finite attentional capacity to be exceeded, leading to a detriment in one or more of the tasks.

An alternative explanation for the diminished gait performance that was observed in the PD group during the concurrent music trials is the idea that the PD patients were aware of the added cognitive demand that the presence of music presented. Therefore in order to accommodate the added attentional load, PD patients allocate attentional resources towards adopting a more conservative gait pattern (i.e. slower speed, shorter strides, longer duration of DLS). It is often suggested that a more conservative gait pattern could reduce the risk of falling, however, in the parkinsonian population where efficient forward progression is already compromised further decreases in stride amplitude and speed could result in difficulty in successfully negotiating a complex environment (i.e. safely navigate an obstacle), and in the most extreme situation a complete cessation of movement could occur.

A third consideration is that the music selections used in this study were self-selected by the subjects, making it highly probable that selections were made due to an emotional or motivational connection to the song. The outcome of this 'connection' could be an increase in arousal level, which we would expect to be reflected in increased gait speed and stride length as well as a decrease in DLS in the single and dual task situations, or an increase in crossing velocities, obstacle clearance and step length during obstacle negotiation which is contrary to our findings for the PD group. Alternatively, the subject may actively attend to the music, which would cause diminished gait performance in the event of attentional demands exceeding the individuals' resource capacity. Whilst my findings propose support for the second

suggestion this could not be confirmed by the present study. Previous studies controlled for motivational and emotional influences from the music used as a cueing strategy by using the same original instrumental pieces for all subjects (McIntosh et al., 1997; Thaut et al., 1996). It was proposed that the repetitiveness and low complexity of the music reduced the affective arousal imposed by the music (Berlyne, 1971) through redundancy of the perceptual process.

5.4 Therapeutic Implications

Whilst the use of salient music may theoretically be an attractive alternative to traditional auditory cueing techniques due to the simplicity, portability, and salience of the strategy and technology, the findings introduced in this thesis suggest that gait performance is compromised in PD patients when simultaneously listening to salient music. I suggest that listening to music acted as a cognitive distracter for the PD patients with a dual- or triple-task situation being created by the addition of concurrent music. This notion is supported by research investigating music as a distracter during cognitive tasks in the young non-neurological population (Furnham & Strbac, 2002; Parente, 1976). These studies found that cognitive performance was diminished in the presence of concurrent music. My findings have primary implications for PD patients who may enjoy listening to music whilst walking or exercising. They imply that PD patients may be increasingly vulnerable to gait impairments in situations that present complex environments or challenging multitask situations, which require considerable attentional resources to safely navigate or successfully complete, potentially increasing the risk of falls. Therefore, I would suggest that PD patients should use caution when walking in complex environments where auditory distracters may be present.

The results presented suggest the possibility of using in salient music as a secondary task during multi-task training. Multitasking has long been identified as being problematic for PD patients (Bloem, Valkenburg et al., 2001; Bond & Morris, 2000; Camicioli et al., 1998; Canning, 2000; Morris et al., 1996; O'Shea et al., 2002; Rochester et al., 2004; Yogev et al., 2005), and has often been associated with an increased risk of falling (Bloem et al., 2006). Traditionally, clinicians and researchers have suggested that patients should avoid situations that impose a dual or multitask (Bond & Morris, 2000; Morris et al., 1996; Morris, 2000). However, recognition that avoidance strategies can be not only impractical, but potentially also compromise the independence of PD patients has led to the emergence of studies involving multitask training protocols (Bedeschi et al., 2008; Canning et al., 2008; Piemonte et al., 2008). The intention of these training protocols is to improve the ability of PD patients to perform tasks simultaneous to walking, thereby increasing the patients functionality. With the risk of falling that accompanies multitasking in the PD population (Bloem et al., 2006), I suggest that concurrent music would be an ecologically relevant and gentle entry-level secondary task during training.

5.5 Future Research

My finding that listening to concurrent music was detrimental to parkinsonian gait does not negate the need for further research into the possibility of using salient music as a training tool in gait rehabilitation. It is probable that the detrimental effects of music on gait performance demonstrated in the studies presented could result at least in part from the novelty of the music presentation. The study populations had not previously been exposed to the use of a portable music player, nor walking to music. In the case of the

PD patients who must actively attend to their walking even in the simplest of contexts (Woollacott & Shumway-Cook, 2002) the additional attentional load imposed by the novel strategy causes attentional resources to be exceeded, causing a decrease in gait performance. In agreement with the premise of multitask training we would consider that repeated exposure to using a portable music player and music during walking might offset any negative effects that were present in the baseline testing.

The wide tempo range of the music playlists selected by the subjects of the study may have influenced the findings of these studies. The tempos of the music selections were not controlled in the experiments included in this thesis, nor were they matched to the subjects' cadence. My intention in these experiments was not to duplicate the known effect of cadence-tempo synchronization amongst PD patients, but instead to explore the effect of concurrent music on spatiotemporal parameters of gait using music selections that are meaningful to the listener. However, it is more than possible that the tempo range of the music contributed to the gait deficits exhibited by the PD patients. I suggest that gait training with cadence-matched salient music will address the issues of potential sensorimotor coupling whilst retaining the benefits associated with salient music.

5.6 Limitations

Whilst considering the findings of this thesis note should be taken of certain limitations. The first limitation of the studies presented is the small sample size, with a total of 10 subjects in each of the PD and CTRL groups. Whilst the small sample size was considered acceptable due to the investigatory nature of the study, further investigations with a sample size that provides apposite power would be necessary to

substantiate these findings. Additionally, the subjects in the patient group were very homogeneous, they were all non-demented and independently mobile with mild to moderate disease severity, therefore the findings presented in this thesis could not be extrapolated to the wider PD population. Studies incorporating patients of varying severity would allow for the wider application of results.

A second limitation of this thesis is the lack of synchronisation between the data collection and music presentation. This is regrettable, as synchronisation of the data collection and music would have allowed us to address the issue of sensorimotor synchronisation. Previous studies of auditory cueing for gait rehabilitation (Miller et al., 1996; Thaut et al., 1996) have utilised the phenomenon of auditory-motor coupling to improve gait performance through actively increasing cadence and therefore indirectly, gait velocity. It was not my intention to replicate these previous studies; however, it is natural to attempt to synchronise rhythmic body movements to external temporal information (Large, 2000), synchronisation of data collection and music presentation would have allowed the exploration of this possibility.

Music selections were played through portable music players in which audio output was directed through small headset speakers (earbuds). This method of delivery presented specific limitations that cannot be overlooked in this study. Firstly, I did not control for music amplitude, the relationship between music amplitude and motor/cognitive performance has been identified as being highly complex (Turner, Fernandez, & Nelson, 1996). Therefore the lack of standardised music amplitude may have been a confounding variable. It is considered that arousal levels and as a result performance (motor or cognitive) are directly affected by music amplitude, with optimal

motor or cognitive performance occurring at an optimal amplitude (Turner et al., 1996). In addition, in this study the music was presented via a personal music player using earphones, which would focalise the music for the participant, potentially drawing their attention towards the music and reducing the potential distraction of alternative auditory cues in the environment. Therefore, it would not be possible to generalise the findings from this study to situations where the same music was presented 'free-form'. Alternative methods of music presentation with music amplitude controlled as a percentage of the participants comfort level would potentially broaden the application of the results.

A third potential limitation of this study is the lack of a measure of gait variability. The measures selected for each section of the study were based on both previous studies (McKenzie & Brown, 2004; Morris et al., 1996; O'Shea et al., 2002) and the capabilities of the motion analysis system. Gait variability has been identified as a predictor of falls during steady state and dual task gait in both the healthy older adult (van Iersel et al., 2007; Yogev et al., 2007) and PD population (Yogev et al., 2005; Yogev et al., 2007), as such it could be considered to be an important measure to include when attempting to develop a training strategy to improve gait performance. Previous studies that have utilized rhythmic auditory cueing in the form of a simple metronome tone (del Olmo & Cudeiro, 2005; Hausdorff et al., 2007) and instrumental music (Thaut et al., 1996) have demonstrated improvements in gait variability, suggestive that they also reduce the risk of the falls that are so prevalent in the PD population. Though gait performance was reduced in the concurrent music trials for the PD group, it remains possible that gait variability may have been improved.

Finally, the obstacle negotiation study may have benefited from additional data collection on the steps preceding that of obstacle crossing, as it has been found that adaptations to the gait pattern in order to successfully cross the obstacle take place a minimum of one step prior to crossing in the healthy older adult population (Chen et al., 1994). It would be of interest to determine if this strategy differed between non-neurological subjects and PD patients as this could conceivably affect the ability of the individual to safely navigate an unexpected obstacle, which in turn has implications with regards to fall risk.

5.7 Conclusions

The purpose of this thesis was to investigate the effects of concurrent salient music on gait in Parkinson's disease patients. My findings suggest that the novel presentation of concurrent music is detrimental to parkinsonian gait, exacerbating gait impairments inherent to the disease. More specifically, spatiotemporal parameters of gait (gait velocity, stride length, percentage of the gait cycle in double limb support) became increasingly bradykinetic in a single task context with concurrent music. Interestingly, this decrease in gait performance reflected that which is observed in Parkinson's disease patients when asked to perform a cognitive task simultaneous to walking. When music was added to a true dual task context the gait deficits displayed in the single task were further exaggerated. I interpreted these findings to indicate that novel exposure to concurrent music imposes an attentional load for the Parkinson's disease patients. This notion was supported by the results of the second experiment presented in this thesis. During obstacle crossing the presence of concurrent music was accompanied by a decrease in obstacle negotiation kinematics (crossing speed and crossing step length), an

alteration to crossing strategy that resembled that observed in the healthy population during dual task obstacle crossing.

The findings of my thesis support the theory that there is indeed coupling between the auditory and motor systems. In addition they substantiate the literature on multitasking limitations amongst the Parkinson's disease population. Taken in combination my findings imply that listening to music during gait is attentionally demanding for Parkinson's disease patients, and can effectively act as an additional task. With the risk of falling that is associated with multitasking in the Parkinson's disease population this proposal has an implication for safety, suggesting an increased risk of experiencing a fall in complex environments in an already vulnerable population.

However, whilst novel exposure to concurrent salient music has not proven to be facilitatory to parkinsonian gait, we suggest that training with concurrent salient music that has a narrow range of tempos warrants further investigation. Salient music offers an attractive alternative to contemporary auditory cueing strategies in the context of gait rehabilitation, addressing both the need of rhythmic temporal stimuli and salience to the individual. The results presented also suggest a complementary role for concurrent music in multitask training protocols aimed at improving patient functionality.

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