

**ICE SKATING IS SAFE AND SKILLFULLY PRESERVED AMONGST SOME PEOPLE LIVING WITH
PARKINSON'S DISEASE: POSSIBILITY OF NEUROTHERAPEUTIC INTERVENTION**

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Dedication

This thesis is dedicated to my greatest supporters, my family. You have been constant and steadfast through my most trying and triumphant times.

Abstract

Some people living with Parkinson's disease (PLwPD) have been observed to have a preserved ability to ice skate. We examined kinematic parameters of ice skating and the immediately preceding and proceeding walking parameters amongst PLwPD to quantify skating preservation and determine if there are gait improvements. During ice skating trials PLwPD were able to maintain similar step length and velocity as older adult controls (OAC). Immediately walking post skating velocity and double stance support time improved. Locomotion was assessed during doorway crossing, an obstacle that increases motor impairments amongst some PLwPD. Ice skating through a doorway had similar results for both step length and velocity for PLwPD and OAC. Walking through a doorway after skating showed significant improvement to step length. These results quantitatively verify that ice skating is a preserved skill amongst some PLwPD in obstructed and unobstructed conditions, and that ice skating yields immediate improvements to gait parameters.

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List of Abbreviations

B & A Door= before and after door

DSST= double stance support time

OAC= older adult control

PD= Parkinson's disease

PK= paradoxical kinesia

PLwPD= people living with Parkinson's disease

PMC= pre- motor cortex

SMA= supplementary motor area

UPDRS= Unified Parkinson's Disease Rating Scale

1.0. Parkinson's Disease

Parkinson's disease (PD) is the second most common neurodegenerative disease after Alzheimer's, with most cases occurring idiopathically. As a result diagnosis is challenging, often occurring only after 70- 80% dopaminergic neuronal death, thus making treatment highly reactive. Despite advancements in pharmacological treatments, disease progression and symptoms still persist, resulting in individuals experiencing gradually worsening motor and functional impairments. Exercise has been shown effective at reducing motor symptoms but implementation is challenging due to expense and accessibility. *Paradoxical kinesia* (PK), the preserved ability amongst some people living with Parkinson's disease (PLWPD) to perform certain movements, may be a way to circumvent these issues. Performance of PK has been shown to activate alternative cortical structures that are largely preserved, resulting in skillful preservation of tasks. With increased skill, intensity, and frequency there may be biopsychosocial improvements, as based on our current understanding of exercise. The aim of this introduction is to provide theory for the use of PK driven exercise as a neurotherapeutic intervention for PLWPD. The introduction will begin with a brief overview of the neurophysiology underlying PD and the symptoms that are most prevalent. The paper will then proceed to detail the use of exercise in PD, the phenomenon of PK, and the potential for PK as a neurotherapeutic exercise intervention.

1.1. PD characteristics

1.1.1. Basal ganglia function

The basal ganglia is a conglomerate of grey matter structures within the cerebrum that include the striatum, globus pallidus pars externa, globus pallidus pars interna, subthalamic nucleus, and substantia nigra (Obeso et al., 2008). Together the structures of the basal ganglia play roles in motor activation, motor habit formation, and reward- based behaviour (Hikosaka, Nakamura, Sakai, & Nakahara, 2002; Pasupathy & Miller, 2005; Roland, 1984).

There are two basal ganglia pathways that modulate activation of the motor cortex. The indirect pathway generates sequential inhibition of the globus pallidus external then subthalamic nucleus, which in turn disinhibits the globus pallidus internal, whose activity inhibits the thalamus and subsequently the motor cortex (Fig. 1.1). The net effect is decreased motor-activation, giving the characterization of the indirect loop as the 'brake' (Graybiel, 2000). In contrast, when the direct pathway is more active the globus pallidus internal is directly inhibited causing a net excitatory effect on the thalamus. Increased excitatory activation from the thalamus increases excitation of the motor cortex and more motor activity results (Albin, Young, & Penney, 1989; Chevalier & Deniau, 1985; Crossman, 1987; DeLong, 1990). Graybiel (2000) classically characterized the direct pathway as the 'accelerator'.

Dopamine is a neurotransmitter that acts to stimulate the activity of the direct and indirect pathways. The neurochemical is released from the substantia nigra pars compacta in a 'blast' that is received at the D1 and D2 receptors of the striatum. The D1 receptors act to increase excitation of the direct motor pathway and the D2 receptors act to increase inhibition of the indirect pathway. During periods of low dopamine release the indirect pathway is able to continuously apply a 'brake' effect that the direct pathway is unable to supersede (Albin et al., 1989; Chevalier & Deniau, 1985; Crossman, 1987; DeLong, 1990; Grace & Bunney, 1984).

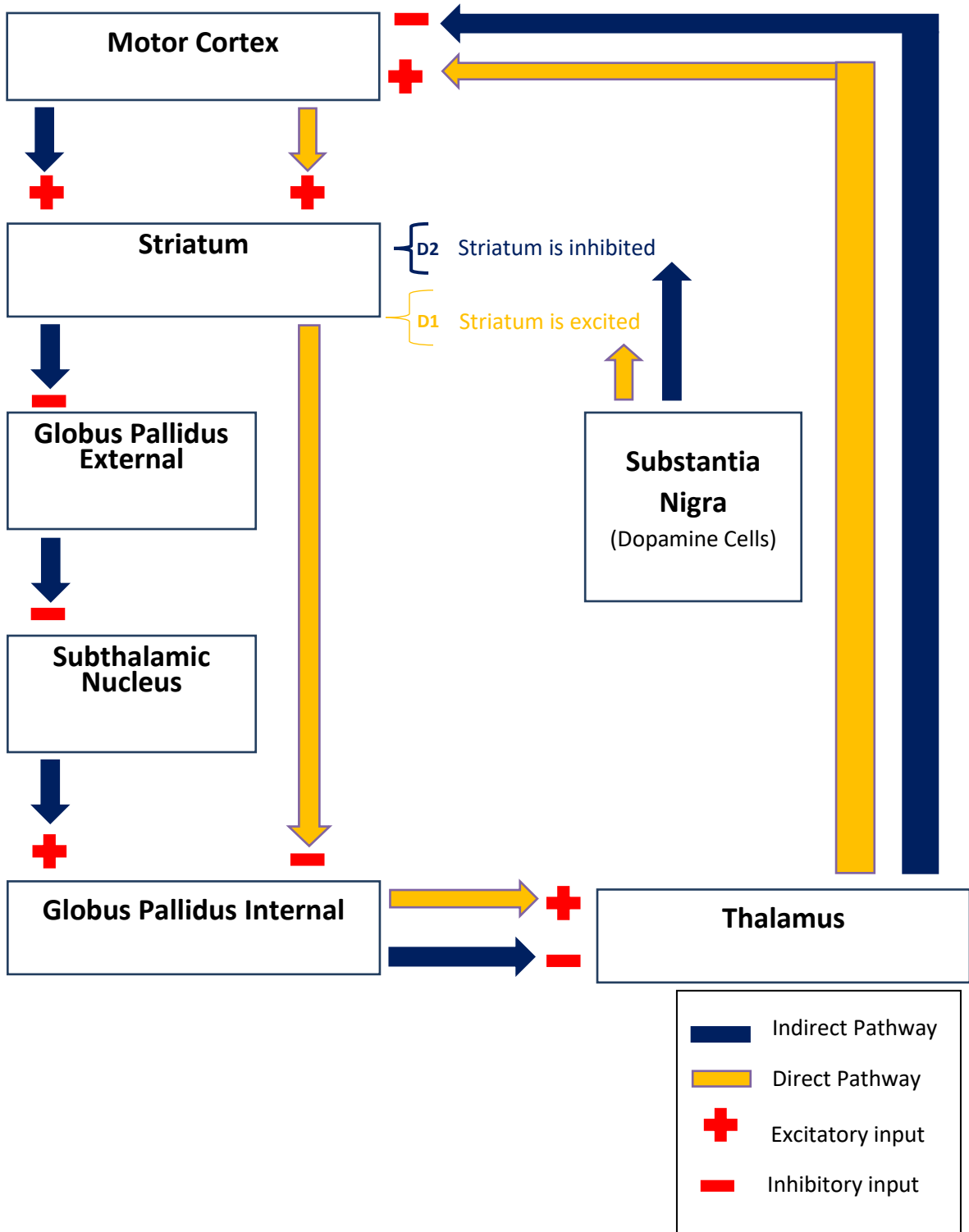


Figure 1.1. Direct and indirect pathway. Direct and indirect pathway activation of the basal ganglia.

1.1.2. PD effects on the basal ganglia

PD is a neurodegenerative disorder that is characterized by the loss of dopamine and dopaminergic receptors in the basal ganglia (Hornykiewicz & Ehringer, 1960). Less available dopamine affects the indirect pathway by lowering the inhibitory signals of the STN, and thereby allowing the globus pallidus internal to over- inhibit the thalamus (Albin et al., 1989; Crossman, 1987; DeLong, 1990). In the direct pathway, low dopamine generates less inhibition on the globus pallidus internal, with subsequent increased inhibition of the thalamus. Both path deficits combine for a weaker excitatory signal transmitted from the thalamus to the motor cortex, resulting in significantly less motor activation (Albin et al., 1989; Bernheimer, Birkmayer, Hornykiewicz, Jellinger, & Seitelberger, 1973; Crossman, 1987; DeLong, 1990). Decreased motor cortex activity leads to the myriad of motor symptoms that characterize PD (Bernheimer et al., 1973; Riederer & Wuketich, 1976). Research is starting to quantify non- motor PD symptoms that PLWPD have long recognized, and current best practices aim to address both motor and non- motor symptoms (Chaudhuri & Naidu, 2008).

1.1.3. Motor symptoms

Decreased motor cortex excitation causes a reduction in motor activation. Because the motor cortex is responsible for voluntary motor actions, a functional decline is evident in motor execution among people living with Parkinson's disease (PLWPD). This decline is clinically categorized through the four cardinal symptoms of rigidity, bradykinesia, postural instability, and resting tremor (Cutson, Laub, & Schenkman, 1995).

1.1.3.1. Rigidity

Rigidity is the state of stiffened muscles causing resistance while moving through a range of motion. Excessive contraction of axial muscles makes daily tasks, like getting out of bed, very

challenging (Shujaat, Soomro, & Khan, 2014). Rotating the head to orient oneself or when making quick muscular adjustments on an unstable surface is more difficult to execute with rigidity (Franzen et al., 2009). The underlying cause of the rigidity is increased activation of antagonist muscles (Carpenter, Allum, Honegger, Adkin, & Bloem, 2004; Dietz, Zijlstra, Prokop, & Berger, 1995). PLWPD may have an increased activation of muscles which are not responsible for the desired action (Berardelli, Sabra, & Hallett, 1983; Dietz et al., 1995). This means that not only are agonist muscles contracting, but muscles which are counter contributive to the motion are contracting as well.

1.1.3.2. Bradykinesia

PLWPD agonist muscles also take longer to effectively contract, and do not produce the same magnitude of contraction as neurotypical individuals (Corcos, Chen, Quinn, McAuley, & Rothwell, 1996; V. Dietz et al., 1995). Voluntary movements then become slower and weaker, which is known as bradykinesia (Phillips, Martin, Bradshaw, & Iansek, 1994). Reaction times slow (Stelmach, Teasdale, Phillips, & Worringham, 1989) and there is an overall decrease in force production (Corcos et al., 1996). Many daily tasks become very challenging to execute (Jankovic, 2008), such as walking at one's desired pace (Ellis et al., 2005) or rising from a chair (Ebersbach et al., 2014). As motions become more challenging performance is decreased resulting in deconditioning of the muscles, which serves to further worsen the contractile issues (Cano-de-la-Cuerda, Pérez-de-Heredia, Miangolarra-Page, Muñoz-Hellín, & Fernández-de-Las-Peñas, 2010; Murphy, Williams, & Gill, 2002).

1.1.3.3. Postural instability

Postural instability in PLWPD is often associated with both rigidity and bradykinesia. The co-activation of agonist and antagonist muscles increase the stiffness of the individual, causing a

slowing of muscular movements (Carpenter et al., 2004). Unexpected perturbations become increasingly harder to respond to, making falls more likely (Carpenter et al., 2004; Wielinski, Erickson-Davis, Wichmann, Walde-Douglas, & Parashos, 2005). Falls increase the risk of injury which potentially decreases an individual's quality of life even further (Wielinski et al., 2005).

Another contributor to postural instability is freezing of gait (Latt, Lord, Morris, & Fung, 2009). Freezing of gait is characterized by a brief block in motor signal production. For example, some PLWPD may have an initial inability to walk forward when that is their intention (Bloem, Hausdorff, Visser, & Giladi, 2004). Temporary immobility leaves the individual susceptible to falls because they are unable to make postural adjustments during the 'frozen' time. Falls from any cause can result in a further fear of falling that may reduce an individual's activity level, increasing deconditioning, and causing a further decline in muscular activity (Murphy et al., 2002).

1.1.3.4. Resting tremor

Resting tremors occur in roughly 75% of all PLWPD (Jankovic, 2008). Occurring at a frequency of 5- 7 Hz (Deuschl et al., 1998), resting tremors can affect the arms, hands, legs, feet , postural muscles, and the facial muscles (Jankovic, 2008). These locations make the tremors very noticeable, and can also make daily tasks challenging to perform (Wasielewski, Burns, & Koller, 1998).

1.1.3.5. Quality of life

Motor symptoms cause an overall decline in the quality of life of PLWPD (Quittenbaum & Grahn, 2004), and decrease their independence (Bloem et al., 2004). Daily tasks become increasingly difficult to execute, and fall- related injuries become more frequent (Earhart & Williams, 2012). Functional tasks such as getting out of bed, rising from a chair (Franchignoni,

Martignoni, Ferriero, & Pasetti, 2005), and even swallowing are filled with challenges (Bushman, Dobmeyer, Leeker, & Perlmutter, 1989). Other motor symptoms that arise in PD, including slurred speech, small handwriting, abnormal posture, and a loss of facial expression can also lead to social withdrawal (Deuschl et al., 1998).

1.1.4. Non motor symptoms

The large psychological impact of PLwPD is not only due to the symptoms brought on by the disease, but also due to poor prognosis. Depression is very common throughout the disease progression (Leentjens, Van den Akker, Metsemakers, Lousberg, & Verhey, 2003), with some individuals becoming increasingly despaired as a result of disease manifested neurochemical changes, and a poor response to prescribed medications (Sawabini & Watts, 2004). This emotional distress can seriously damage their relationships with family and friends and often leads to them withdrawing from their own support network (Sawabini & Watts, 2004). A general sense of apathy also affects many individuals with PD (Pedersen, Larsen, Alves, & Aarsland, 2009), resulting in a loss of interest in daily tasks and in activities they once enjoyed (Calne, Lidstone, & Kumar, 2008). This disinterest can make it very difficult to reciprocate in relationships, which puts a large strain on families and marriages. PLwPD struggle with sympathizing, which makes it challenging for them to react appropriately to the plights and successes of those around them (Pluck & Brown, 2002).

Eventually dementia will transpire in many PLwPD (Hely, Reid, Adena, Halliday, & Morris, 2008). Dementia first presents as a general forgetfulness and progresses to an extensive loss of reasoning, memory, personality changes, and ultimately overall mental decline (Oh et al., 2015). In advanced stages, around the clock care may be required and there are rare moments of lucidity (Hughes, Jolley, Jordan, & Sampson, 2007). Inevitably death is the result, with dementia

being one of the associated causes of mortality in PLwPD (Lethbridge, Johnston, & Turnbull, 2013).

1.1.5. Affected population

In the developed world PD prevalence is currently estimated at 1- 2% of the population over the age of 65 years old (van den Eeden, 2003), with the average age of diagnosis being 64.3 years (Mehanna, Moore, Hou, Sarwar, & Lai, 2014). It is important to recognize that a range of ages can be affected by PD. An epidemiological study found that 11% of the patients were under 49 years old (Mehanna et al., 2014). This results in a substantial portion of the PD population, namely young onset, presenting with a unique set of needs when compared to those in the 'typical' age group (Schrag, Hovris, Morley, Quinn, & Jahanshahi, 2003). Young onset patients (diagnosed under the age of 49) have a relatively long life expectancy and the disease progresses at a much slower rate. On average they can expect to live 32 years post diagnosis (Mehanna et al., 2014) and after 8 years have one- third the clinical decline, according to the Unified Parkinson's Disease Rating Scale, as their late onset (diagnosed over 65 years) counterparts (Jankovic & Kapadia, 2001).

Unfortunately, the most prescribed medication, levodopa, induces severe motor side effects (Ahlskog & Muentner, 2001; Kostic, Przedborski, Flaster, & Sternic, 1991; Obeso, Olanow, & Nutt, 2000). After 4- 6 years of treatment with the drug levodopa, one third of PLwPD will develop dyskinesia and 40% experience motor fluctuations (Ahlskog & Muentner, 2001). Incidences increase after 9 years of use, with nearly 90% developing dyskinesia and 70% being affected by motor fluctuations (Ahlskog & Muentner, 2001). In the young onset population, medication induced side effects occur much sooner (Kostic et al., 1991). After 3rd and 5th year

follow-ups post prescription of levodopa, young onset PLWPD present with significantly more motor fluctuations and side effects due to levodopa therapy (Kostic et al., 1991).

Beyond motor fluctuations and disease severity, individuals with young onset PD also express higher rates of depression than their late onset counterparts (Kostic et al., 1989; Schrag et al., 2003). One study found that 36% of individuals diagnosed before the age of 50 suffered from major depression, whereas only 16% diagnosed after age 50 had major depression (Kostic et al., 1989). While both of these numbers are staggering, young onset individuals are significantly more affected and feel even greater repercussions in their perceived quality of life (Schrag et al., 2003). Young onset PLWPD feel their quality of life is much lower than late onset PLWPD, with the young on- set reporting troubles maintaining marital success, troubles coping, and a strong sense of stigmatization (Schrag et al., 2003).

Effective and efficient interventions are a necessity during the diagnosis of all ages but are especially important in the young onset group because of these additional compounding issues. Efficiency, however, is very challenging as PD has no definitive diagnostic process. Currently there are no neuroimaging, neuropsychological, or biomarker tests clinically validated to determine if an individual has the disease (Hughes, Daniel, Kilford, & Lees, 1992; Tolosa, Wenning, & Poewe, 2006). Diagnosis takes years to determine, and estimates vary from 40% to over 80% dopaminergic depletion before clinically identifiable motor symptoms are present (Bezard et al., 2001; Vingerhoets et al., 1994). This means that a patient's dopamine stores have been depleting for years before they are given any intervention.

Therapies that can be implemented early or even prior to diagnosis and with decreased ramifications are necessary, with one such therapy being exercise. Physical activity has been shown to be effective at improving bio- psychosocial health (Cotman & Berchtold, 2002;

Cotman, Berchtold, & Christie, 2007; Fletcher et al., 1996; Kaufman et al., 2014; Warburton, Nicol, & Bredin, 2006).

1.2. Introduction to exercise

Exercise is purposeful, repetitive and structured physical exertion with the intention of physical fitness (Caspersen, Powell, & Christenson, 1985). Following sustained repetition of regular exercise, individuals may experience improvements in endurance (Smith et al., 2001), strength (Taaffe, Duret, Wheeler, & Marcus, 1999), balance (Barnett, Smith, Lord, Williams, & Baumand, 2003), range of motion (Yuktasir & Kaya, 2009), and coordination (Barnett et al., 2003). Exercise programs may make performing tasks of daily living easier (Sato, Kaneda, Wakabayashi, & Nomura, 2007), and less fatiguing (Singh, Clements, & Fiatarone, 1997). Secondary health benefits resulting from exercise include a decrease in the relative risks of cardiovascular disease (Blair et al., 1989), diabetes mellitus (Helmrich, Ragland, Leung, & Paffenbarger Jr., 1991), cancer (Thune & Furberg, 2001), and premature death (Blair et al., 1989).

Exercise has also been shown to be advantageous for brain health (Colcombe et al., 2006; Kramer et al., 1999). This has been observed following implementation of aerobic walking programs amongst sedentary neurologically intact individuals. After six months of training, exercisers cardiorespiratory fitness improved, and their executive function was significantly enhanced (Kramer et al., 1999). Increasing the intensity of aerobic exercise over a similar timeframe has also been shown to increase the volume of grey and white matter in the prefrontal and temporal cortices (Colcombe et al., 2006), with greater attentional control (Colcombe et al., 2004) and increased synaptic connections and hippocampal volume amongst the neurotypical population (Erickson et al., 2011).

1.2.1. Exercise among PLWPD

The many benefits of exercise are well known for neurotypically intact individuals, but less so for PLWPD. The motor symptoms that develop as a result of the disease, discussed in section 1.1.3., often lead individuals to reduce their physical activity in addition to some patients having reported being discouraged to participate or were uninformed about physical activity benefits from their physician (Canning, Alison, Allen, & Groeller, 1997; Franchignoni et al., 2005; Murphy et al., 2002; Ravenek & Schneider, 2009). Exercise can be an important positive contributor to PLWPD's overall well-being, and directed investigation has found that exercise can be performed with similar capacity by PLWPD (Canning et al., 1997). Implementing vigorous exercise programs may be effective at enhancing general health, plus improving motor and non motor symptoms for many PLWPD.

1.2.1.1. Gait training

Dysfunctional gait is a prevalent characteristic of PD. PLWPD commonly display a shortened stride length, prolonged double stance support time, slowed gait velocity, freezing, shuffling, and difficulties initiating movement (Morris, Iansek, Matyas, & Summers, 1994b). Many researchers have focused on addressing these issues, most commonly with gait training on a treadmill. To illustrate short term benefits, one study applied a single 30 minute gait training session and found immediate increases in both self-selected walking speed and stride length (Pohl, Rockstroh, Rückriem, Mrass, & Mehrholz, 2003). In addition, there was also a decrease in double stance support time during the gait cycle. These changes decrease hesitation of movement, providing a more normalized gait pattern (Pohl et al., 2003).

Exercise dose response and duration of effectiveness has also been examined in longer term gait training interventions. Protas et al (2005) used an eight-week intervention comprised of two training sessions per week. Upon conclusion of the 8 weeks, participants demonstrated

stride length, gait speed, and dynamic balance improvements (Protas et al., 2005). Herman et al., (2007) furthered the work on training programs by using adjusting pace, as well as assessing individuals at four weeks post intervention. The program consisted of a 30 minute treadmill walking sessions four times a week for six weeks. Each week the speed was readjusted based on the subject's re- evaluated self- selected over- ground walking speed. This increasing intensity allowed for progression and a more natural pace selection based on the current participant's condition. As a result, immediately post intervention subjects displayed an increased gait speed and stride length, as well as improvements in their overall motor score as determined by the Unified Parkinson's Disease Rating Scale (UPDRS) section 3. Four weeks later these improvements had a slight wane but remained significantly improved over baseline values (Herman, Giladi, Gruendlinger, & Hausdorff, 2007).

Variable speed treadmill training programs have also been used as a PD intervention. Cakit et al., (2007) delivered an eight week graded speed program that had subjects progressively increasing gait speed throughout each training session. This afforded the individual the opportunity to push their boundaries and walk at their peak safe pace. Upon concluding the program it was found that participants increased their attainable gait speed as well as their dynamic balance (Cakit, Saracoglu, Genc, Erdem, & Inan, 2007), a key component of gait and another affected motor symptom of PD (Morris, Martin, & Schenkman, 2010).

1.2.1.2. Balance training

PLwPD have impaired postural control, leading to a marked increase in falls and a decrease in independence compared to neurotypical older adult controls (Ashburn, Stack, Pickering, & Ward, 2001; Vaugoyeau, Viel, Assaiante, Amblard, & Azulay, 2007). Regular balancing exercises may strengthen the postural control system, enhance stability, and decrease

falls. Smania et al., (2010), sought to determine which of the traditional methods typically employed was most effective at improving postural stability among PLWPD. Their study had three experimental groups where each group was given a different type of balance training. The first group performed repetitions of balance compromising daily tasks, such as transfers, the second group executed modified balance equilibrium stability score test activities, and the third group practiced walking on an obstacle course. The control group performed a stretching and joint mobilization regime. The groups were tested both immediately after and at one month post- training. Testing consisted of both dynamic and static postural stability, as well as perceived fear of falling. All experimental groups had a significant improvement in these categories at both time points tested, and the control group had no change at either (Smania et al., 2010).

In an attempt to elicit more robust balance gains, a combination of resistance training in conjunction with balance training has been used. Hirsch et al., (2003) used a similar balance protocol as Smania et al (2010), where all participant groups performed a series of balance error scoring system modified exercises, such as standing on foam or maintain balance during perturbations. In addition, one group also took part in high- intensity resistance strength training that specifically targeted muscles known to be important in the control of balance, namely the knee extensors and flexors, and ankle plantarflexors. At the end of the designated programs both groups had an improvement in balance scores but the individuals that also took part in resistance training had a greater enhancement in balance, along with improved strength (Hirsch, Toole, Maitland, & Rider, 2003).

Similar results were also found in another study that had one group perform movement strategy training focused on attention and cue adherence, and the other cohort take part in resistance training. At conclusion of the intervention both groups had increased speed during 10

meter walk and two minute walk, and improved balance and quality of life score, but after three months only the resistance trained group retained benefits (Morris, Iansek, & Kirkwood, 2009).

Resistance training is also helpful for improving muscular weakness and general disease outcome measures (Corcos et al., 1996). This was seen after a 12 week intervention of strength training where PLWPD experienced an improvement in their behavioural and motor symptoms, as scored in the UPDRS. Participants also experienced improvements in functional capacity, balance, and cortical activation as associated to EEG mean frequency (Carvalho et al., 2015).

Exercise is not only able to be performed by PLWPD but can be performed through conventional implementation. Also, when a regime is followed there are numerous benefits that improve general health and well-being of PLWPD. In addition, motor and non-motor symptoms that hinder function and quality of life have been shown to improve through the use of exercise.

1.2.2. Issues with exercise classes among PLWPD

PLWPD can obtain great benefits by adding exercise into their daily regime, but active participation has numerous issues. Exercise programs require large commitments of time, with many researched programs that have shown functional improvements requiring individuals to participate in 60- 90 minute sessions two- four times per week for 12- 48 weeks (Ayan, Cancela, Gutierrez-Santiago, & Prieto, 2014; Carvalho et al., 2015; Combs et al., 2013; Dibble et al., 2006; Gusi et al., 2012; Kara, Genc, Colakoglu, & Cakmur, 2012; Park et al., 2014; Paul, Canning, Song, Fung, & Sherrington, 2014). This is not only a substantial time commitment but it may also require professional supervision and specialized equipment, forcing the exercise session outside the home. In addition to the time needed to complete the exercise, the time spent commuting to the designated facility needs to be factored in as well. This makes participation unattainable for many rural patients because specialized programs are typically only held in large centers that

may be hours from their homes. If the prospective participant is not retired, work obligations may provide an additional barrier to participation. Specialized programs are also expensive to operate. The instructor implementing the program needs to be educated about this population, thus making their time expensive. Exercise facilities can also be costly whether they are for exercise interventions or conventional drop-in facilities.

Adherence is another issue (Woodard & Berry, 2001). Isolated exercises, like treadmill walking, can be perceived as boring and non-social (Morenilla et al., 2013), and social interaction is one of the main factors encouraging people to regularly participate in fitness classes (Ryan, Fredrick, Lepas, Rubio, & Sheldon, 1997). Breaking an activity down into isolated components diminishes the accomplishment, which can also reduce regular participation (Dishman & Buckworth, 2007).

Complex sport and recreational activities that incorporate a multitude of skills, that can be done within the community, and that can be performed amongst peers would seem to address some of the barriers to structured exercise. Executing complex motor skills may be challenging, as established in section 1.1, as PLWPD face a wide range of symptoms that may hinder their performance in many functional movements. Some case studies and current research, however, has shown that some PLWPD have preserved ability to execute complex motor actions, which may create a possibility for alternative exercise interventions.

1.3. Paradoxical kinesia

1.3.1. Preserved function

Despite the motor symptoms that PLWPD experience, some patients have situational enhancements in motor function (Glickstein & Stein, 1991). This phenomenon is known as *paradoxical kinesia* (PK), a persistent capacity to skillfully perform some actions contradictory to the typical parkinsonsonian state. Souques (1921) was the first to record observations of this astounding occurrence, where he described three case study examples. The first was an individual affected by PD for 10 years, with difficulties walking, notably feeling 'as if their feet were stuck to the ground'. Occasionally, however, the person was observed as able to run and even jump over obstacles. The second person's motor symptoms had progressed to the extent of making him largely non- ambulatory, and requiring assistance for any sort of locomotion. There were, however, times he was able to run from his chair to his bed. The third patient in Souques (1921) case studies had been affected by PD for over 20 years, and usually required two aides when walking. Many times the individual was unable to raise his feet, but when asked to climb stairs he was able to 'bound' up them.

Similar cases have since been described, with particularly vibrant examples occurring in life threatening situations. During missile attacks in Israel, a rehabilitation hospital came under threat and required immediate evacuation (Schlesinger, Erikh, & Yarnitsky, 2007). Faced with dire consequences, a bed- ridden patient in advanced stages of PD experienced an episode of PK where he was able to run to safety and assist his wife in her escape as well. In Italy, an earthquake struck an area that had a large cohort of PLWPD in residence (Bonanni et al., 2010). As the danger rose, the bed- ridden and ambulation- impaired inhabitants were able run to safety. Some of these individuals were required to descend from four story buildings when the danger hit, yet they were able to execute motor actions in a timely and sustained fashion.

Many other anecdotal cases have been recorded, spanning from saving children from runaway horses to escaping fires (Glickstein & Stein, 1991). In all of these threatening but stimulating events, the PLWPD were able to perform motor functions at rates and amplitudes they were typically unable to achieve, only to return to a parkinsonian state shortly after the removal of the arousing stimulus.

The opposite of these positive effects can also occur. When some PLWPD, at some stage of the disorder, are presented with visual stimulation of an event requiring specific motor control, the person may freeze (Cowie, Limousin, Peters, & Day, 2010). One of the most common situations PLWPD experience freezing is when approaching a doorway (Cowie et al., 2010). After walking a distance without interruption, some PLWPD approaching a door experience a temporary but powerful block in their ability move (Rahman, Griffin, Quinn, & Jahanshahi, 2008), becoming frozen to the spot. Similar occurrences have also been seen when changing direction or crossing an obstacle (Brown, de Bruin, Doan, Suchowersky, & Hu, 2010; Rahman et al., 2008). The resulting freezing can be particularly debilitating, because it can expose the individual to personal distress, unwanted attention, even physical injury. For example, when on an unstable surface, being unable to move hinders PLWPD ability to make postural adjustments, increasing their risk of falling. Similarly, if they were to be crossing a street and experience an episode, they may be struck by oncoming traffic (Rahman et al., 2008).

1.3.2. Possible mechanisms for PK

The basal ganglia are involved in the motor activation of well-learned actions. This is accomplished through specialized groupings of neural networks that increase in activation through repetition of sequential movements (Graybiel, Aosaki, Flaherty & Kimura, 1994). The basal ganglia then relay this information to the supplementary motor area (SMA) (Roland,

Larsen, Lassen, & Skinhøj, 1980), which is then responsible for phasic modulation of these motor actions, based on internal cueing (Brotchie, Iansek, & Horne, 1991; Jahanshahi et al., 1995; Mushiake, Inase, & Tanji, 1991). In PD, there is a decreased activation of the basal ganglia- SMA pathway, or internal motor pathway, and this deficit has been postulated to be the underlying factor in hypokinetic movement (Hanakawa, Fukuyama, Katsumi, Honda, & Shibasaki, 1999; Samuel et al., 1997). Since there is less subcortical and cortical activity, the movements are smaller, causing shortened stride length and shuffling gait.

Drawing attentional focus to stimulating features of the external environment may result in a shift from the internally stimulated basal ganglia- SMA pathway to alternative cortical structures for movement initiation and progressive control (Morris, Iansek, Matyas, & Summers, 1996; van der Hoorn, Renken, Leenders, & de Jong, 2014). Imaging studies have verified an altered cortical activation, being increased activation of the external motor pathway during externally cued walking amongst PLWPD (Hanakawa et al., 1999; Samuel et al., 1997). The paradigm used to capture this information was based off the landmark study by Martin (1967), which incorporated the use of white line markings on an experimental gait pathway. Individuals were asked to walk over transverse lines that were positioned parallel or perpendicular to the walking direction, with the resultant effect of PLWPD having improved stride length and cadence with the perpendicular lines (Martin, 1967). Hanakawa et al., (1999) used the same procedure, but performed testing on a treadmill. By using contrasting injections prior to the walking task, post- activity single- photon emission computed tomography scans were able to show a cortical difference between parallel and perpendicular line walking. In both PLWPD and neurotypical individuals, perpendicular lines caused increased cortical activation of the posterior parietal cortex and cerebellum. In addition, PLWPD had increased activation of the pre- motor cortex (PMC), which was not observed in neurotypical individuals.

The PMC makes up half of the non- primary motor cortex. The other half of the non-primary motor cortex is the SMA (Mushiake et al., 1991). These two structures send projections to the primary motor cortex to modulate motor actions. The activation these structures exhibit, however, are largely different because the PMC and SMA receive very different inputs (Matelli, Luppino, Fogassi, & Rizzolatti, 1989). The PMC plays a large role in visually guided motor tasks (Mushiake et al., 1991). When visual cueing is presented, the PMC has increased activation. When habitual motor sequences are required, with significantly less external cueing driving the action, the SMA has increased activation (Mushiake et al., 1991). Since the SMA has decreased activation resulting from the basal ganglia deficit, PLWPD have trouble relying on internal cueing. As a result, they rely more heavily on those cues available in the environment. PK is therefore believed to be made possible by the increased activation of the PMC in the external motor pathway. In situations where highly arousing external cueing is available, the preserved cortical structures can be utilized to execute successful motor performance.

1.3.3. Negative mechanisms for movement

Hindered motor performance, shortened stride length and decreased velocity, is typically the result of decreased external information from a narrowing of the optic field (Kompoliti, Goetz, Leurgans, Morrissey, & Siegel, 2000), such as when approaching a doorway (Cowie, Limousin, Peters, Hariz, & Day, 2012; van den Heuvel et al., 2014; van der Hoorn, Beudel, & De Jong, 2010). Decreased availability of visual cueing creates an increased reliance on internally based cues. Internally based cues depend upon activation of the SMA, which has decreased activation capacity in PD (Samuel et al., 1997; van der Hoorn et al., 2014). Motor blocks typically occur amongst more severe cases of PD, with presumably even greater impairment of the SMA and insufficient control from alternative compensatory pathways (van der Hoorn et al., 2014).

1.3.4. Psychological and emotional factors for movement

The psychology of external visual stimulation may also play a role in PK (Naugle, Hass, Bowers, & Janelle, 2012). In the anecdotally observed cases of PK, as described previously, many individuals respond when aroused by a threatening context (Glickstein & Stein, 1991; Schlesinger et al., 2007). Threatening visual stimuli in healthy individuals has been shown to alter body movements. Naugle et al. (2012) tested if this held true for PLWPD, and showed that threatening or happy visual stimulation both improved motor performance, including faster motor response time when initiating gait. Response time and movement amplitude for gait were improved during happiness inducing pictures, like a baby or child (Naugle et al., 2012). Visual scenes of dismemberment and contamination caused a decline in motor performance (Naugle et al., 2012). Strong negative images that are not associated with the flight or fight response appear to hinder motor performance. Anxiety inducement has shown like results. When PLWPD are placed in a scenario of increased threat and anxiety freezing of gait is more likely to occur (Delval et al., 2010; Ehgoetz Martens, Ellard, & Almeida, 2014). Emotional state affects all populations motor performance, but PLWPD seem to have increased sensitivity.

1.3.5. Clinical application

Translating PK past the phenomenological stage, and harnessing this amazing ability for purposeful action has been the focus of recent research. Case study reports first started by exposing individuals to sports that they previously enjoyed to see if they still retained function to perform them. In the Netherlands, a 58 year old man who was diagnosed with PD 10 years previously, was unable to walk without shuffling and falling. After being assisted onto a bicycle he was able to pedal, steer and negotiate in his surroundings (Snijders & Bloem, 2010). A 68 year old man with PD, who was affected by freezing of gait and poor mobility, had a history of soccer

participation. When presented with a ball on a string and told to dribble the ball like in soccer, he was able to perform complex foot adjustments and move forward with great ability (Asmus, Huber, Gasser, & Schöls, 2009). In the less formalized setting of the Oprah Winfrey show the actor Michael J Fox, who has been diagnosed with PD, displayed a remarkably preserved ability to ice skate. In this video he was not only able to ice skate, but also perform crossovers and changes of directions, both complex motor skills (Terry, 2009). Further preliminary validation has since been performed, indicating the persistence of ice skating amongst other PLwPD (Bartoshyk et al., 2014; Doan, de Bruin, Bartoshyk, & Brown, 2012).

Discovery of preserved purposeful sporting skills has since prompted implementation of more structured protocols and investigation. Irish set dancing, over 6 months, and Argentinian tango, over 13 weeks, have both been applied with great success, yielding positive changes to balance, freezing of gait, and motor disability (Hackney, Kantorovich, Levin, & Earhart, 2007; Volpe, Signorini, Marchetto, Lynch, & Morris, 2013). Boxing has been utilized over a 12 week intervention, resulting in improvements in balance confidence, gait, motor initiation, and perceived quality of life (Combs et al., 2013). Bicycling has been tested with an alternative approach of not only performing the task but doing so at a forced cadence. By increasing the intensity of the exercise, participants not only showed positive motor symptom changes, but also prolonged cortical activation improvements in the basal ganglia and the SMA (Alberts, Linder, Penko, Lowe, & Phillips, 2011; Ridgel, Vitek, & Alberts, 2009), impaired areas in PD as discussed in sections 1.3.3. and 1.3.4.

Implementing sporting skills therefore not only improves functional motor outcomes, but appears to have a neuroprotective or possibly a neurorestorative effect. Further investigation into sporting skills that may be able to affect these changes is of importance of not only improving quality of life, but potentially stalling or reverting disease motor symptoms. Ice

skating presents an intriguing model for exercise in this population as not only is it popular among northern nations, especially in rural areas that may be isolated from many services and amenities, but also because it is highly balance challenging (Hrysomallis, 2011; Lamothe & van Heuvelen, 2012; Roullet, Adjizian, Lefebvre, & Lapierre, 2014; van Saase, Noteboom, & Vandenbroucke, 1990). As discussed in section 1.1.3. many PLWPD suffer from stability issues that transpire into gait impairments and even falls (Kara et al., 2012; Protas et al., 2005). However, if individuals are able to maintain stability while ice skating and perform the physical activity, this may transpire into prolonged improvements in motor function, specifically gait. This work would then validate ice skating to be used as a neurotherapeutic intervention for PLWPD.

1.4. Summary

In summary:

1.4.1. Dopaminergic depletion results in PD, causing an increase in inhibition of motor pathways resulting in a hypokinetic system. Increased inhibition is seen symptomatically as motor and non- motor deficits.

1.4.2. Exercise has been shown to improve motor function and quality of life in PLWPD, but implementation is challenging. Programs are often expensive, difficult to access, and have low social interaction causing decreased adherence.

1.4.3. Some PLWPD have a preserved ability to execute motor functions skillfully and quickly, and these actions might provide a highly effective paradigm for therapy. Not only might this circumvent the problems faced with traditional exercise programs, but sport performance has been shown to yield a latent improvement on motor symptoms with increased cortical activation of effected neurological structures.

1.5. Outline of thesis

Based on the information presented in this literature review a theory of paradoxical kinesia, the preservation of motor function from activation of the more preserved external motor pathway triggered by external cues, has been established. The remainder of this thesis will be investigating this theory as it applies to ice skating to kinematically validate the preservation of motor function and latent improvements that result from performance. This knowledge will help establish ice skating as a neurotherapeutic intervention

Application of this theory has led to two testable hypotheses:

1.5.1. PLWPD who have previous skill at ice skating have a preserved ability to ice skate safely and skillfully.

1.5.2. Immediately after one session of ice skating PLWPD will have improved gait function during unobstructed and obstructed walking.

The remainder of this thesis will be divided into two experimental chapters that test the above hypotheses, and a final general discussion chapter. Each experimental section will test a hypothesis and be formatted as stand-alone manuscripts, and the general discussion will look at underlying theory, implications of this work, and future directions that should be investigated.

The experimental sections are as follows:

Section 2.0

A kinematic comparison of PLWPD and older adult controls (OAC) walking and ice skating, plus a comparison of the immediate effects of skating on walking kinematics.

Section 3.0

A kinematic comparison of PLWPD and OAC ice skating in unobstructed and obstructed contexts, where the obstruction was a typically sized North American door. Comparison of walking parameters during unobstructed and obstructed trials immediately before and after ice skating to determine latent motor improvements.

2.0. Ice skating is safe, skillfully preserved, and has immediate improvements on walking parameters amongst people living with Parkinson's disease

2.1. Introduction

Locomotion is a complex task that requires the coordination of multiple neuromechanical systems (Hausdorff, Yogeve, Springer, Simon, & Giladi, 2005). Parkinson's disease (PD), the second most common neurodegenerative disorder (Paisan- Ruiz et al., 2004), affects patients' ability to execute locomotion, including gait (Canning et al., 2006). As the disease progresses, stride length and cadence become more variable, gait speed is slowed, and arm swing amplitude is reduced (Hausdorff et al., 2003; Hausdorff, Cudkowicz, Firtion, Wei, & Goldberger, 1998; Morris, Iansek, Matyas, & Summers, 1994a, 1994b, 1996). Together these changes create a shuffle-like gait that can increase the risk of falls, and decrease the efficiency of motion and the ability to negotiate changes in the environment (Blin, Ferrandez, & Serratrice, 1990; Cowie et al., 2010; Robinson et al., 2005; Schaafsma et al., 2003; Wood, Bilclough, Bowron, & Walker, 2002). These fundamental motor impairments also present major challenges to meeting physical activity recommendations (Ellis et al., 2013), maintaining independence (Ellis et al., 2005), and performing activities of daily living (Knipe, Wickremaratchi, Wyatt-Haines, Morris, & Ben-Shlomo, 2011) amongst some people living with Parkinson's disease (PLWPD).

Despite these impairments some PLWPD have a paradoxically preserved ability to perform certain complex motor skills. Snijders & Bloem (2010) presented the case of a 58 year old man diagnosed with PD for 10 years and suffering from severe freezing of gait. When assisted onto a bicycle, this patient was able to pedal, steer, and cycle on his own. A similar finding was documented for a man, diagnosed with PD, who had frequent freezing during walking (Asmus et al., 2009). When provided with a tennis ball strung from his wrist and hanging

to the floor the patient was able to walk and kick with great ability. These fascinating cases build on early clinical evidence of *paradoxical kinesia* (Souques, 1921), and may provide a useful foundation for vigorous exercise as both neuroprotective and neurorestorative intervention amongst PLwPD (Lau, Patki, & Das-Panja, 2011; Tajiri et al., 2010). Specifically, *paradoxical kinesias* as persistently skillful specific motor behaviors amongst mild to later stage PD that could be an attractive exercise modality (Palfreman, 2015). Alberts et al., (2011) have shown that using a tandem bicycle to force accelerated cadence resulted in increased grip magnitude and rate, as well as increased activity in critical neural structures, specifically the putamen, globus pallidus, thalamus, primary motor cortex, and supplementary motor area, amongst mid- to- moderate PLwPD. In a study of boxing training (Combs et al., 2013), freely ambulatory PLwPD performed between 24 and 36 sessions of a combination program including aerobic, range of motion, stretching, and circuit boxing skills. At the end of the 12 week boxing intervention, participants demonstrated significantly improved gait velocity, dynamic balance, clinical performance, and perceived quality of life (Combs et al., 2013). Taken together, these studies suggest that *paradoxical kinesia* may present a viable entry point for exercise interventions to improve motor deficits and general outcome measures amongst PLwPD.

Ice skating has also been identified as a *paradoxical kinesia* amongst some PLwPD (Bartoszyk, de Bruin, Brown, & Doan, 2015; Doan et al., 2012; Palfreman, 2015), and could be a highly viable exercise intervention. Beyond its paradoxical potential amongst some PLwPD, skating is readily available and popular in northern locations (Sim, Simonet, Melton, & Lehn, 1987; Tammelin, Nayha, Hills, & Jarvelin, 2003; van Saase et al., 1990; Wiley et al., 2016), and it provides a great opportunity for socialization (Reid & Reid, 2016) at relatively low cost (Kitchen & Chowhan, 2016), with both aerobic and anaerobic health benefits (Roczniok et al., 2016). Ice skating also seems to specifically challenge many motor deficits that affect PLwPD, namely

balance, rhythmic striding, and coordinated arm swing. With growing patient interest in early and vigorous exercise neurotherapy, it is important to scientifically study *paradoxical kinesias* for PLWPD, so evidence- based exercise interventions that capitalize on these convenient entry points can be developed and tested (Palfreman, 2015). The purpose of this study was to examine the kinematics of ice skating amongst PLWPD. We predicted that people living with mild to moderate PD who have previously and regularly ice skated would be able to skate safely and skillfully. Confirmation of these predictions could set up ice skating as an attractive and available exercise neurotherapy for PLWPD in northern locations.

2.2. Methods

2.2.1. Subjects

Participants living with PD (2 female, 17 male; Mean age: 56.6 years; SD: 13.5 years) were recruited through convenience sample. Electronic invitations were sent to regional Parkinson Canada support groups and previous research participants that had consented to future direct contact in Lethbridge, Red Deer, Kelowna, Saskatoon, Vernon, Ottawa, and Vancouver. All PD participants had been diagnosed by a neurologist, and had an average diagnosed disease duration of 5.3 years (SD: 3.1 years) and an average Hoehn and Yahr (Hoehn & Yahr, 1967) score of 1.0 (SD: 0.64). At the time of the testing subjects self-reported being in the 'on' phase of their medication cycle, and participants maintained scheduled drug treatment during testing. Older adult controls (OAC) (1 female, 13 male; Mean age: 57.9 years; SD: 12.2 years) were recruited through convenience sample, namely by electronic invitation plus oral invitation provided to local seniors' fitness class.

During recruitment all participants were informed that a portion of testing was to take place on ice and in skates. No specific level of ice skating expertise was required, but it was suggested that participants be competent at basic skating skills. All participants skated in their own ice skates or a pair of ice skates gifted by the researchers if they did not own their own skates, and all participants wore a Canadian Safety Association approved helmet while on the ice. The study was also approved by the University of Lethbridge's Human Subjects' Research Ethics review.

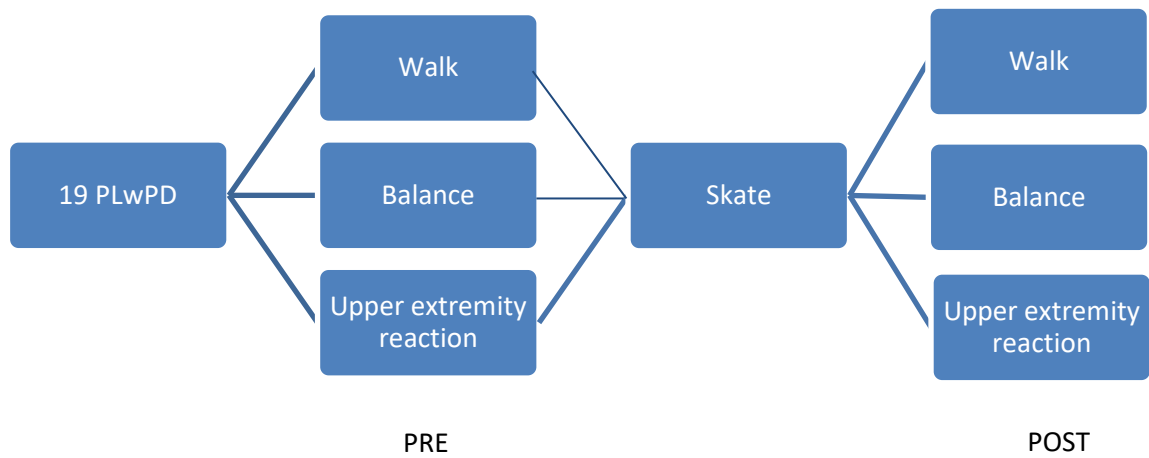
2.2.2. Protocol

Testing took place at local ice arenas on freshly cleaned ice. Ice features, lights, and boards remained the same as the facility maintained. Upon arrival, participants were greeted,

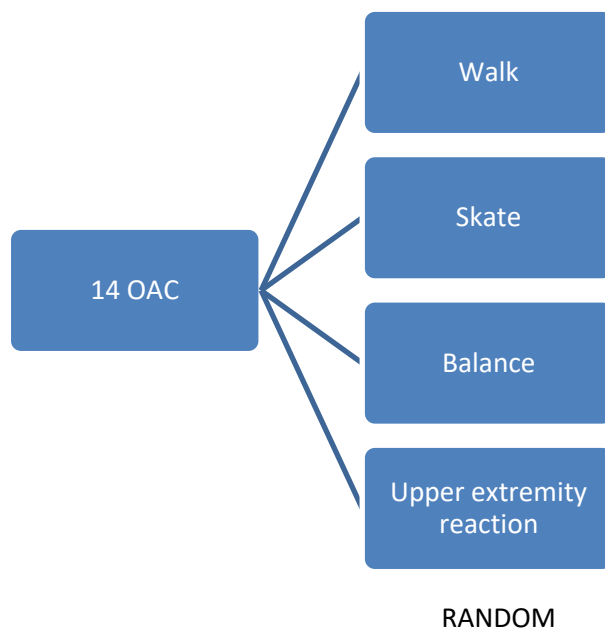
provided a verbal overview of test protocols, and invited to complete an informed consent. PD participants first performed walking trials, balance trials, and upper extremity action tests in randomized blocks. After completion of this dry land testing, skating trials took place. Immediately after skating, PD participants repeated the dry land post- tests (Fig. 2.1.a). OAC took part in one set of skating trials, walking trials, balance trials, and upper extremity impulse testing in randomly assigned blocks. We predicted that ice skating would make no significant changes to the assessed parameters for OAC as they suffered no gait impairments and would already be at the 'ceiling' of their gait function for the tested parameters, so repeat testing was not performed (Fig. 2.1.b). Findings from balance tests and upper extremity reaction trials have been reported elsewhere (Doan et al, 2016; Bartoszyk, de Bruin, Brown, & Doan, 2015).

Skating trials took place on open ice, in the presence of two investigators, and participants did not have assistance of rink boards or other locomotion aids. Pathway markers were placed two meters apart for a distance of twelve meters (Fig. 2.2.a). Participants were instructed to skate at self- selected pace from one end of the pathway to other. At the end of the pathway they could turn as desired and return to the starting position. Participants could take a break as required, and all participants wore a helmet while on the ice surface.

Walking trials took place in available space at the ice skating area, and all participants wore their own everyday shoes. A twelve meter level pathway was marked with pathway markers spaced two meters apart (Fig. 2.2.b). The same instructions that were given for skating were given for walking. Skating and walking trials were recorded from a sagittal view with a digital video recorder (JVC GC- PX100B, JVC, KENWOOD Corporation, USA).



(a)



(b)

Figure 2.1. Experimental design. Protocol testing order for PLwPD (a) and OAC (b)

(a)



(b)



Figure 2.2. Trial execution. Skating (a) and walking (b) trial pathways with markers 2 meters apart

2.2.3. Analysis

Videos were organized into trials and desampled into individual frames using Windows Movie Maker© (Microsoft, Seattle, Washington, USA). Segment endpoints were hand digitized frame by frame using Image J© (National Institute of Health, Bethesda, Maryland, USA). Digitized endpoints were the right ear, right hip, right hand, left hand, right knee, left knee, right heel, right toe, left heel and left toe (Fig. 2.3). When the left hand was hidden behind the body that marker was also assigned to the right hip. Pixel coordinate information for each trial was imported into an Excel© (Microsoft, Seattle, Washington, USA) spreadsheet. Calculations of spatiotemporal parameters of locomotion were performed for each trial then averaged for each individual in each locomotion type. Parameters of interest were average and maximum horizontal step length, maximum arm swing amplitude averaged across both arms, average and maximum horizontal locomotion velocity, and percentage of time spent in double limb support. See formulas in Appendix A. Measures were chosen based on previous research recognized areas of motor deficits during gait (Nieuwboer et al., 2001).

IBM SPSS Statistics 24 © was used for all statistical processing. There were two primary ANOVAs used to process the data. The first primary test was a two way ANOVA, with the factors being group (PLwPD, OAC) and locomotion type (WALK, SKATE). Significant locomotion factors underwent follow- up pairwise comparison testing using two individual one way ANOVAs separated by group. This method was employed as there were less than 15 subjects in the OAC group and multiple t- test would have to be run. As the potential of Type I error is ~5% per t- test and the group is small there was an increased chance of poor population representation versus using a split one- way ANOVA (Lindenmayer & Burgman, 2005). The second primary test was a one way repeated measures ANOVA of locomotion time (WALK PRE SKATE, WALK POST SKATE), restricted to PLwPD. Level of significance was determined to be $p = .1$. Exercise has well-

established general health benefits, which would persist even if skating- specific benefits were actually based on false positive information, so a less sensitive restriction on Type I error was chosen as appropriate.

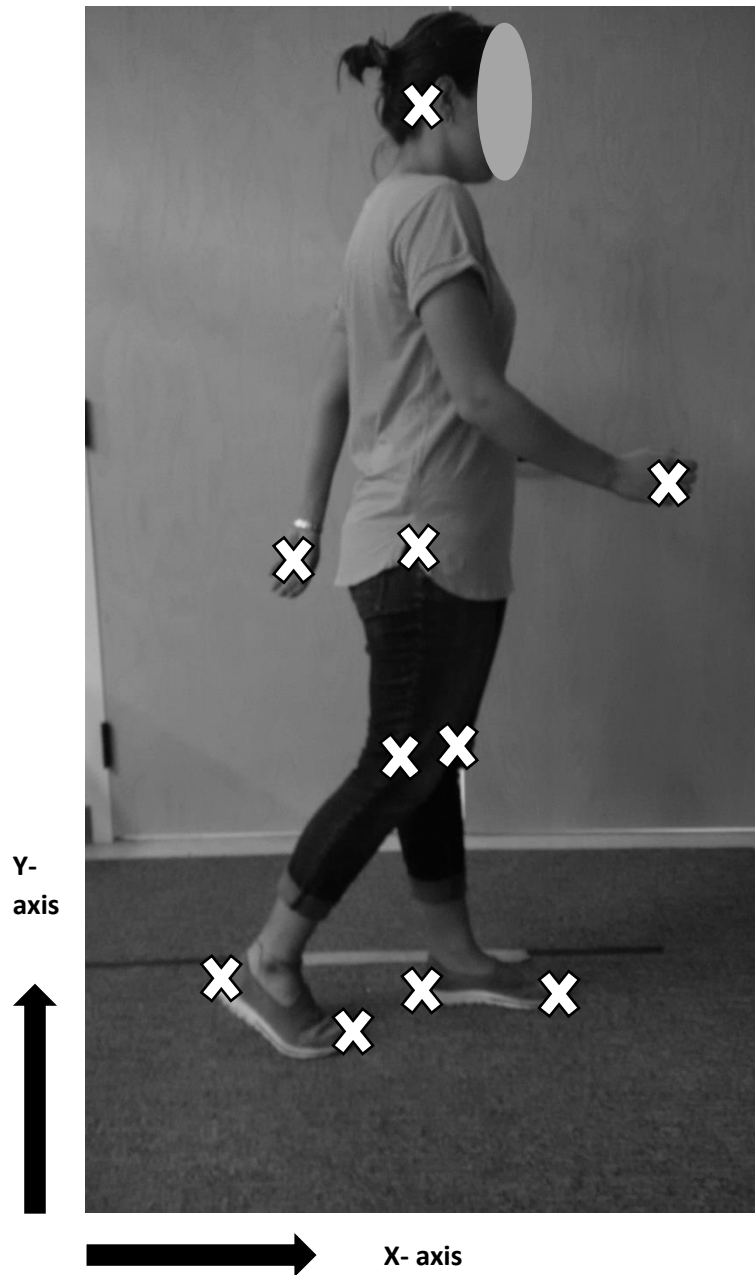


Figure 2.3. Segment endpoints. Reproduction of Image J © segment endpoint digitization at right ear, right hand, left hand, right hip, right knee, left knee, right heel, right toe, left heel, and left toe. These markers provided the coordinates used for calculations of average and maximum horizontal stride length, maximum arm swing average across both arms, average and maximum horizontal velocity, and percentage of time spent in double limb support.

2.3. Results

All participants were able to complete all trials. There was one fall amongst the PLwPD, one fall amongst the OAC, and one fall amongst the experimenters. There were no injuries resulting from these falls. There were no missing data, and no evidence of skewness, kurtosis, or outliers. As Mauchly's test for sphericity was significant, the Geisser- Greenhouse correction was used for both ANOVA's.

2.3.1. PLwPD can skate

Comparison of PLwPD WALK PRE SKATE and SKATE and OAC WALK and SKATE trials showed a significant main effect for group [$F(8, 24) = 5.403, p < .001, \text{partial } \eta^2 = .643$], a significant main effect for locomotion type [$F(8, 24) = 115.0, p < .001, \text{partial } \eta^2 = .975$], and a significant interaction for group x locomotion type [$F(8, 24) = 2.678, p = .029, \text{partial } \eta^2 = .472$]. Follow- up comparisons revealed that the group effect existed for the measure of double stance support time (DSST), with OAC spending significantly less time in this phase [$F(1,31) = 27.658, p < .001, \text{partial } \eta^2 = .472$], and maximum horizontal velocity [$F(1, 31) = 3.432, p = .073, \text{partial } \eta^2 = .100$], with OAC being significantly faster. No other parameters yielded significant group effect differences: maximum step [$F(1, 31) = 2.869, p = .100, \text{partial } \eta^2 = .085$], average step length [$F(1, 31) = 2.323, p = .138, \text{partial } \eta^2 = .070$], average velocity [$F(1, 31) = 2.015, p = .166, \text{partial } \eta^2 = .061$], and maximum arm swing [$F(1, 31) = 2.601, p = .117, \text{partial } \eta^2 = .077$].

Examination of locomotion type showed that both groups spent significantly more time in DSST during SKATE than WALK [$F(1, 31) = 20.952, p < .001, \text{partial } \eta^2 = .403$]. PLwPD had a 9% increase in DSST from WALK to SKATE [$F(1, 18) = 22.056, p < .001, \text{partial } \eta^2 = .551$] and OAC had a 2% increase in DSST [$F(1, 13) = 5.900, p = .030, \text{partial } \eta^2 = .313$] (Fig. 2.4). From SKATE to WALK there were significant increases in maximum and average step length [$F(1, 31) = 39.247, p$

<.001, *partial* $\eta^2 = .559$ and $F(1, 31) = 109.691$, $p < .001$, *partial* $\eta^2 = .780$, respectively]. These increases occurred amongst both PLwPD [$F(1, 18) = 20.512$, $p < .001$, *partial* $\eta^2 = .533$ and $F(1, 18) = 49.716$, $p < .001$, *partial* $\eta^2 = .734$, respectively] and OAC [$F(1, 13) = 22.269$, $p < .001$, *partial* $\eta^2 = .631$ and $F(1, 13) = 74.005$, $p < .001$, *partial* $\eta^2 = .851$, respectively] (Fig. 2.5.). Both groups had a significantly greater average horizontal velocity in SKATE compared to WALK locomotion [$F(1, 31) = 193.493$, $p < .001$, *partial* $\eta^2 = .862$]. This difference was significant within both PLwPD and OAC groups [$F(1, 18) = 116.34$, $p < .001$, *partial* $\eta^2 = .866$ and $F(1, 13) = 103.37$, $p < .001$, *partial* $\eta^2 = .888$, respectively]. A similar significant difference existed for maximum horizontal velocity, with SKATE being greater than WALK [$F(1, 31) = 213.024$, $p < .001$, *partial* $\eta^2 = .873$] for both PLwPD [$F(1, 18) = 79.502$, $p < .001$, *partial* $\eta^2 = .815$] and OAC [$F(1, 13) = 147.486$, $p < .001$, *partial* $\eta^2 = .919$] groups (Fig. 2.6.). There was also a significant increase in both groups maximum arm swing during SKATE versus WALK locomotion [$F(1, 31) = 16.802$, $p < .001$, *partial* $\eta^2 = .351$]. This increase was significant for both PLwPD [$F(1, 18) = 8.492$, $p = .009$, *partial* $\eta^2 = .321$] and OAC [$F(1, 13) = 9.424$, $p = .009$, *partial* $\eta^2 = .420$] (Fig. 2.7.).

Group x locomotion type interaction revealed that PLwPD had significantly higher DSST than OAC during WALK and SKATE [$F(1, 31) = 10.367$, $p = .003$, *partial* $\eta^2 = .251$] (Fig. 2.4.). During WALK PLwPD spent 5.4% greater time in DSST, and during SKATE 14.4% more time. There were no significant differences for maximum [$F(1, 31) = .047$, $p = .829$, *partial* $\eta^2 = .002$] or average step length [$F(1, 31) = .076$, $p = .785$, *partial* $\eta^2 = .002$], or maximum [$F(1, 31) = .793$, $p = .380$, *partial* $\eta^2 = .025$] and average horizontal velocities [$F(1, 31) = .003$, $p = .959$, *partial* $\eta^2 = .000$] (Fig. 2.5 and 2.6). There was also no significant interaction in maximum arm swing [$F(1, 31) = .000$, $p = .992$, *partial* $\eta^2 = .000$].

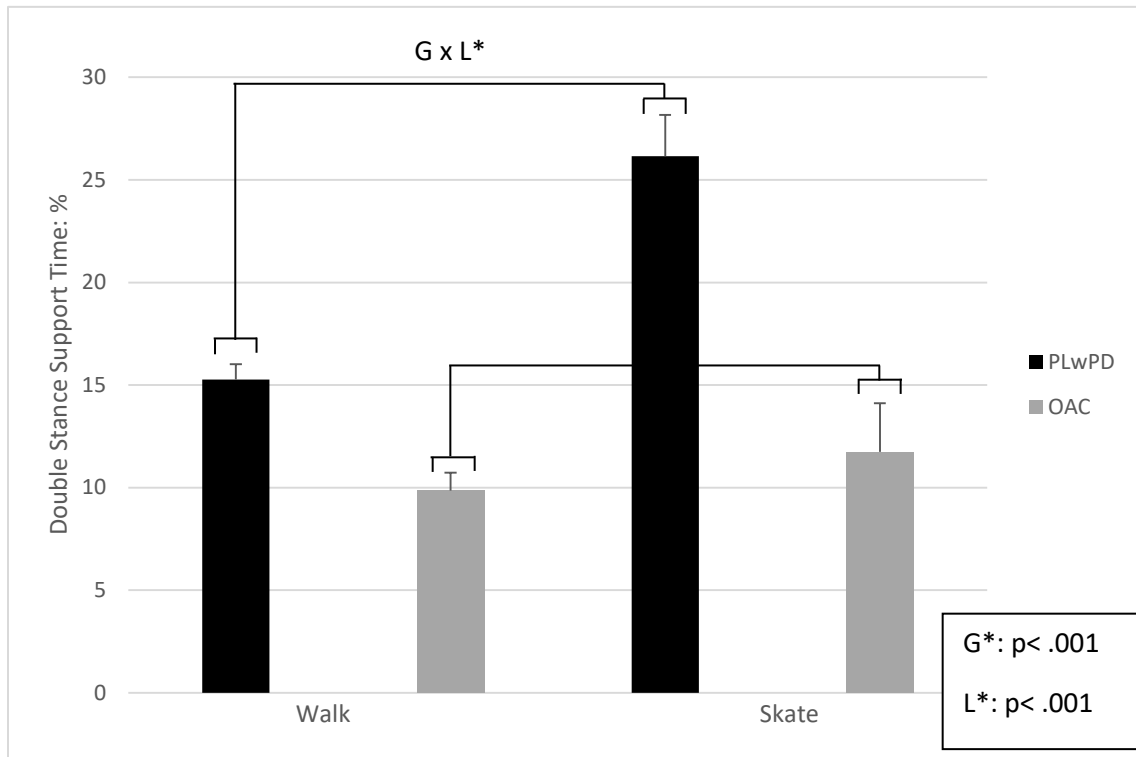


Figure 2.4. Double stance support time percentage for PLwPD during PRE WALK and SKATE and OAC during WALK and SKATE. There is a significant difference of double stance support time during both PLwPD WALK PRE SKATE and OAC WALK, and PLwPD and OAC SKATE. Double stance support time had a significant main effect for group (G) [$F(1, 31) = 27.658, p < .001, \text{partial } \eta^2 = .100$], locomotion (L) [$F(1, 31) = 20.952, p < .001, \text{partial } \eta^2 = .403$], and group x locomotion (G x L) [$F(1, 31) = 10.367, p = .003, \text{partial } \eta^2 = .251$].

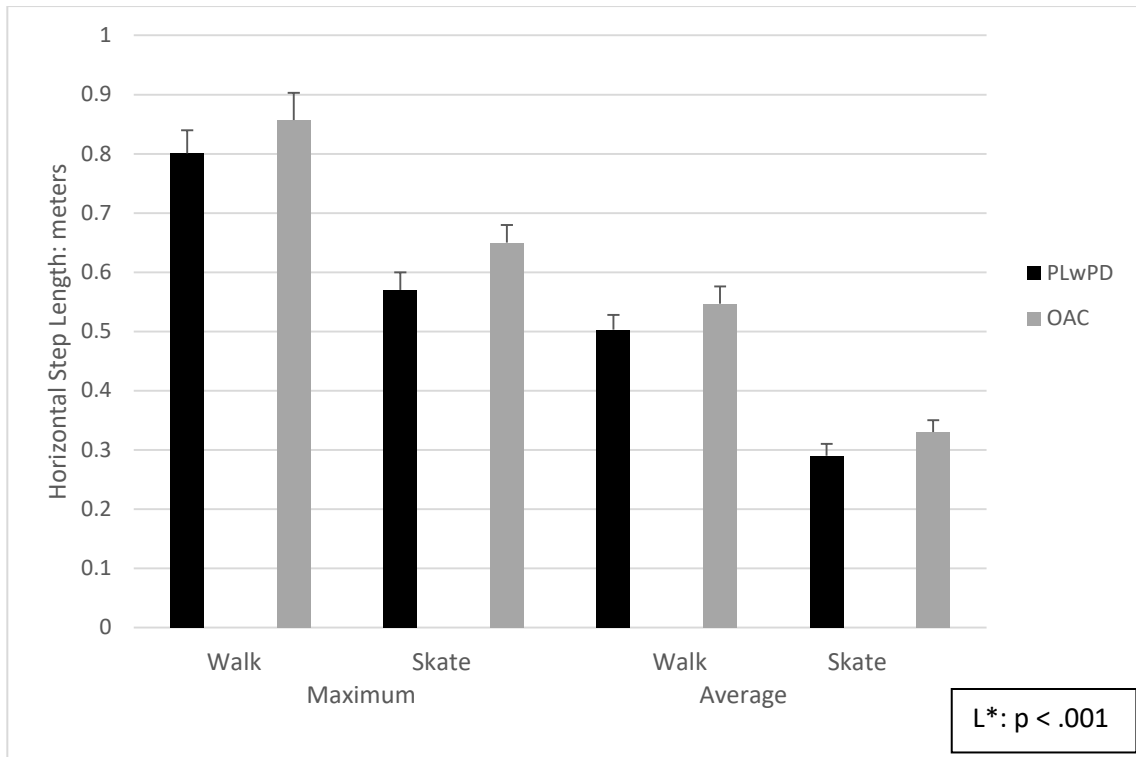


Figure 2.5. Maximum and average horizontal step length during WALK and SKATE. There is no significant difference between PLwPD and OAC's maximum and average step length during WALK and SKATE [$F(1, 31) = .047, p = .829, \text{partial } \eta^2 = .002$; $F(1, 31) = .076, p = .785, \text{partial } \eta^2 = .002$]. There was a significant difference of longer maximum and average horizontal step length during WALK than SKATE locomotion [$F(1, 31) = 39.247, p < .001, \text{partial } \eta^2 = .559$; $F(1, 31) = 109.691, p < .001, \text{partial } \eta^2 = .780$, respectively]. These results were from the main effect of locomotion (L).

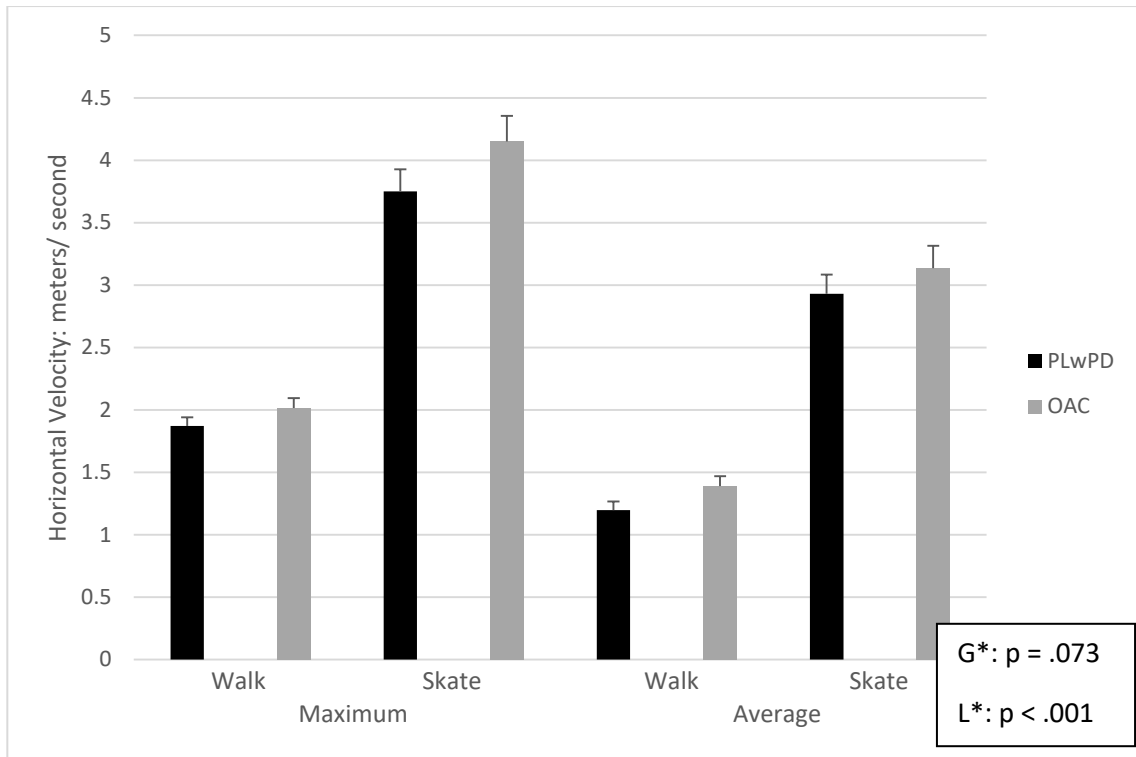


Figure 2.6. Maximum and average horizontal velocity for PLwPD during WALK PRE SKATE and SKATE, and OAC during WALK and SKATE. There was a significant overall group (G) effect of OAC having greater maximum horizontal velocity [$F(1, 31) = 3.432, p = .073, \text{partial } \eta^2 = .100$]. Both PLwPD and OAC average SKATE velocity were significantly faster than their average WALK PRE SKATE and WALK velocities. Between SKATE and WALK PRE SKATE PLwPD average velocity increased by 1.16 times, [$F(1, 18) = 116.34, p < .001, \text{partial } \eta^2 = .866$], and OAC's average velocity increased by 1.07 times, [$F(1, 13) = 103.37, p < .001, \text{partial } \eta^2 = .888$]. There was no significant difference between PLwPD and OAC's maximum or average velocity during SKATE, [$F(1, 31) = .793, p = .380, \text{partial } \eta^2 = .025$], [$F(1, 31) = .003, p = .959, \text{partial } \eta^2 = .000$], or WALK, [$F(1, 31) = 3.432, p = .073, \text{partial } \eta^2 = .100$]. These results were from the main effect of locomotion (L).

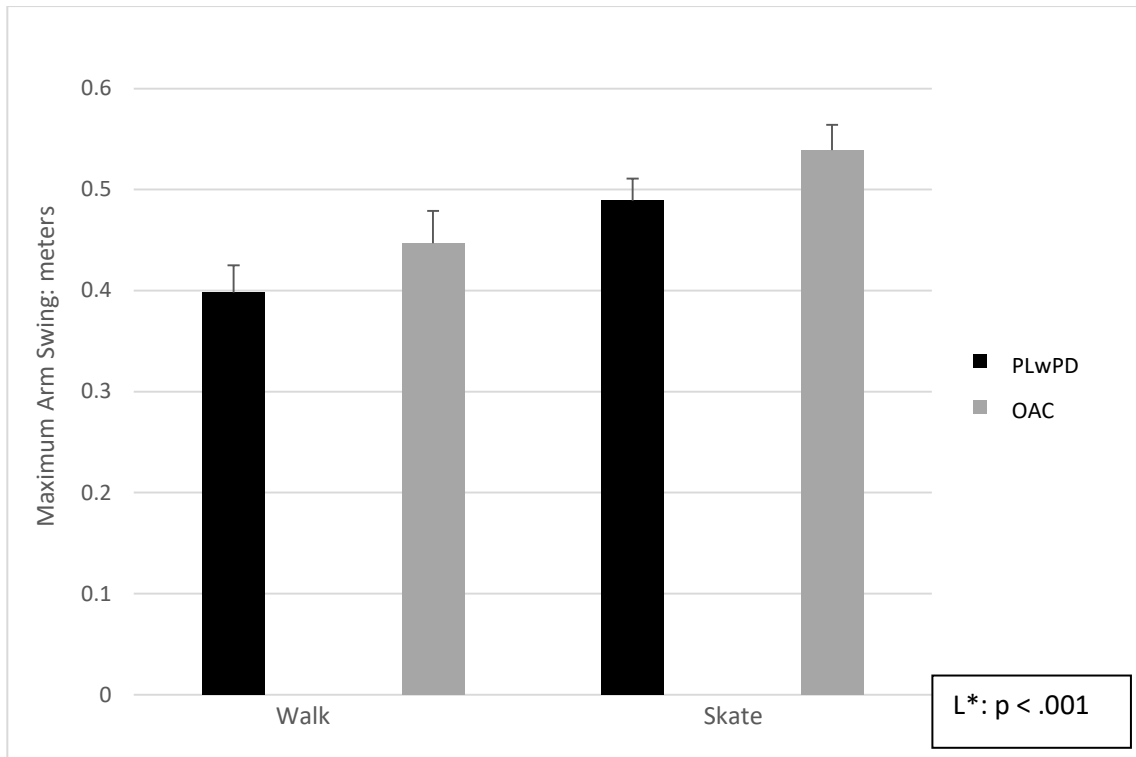


Figure 2.7. Maximum arm swing of PLwPD WALK PRE SKATE and SKATE, and OAC WALK and SKATE. Maximum arm swing significantly was significantly greater during SKATE versus WALK locomotion [$F(1, 31) = 16.802, p < .001, \text{partial } \eta^2 = .351$]. This increase was significant for both PLwPD [$F(1, 18) = 8.492, p = .009, \text{partial } \eta^2 = .321$] and OAC [$F(1, 13) = 9.424, p = .009, \text{partial } \eta^2 = .420$].

2.3.2. PLwPD walk better after they skate

PLwPD WALK PRE SKATE versus WALK POST SKATE analysis yielded a main effect of time [$F(8, 11) = 68.483, p < .001, \text{partial } \eta^2 = .980$]. Further investigation showed that this difference was due to PLwPD having a significant decrease in DSST [$F(1, 18) = 5.020, p = .038, \text{partial } \eta^2 = .218$] (Fig. 2.8.), and a significant increase in average horizontal velocity [$F(1, 18) = 3.562, p = .075, \text{partial } \eta^2 = .165$] (Fig. 2.9.) during POST WALK trials. There were no differences between WALK PRE SKATE and WALK POST SKATE for maximum horizontal velocity [$F(1, 18) = 2.417, p = .137, \text{partial } \eta^2 = .118$] (Fig. 2.9), maximum horizontal step length [$F(1, 18) = 1.805, p = .196, \text{partial } \eta^2 = 0.91$], average horizontal step length [$F(1, 18) = 2.064, p = .168, \text{partial } \eta^2 = .103$] (Fig. 2.10), or maximum arm swing [$F(1, 18) = .001, p = .975, \text{partial } \eta^2 = .000$] amongst PLwPD (Fig. 2.11).

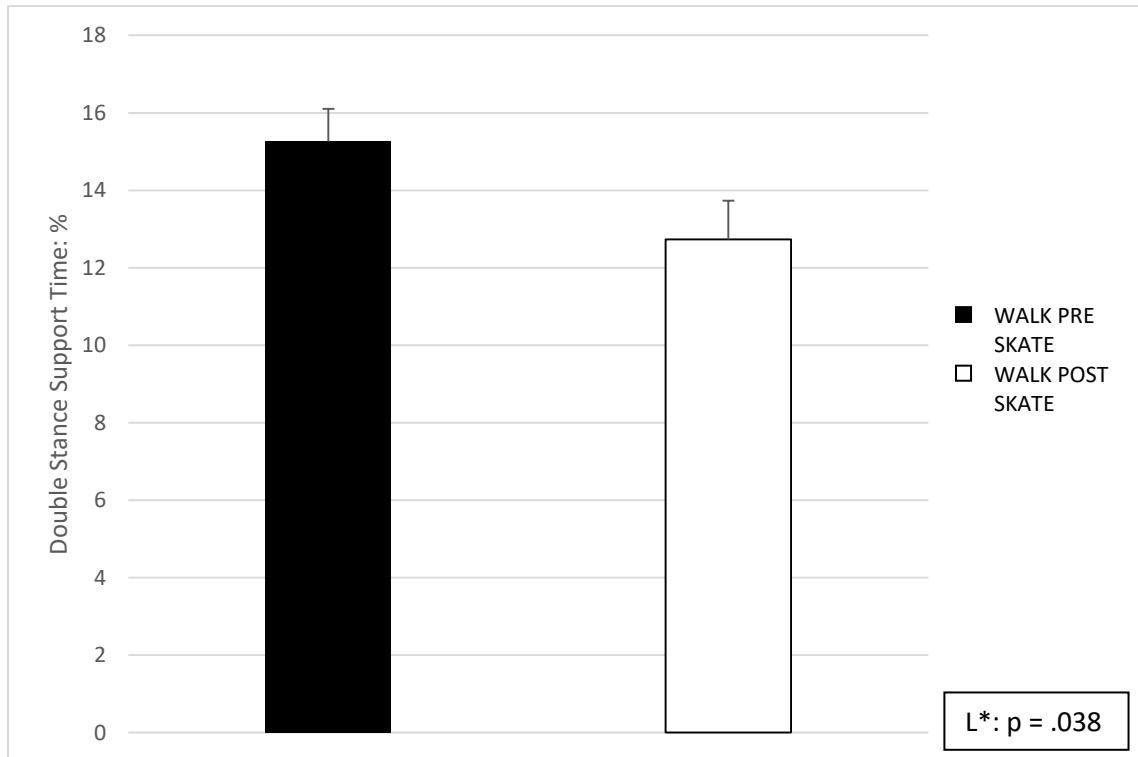


Figure 2.8. Double stance support time percentage of PLwPD during WALK PRE SKATE and POST WALK. There is a significant locomotion difference in double stance support time between PLwPD WALK PRE SKATE versus POST WALK [$F(1, 18) = 5.020, p = .038, \text{partial } \eta^2 = .218$].

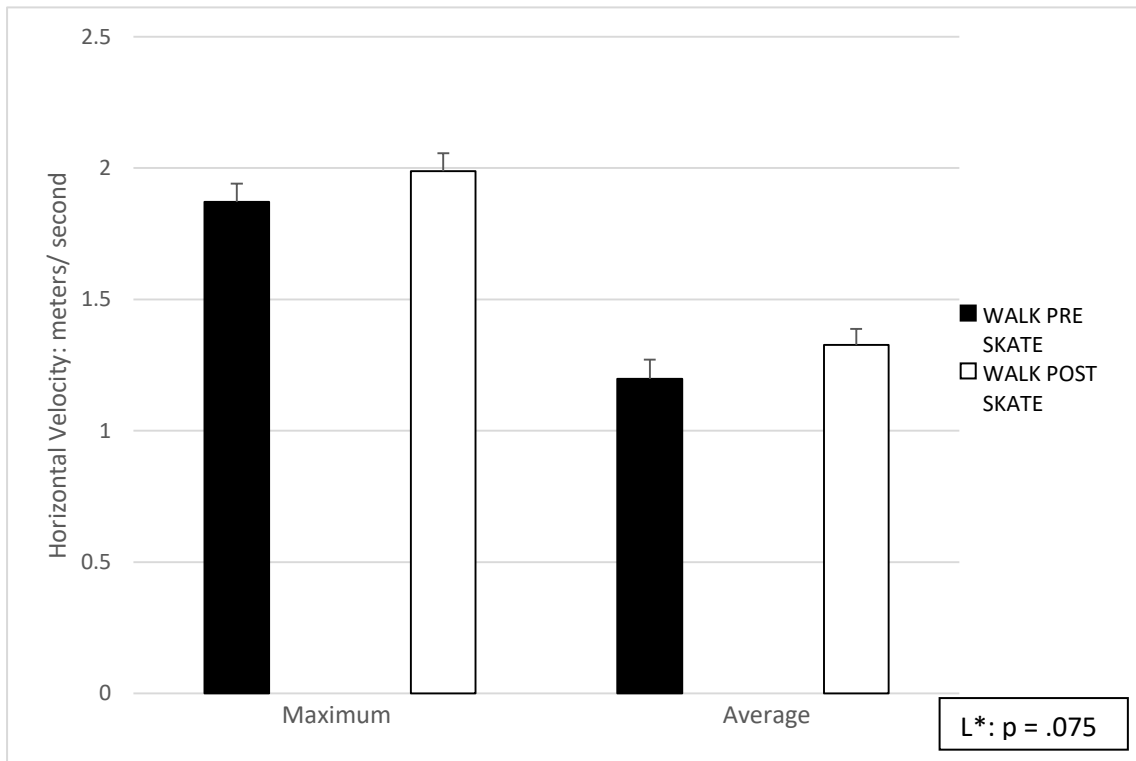


Figure 2.9. Maximum and average horizontal velocity of PLwPD during WALK PRE SKATE and WALK POST SKATE. There was a significant increase in average velocity between PLwPD WALK PRE SKATE versus WALK POST SKATE [$F(1, 18) = 3.562, p = .075, \text{partial } \eta^2 = .165$]. There was no significant difference for maximum horizontal velocity [$F(1, 18) = 2.417, p = .137, \text{partial } \eta^2 = .118$].

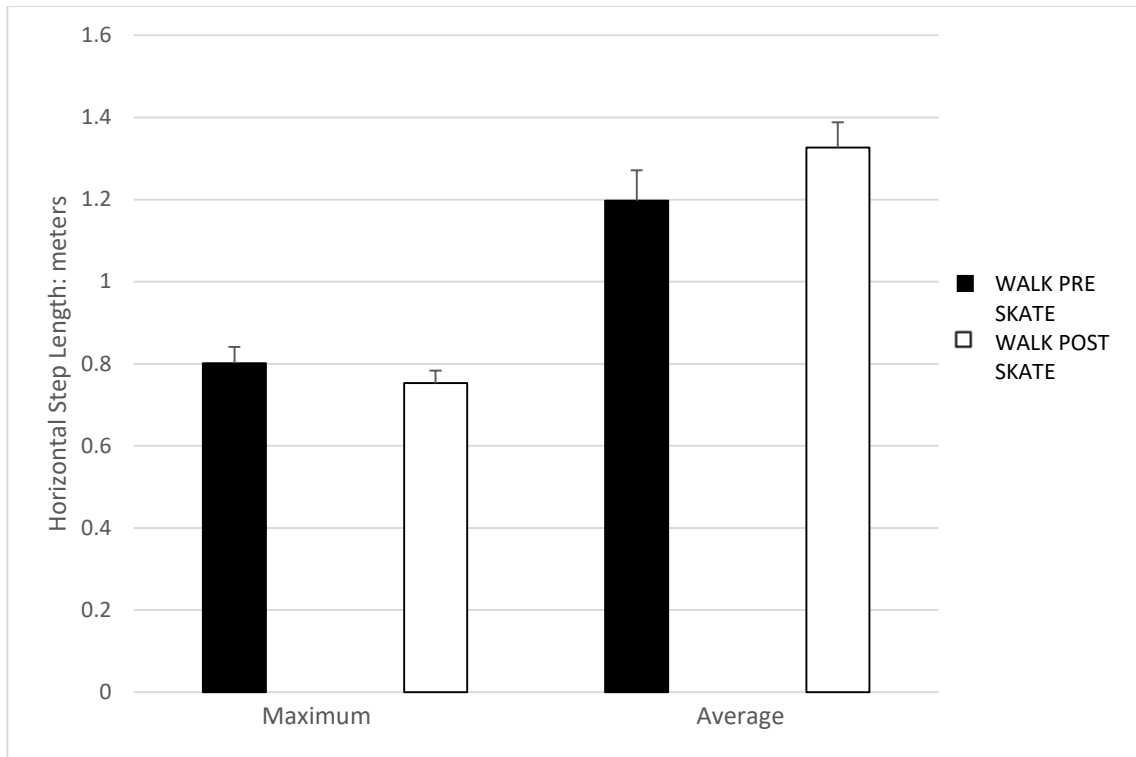


Figure 2.10. Maximum horizontal step length and average horizontal step length of PLwPD during PRE WALK and POST WALK. There was no significant difference in PLwPD maximum horizontal step length [$F(1, 18) = 1.805, p = .196, \text{partial } \eta^2 = 0.91$] or average horizontal step length [$F(1, 18) = 2.064, p = .168, \text{partial } \eta^2 = .103$] from PRE WALK to POST WALK.

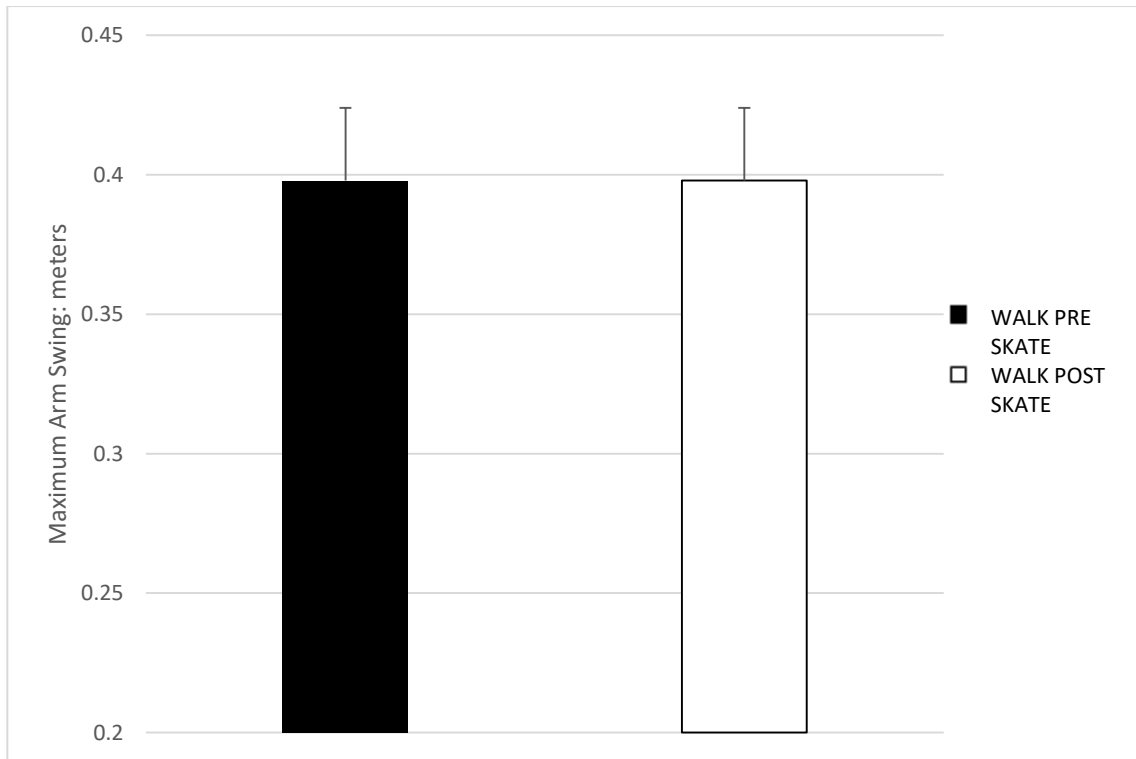


Figure 2.11. Maximum arm swing of PLwPD during PRE WALK and POST WALK. There was no significant difference in PLwPD maximum arm swing amplitude [$F(1, 18) = .001$, $p = .975$, partial $\eta^2 = .000$] from PRE WALK to POST WALK.

2.4. Discussion

This study examined the kinematics of walking and ice skating amongst people living with Parkinson's disease (PLWPD). The purpose was to determine if ice skating was a safe and feasible exercise activity, and if an episode of skating generated immediate improvements in walking. We found that PLWPD were able to ice skate safely and, with similar kinematics as older adult controls (OAC). Specifically, both groups made similar decreases to horizontal step length and increases to horizontal velocity and arm swing from walking to skating locomotion. This is seen as a positive change as PLWPD locomotion is typically diminished in velocity and arm swing. Differences in behavior were still observed, with PLWPD spending more time in double stance support time (DSST) for both locomotion skills. This cautious behavior did not negate skating ability amongst PLWPD, nor did it diminish beneficial transfer to walking immediately after skating, namely decreased DSST and increased average horizontal velocity compared to pre-skate walking. These exciting results suggest that ice skating exercise might be used to improve walking performance amongst some PLWPD, with subsequent improvements for mobility and quality of life.

Exercise has been shown to improve balance (Hirsch et al., 2003; Kara et al., 2012; Smania et al., 2010), strength (Carvalho et al., 2015; Dibble et al., 2006), and perceived quality of life amongst some PLWPD (Herman et al., 2007; Morris et al., 2009), however, interventions are too often implemented using highly supervised, structured, and restrictive methods that have low social interaction (Carvalho et al., 2015; Comella, Stebbins, Brown- Toms, & Goetz, 1994; Quinn et al., 2010). Using sport like ice skating might address some of these issues. Ice skating has the beneficial effects of aerobic, anaerobic (Roczniok et al., 2016), and balance improvements (Hrysomallis, 2011; Lamothe & van Heuvelen, 2012), in addition to being readily available in rural and urban Canada, and can be highly social (Reid & Reid, 2016; Sim et al., 1987;

van Saase et al., 1990). Together this may increase the satisfaction that is felt by participants, improve adherence to activity (Mulligan, Whitehead, Hale, Baxter, & Thomas, 2012), and also potentially heighten feelings of happiness, which has also been shown to increase cortical activation levels in PLWPD (Naugle et al., 2012).

We can make some inference about the neuromechanics that allows for ice skating *paradoxical kinesia*, and possibly *paradoxical kinesis* in general. Research consistently shows that PLWPD display hypokinetic movements during locomotion (Hausdorff et al., 2003; Morris et al., 1996). These deficits are believed to be caused by poor internal stimulation of motor actions due to decreased activation of the basal ganglia and the supplementary motor area (SMA) (Buhmann et al., 2003; Cunnington, Iansek, Bradshaw, & Phillips, 1995; Jahanshahi et al., 1995; Mushiake et al., 1991; Playford et al., 1992; Samuel et al., 1997; Yu, Sternad, Corcos, & Vaillancourt, 2007). These areas are primarily responsible for internally cued motor planning and regulation of highly learned and cyclical tasks, like walking. Due to these lower activation levels, the kinematics of volitional motions are often impaired (Fukuyama, Ouchi, Matsuzaki, & Nagahama, 1997; Hausdorff et al., 2003; van der Hoorn et al., 2014). These kinematic deficits were evidenced in this study by the prolonged DSST and decreased horizontal velocity in the baseline walking trials amongst PLWPD. During ice skating, however, we observed relatively preserved function, with PLWPD producing similar horizontal velocity and step length as OAC. We postulate that this improvement may be the result of the external motor pathway being stimulated by the relatively rapid visual flow of ice skating locomotion. The external motor pathway is largely preserved in PLWPD (Hanakawa et al., 1999; Samuel et al., 1997). As a result, there may be improved motor performance when the external motor pathway is stimulated, as has been shown previously in conjunction with sensory cueing (Cunnington, Windischberger, Deecke, & Moser, 2002; Majsak, Kaminski, Gentile, & Flanagan, 1998; Roland et al., 1980; Samuel et al.,

1997). Imaging studies that have recorded these effects typically use direct visual cues, like lighted buttons or transverse line markings (Cunnington et al., 1995; Hanakawa et al., 1999), but the same effect may be driven by familiar cues as well. Several case studies have shown that when PLWPD are presented with ecologically relevant and vibrant contexts, like bicycling down a street, they are able to produce bouts of advanced motor function (Asmus et al., 2009; Snijders & Bloem, 2010). In these cases, artificially added cueing was not required (Azulay et al., 1999). Instead, there appears to be some inherent connection between the pre-existing motor repertoire and re-immersion in the context that triggers the external pathway to be active to deliver skillful motor control. We believe that ice skating similarly delivers ecologically relevant and vibrant visual stimuli that stimulates this preserved external motor pathway, thus yielding improved locomotor kinematics, namely horizontal velocity and stride length.

Improved motor function during ice skating may have also been enhanced by increased cerebellar volume. Imaging has shown that skilled ice skaters have more cerebellar volume than non-ice skaters (Park et al., 2012; Park, Yoon, Kim, & Rhyu, 2013). This is believed to be a cortical adaptation to improve postural control and coordination, both skills that are highly challenged when skating, and partially the responsibility of the cerebellum (Holmes, 1917; Park et al., 2012; Park et al., 2013). However, in the above studies all the subjects were currently highly active skaters, whereas in this study participants were not. Presumably increased cerebellar volume would positively affect all balance and locomotor behaviors, a benefit not observed here.

Improvements in walking kinematics that followed skating behavior may also be the result of exercise induced increases in cortical activation of the basal ganglia and SMA. Alberts et al (2011) performed imaging in PLWPD before and after one bout of forced exercise bicycle training and found that there was a prolonged increase in basal ganglia and SMA activation. As

the basal ganglia and SMA are partially responsible for internal regulation of motor actions, an improvement in these areas would increase non- externally cued motor function, allowing for PLwPD to be more able to regulate gait velocity as well as spend less time in DSST, a phase of restabilization that, when prolonged, is indicative of poor stride regulation (Nieuwboer et al., 2001; Winter, Patla, Frank, & Walt, 1990).

This study was prone to self- selection bias. A relatively highly active PD population, with mild to moderate disease severity, may have volunteered as the study targeted individuals with ice skating experience, and asked them to perform ice skating. This same active cohort may also pose a 'ceiling effect', as their locomotor kinematics were neither largely different from OAC nor deficit enough to be significantly improved by a single episode of ice skating activity. For safety and practicality issues future implementation of vigorous protocols has been supported for this population (Lau et al., 2011; Pohl et al., 2003; Schenkman et al., 2012).

Another limitation was that testing was performed on- site at multiple rinks instead of in a controlled laboratory setting. Experimental ice skating can be done under laboratory control, using a skating treadmill, but these devices have been shown to decrease stride lengths and reduce glide phase of ice skating, making laboratory skating behaviors and decisions about skating safety potentially altered for the PD population (Nobes et al., 2003). On- site testing also has the benefit of ecological context. Being in an ice rink may induce a psychological response for some participants. Depending on feelings of stress, anxiety, and happiness motor performance is changed (Naugle et al., 2012). This has been shown as improved gait performance with images designed to induce happiness and decremented gait performance with images designed to induce negative emotions. Testing in the community- based ice rinks also increases the possible translation of this research, as community rinks would be the setting for proposed future interventions. We suggest that (re)introducing ice skating vigorous exercise in

these settings to PLWPD has the potential for accessible therapy with a strong potential for biological, psychological, and social gains.

2.4.1. Conclusion

PLWPD who have previous experience of ice skating retain the ability to ice skate safely and skillfully. Immediately after a single ice skating bout there were improvements in walking parameters amongst PLWPD, suggesting that ice skating may be an appealing option for a neurorehabilitative therapeutic exercise. Future research is required to determine dose-response and retention and transfer of kinematic improvements and enhanced function.

3.0. Ice skating improves doorway crossing amongst people living with Parkinson's disease: potential for neurotherapeutic intervention

3.1. Introduction

Parkinson's disease (PD) is a neurodegenerative disease characterized by motor symptoms that affect many activities of daily life (Ellis et al., 2005). People living with Parkinson's disease (PLWPD) often have shortened stride length (Blin et al., 1990; Lewis, Byblow, & Walt, 2000), reduced arm swing (Earhart & Williams, 2012), decreased gait velocity (Blin et al., 1990), and prolonged double stance support time (Nieuwboer et al., 2001). Combined, these characteristics create a shuffle- like gait appearance, with decreased efficiency of motion (Hausdorff et al., 2003; Schenkman et al., 2012). As the disease progresses these impairments typically become more pronounced, with walking impairments being amongst the most detrimental to quality of life (Ellis et al., 2005). Walking is furthered compromised amongst some PLWPD who develop a transient freezing of gait (Giladi et al., 1992; Okuma, 2006). Initially, freezing of gait may present as a slowing of movement, and then progress to inability to produce any movement for periods of time (Giladi et al., 1992). Freezing of gait typically occurs when commencing locomotion, changing path, approaching an obstacle, or walking through a doorway (Rahman et al., 2008). Following a freezing episode there is often a phase of accelerated motion that is difficult to control and increases the likelihood of falls (Bloem, Hausdorff, Visser, & Giladi, 2004; Nutt et al., 2011; Snijders & Bloem, 2010), with falls presenting a high risk for injuries and subsequently decreased quality of life (Moretti, Torre, Antonello, Esposito, & Bellini, 2011).

The underlying neuromechanism behind freezing of gait is multifaceted, with one characteristic being decreased supplementary motor area (SMA) activation (Snijders et al., 2011). Reduced SMA activation is prevalent amongst many PLWPD but is more pronounced in

those that experience freezing of gait (Buhmann et al., 2003; Jahanshahi et al., 1995; Playford et al., 1992; Samuel et al., 1997; Snijders et al., 2011; Yu, Sternad, Corcos, & Vaillancourt, 2007). The SMA is involved in internally regulated voluntary motor action regulation, a function used during periods of decreased external stimulation, like walking through a doorway (Ianssek, Bradshaw, Phillips, Cunnington, & Morris, 1995; Roland et al., 1980). As an individual with PD approaches the doorway the visual field is narrowed, decreasing external stimuli and increasing reliance on the poorly activated SMA, potentially leading to freezing of gait (Cowie, Limousin, Peters, & Day, 2010; van der Hoorn, Renken, Leenders, & de Jong, 2014; van der Hoorn, Beudel, & De Jong, 2010).

Reducing reliance on internal regulation through the use of supplemental external visual cues have been used to decrease the incidence of freezing of gait (Azulay, Mesure, & Blin, 2006; Frazzitta, Maestri, Uccellini, Bertotti, & Abelli, 2009; Kompoliti et al., 2000; Martin, 1967). Martin (1967) showed the power of cueing by asking patients to step over transverse line markings placed along a pathway, which resulted in improvement of gait. By providing the visual cues of lines PLWPD were able to regulate stride based on an external cue rather than internal cues. Although successful at reducing freezing of gait, cueing has low transfer when cues are absent, making the constant presence of cues in the environment necessary. Portable cues, like canes, inverted walking sticks, and optical stimulating glasses have all been studied, but have had only modest success at effectively reducing freezing of gait. This failure has been postulated to be caused by a locomotion reliance on the aid, like loading weight on the cane, versus a cue to advance from (Dietz, Goetz, & Stebbins, 1990; Donovan et al., 2011; Ferrarin et al., 2004).

External visual cues also appear to be part of the stimulation of *paradoxical kinesia* (PK), a phenomenon of preserved motor action experienced by some PLWPD (Glickstein & Stein, 1991; Martin, 1967; Siegert, Harper, Cameron, & Abernethy, 2002). PK has been found to occur during

stressful situations (Bonanni et al., 2010; Glickstein & Stein, 1991; Schlesinger et al., 2007) and complex sporting skills (Asmus et al., 2009; Bartoszyk et al., 2015), with subsequent improvements to freezing of gait (Snijders & Bloem, 2010). Snijders et al (2011) illustrated this with a case study of two patients that were unable to walk due to severe freezing of gait but had remarkable preservation for bicycling, with no freezing episodes.

Ice skating is another paradoxically preserved skill amongst some PLWPD (Bartoszyk et al., 2014; Doan et al., 2012), and is widely enjoyed by many individuals from northern regions (van Saase et al., 1990). Early evidence has shown that ice skating is safe, feasible, and has latent positive effects on motor function in unobstructed situations (Bartoszyk et al., 2015; Doan et al., 2012). Our group and others have postulated that PK is driven by familiar visual flow, a hypothesis that logically intersects with observations of visually- induced freezing of gait (Bartoszyk et al., 2014; Majsak, Kaminski, Gentile, & Flanagan, 1998; Snijders, Toni, Ruzicka, & Bloem, 2011). The purpose of this study is to directly compare skating and walking locomotor kinematics for one of the most evoking freezing stimuli, passing through a doorway (Kompolti et al., 2000). We predict that the primer of PK will exceed the reduced visual stimulation of the doorway, resulting in locomotor improvements associated with decreased freezing of gait. This will potentially be evidenced by initial walking trials having hesitant locomotor kinematics reflective of freezing, specifically increased double stance support time, variable step length, and decreased velocity. We hypothesize that these hesitation factors will be reduced during ice skating, and that immediately post- ice skating walking parameters will continue to be improved.

3.2. Methods

3.2.1. Subjects

Thirteen (13) PLwPD (2 female, 11 male; Mean age: 59.7; SD: 6.4 years) were recruited through convenience sample. Electronic invitations were sent to regional PD support groups and previous research participants from Lethbridge, Red Deer, Kelowna, Saskatoon and Vancouver. All subjects with PD had been diagnosed by a neurologist, and had an average disease duration of 5.4 years (SD: 3.2 years) and an average Hoehn and Yahr score of 1.0 (SD: 0.7) (Hoehn & Yahr, 1967). At the time of the testing PLwPD self-reported being in the 'on' phase of their medication cycle, and participants maintained scheduled drug treatment during testing. Eight (8) older adult controls (OAC) (1 female, 7 male; Mean age: 57.9; SD: 12.2 years) were recruited through convenience sample. This took place by electronic invitation and subsequent to an oral presentation given to a local senior's fitness class.

During recruitment all participants were informed that a portion of testing was to take place on ice and in skates. No specific level of ice skating expertise was required, but it was suggested that participants be competent at basic skating skills. All subjects participated in their own ice skates or a pair of ice skates gifted by the researchers, and wore a Canadian Safety Association approved helmet while on the ice. The study was approved by the University of Lethbridge's Human Subjects' Research Ethics review.

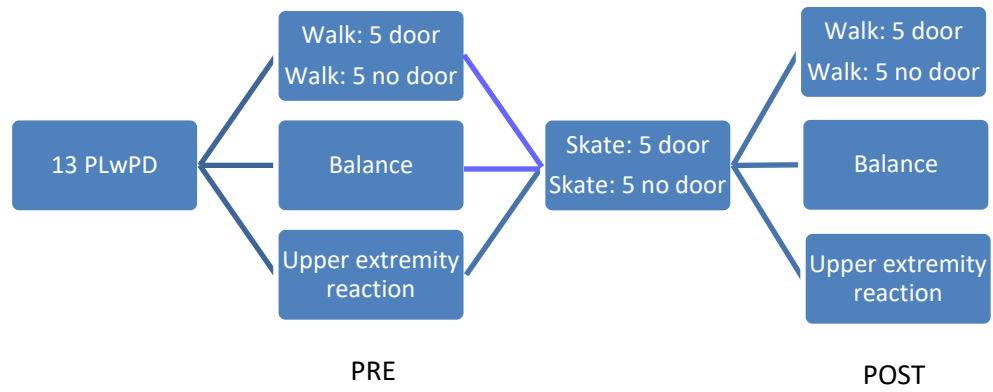
3.2.2. Protocol

Testing took place at local ice arenas. Upon arrival, participants were greeted, provided a verbal overview of test protocols, completed informed consent, and OAC were randomly assigned to locomotion testing order. In randomized blocks, PD subjects first performed a set of walking trials, balance trials and reaction tests. After completion of dry land testing, skating trials

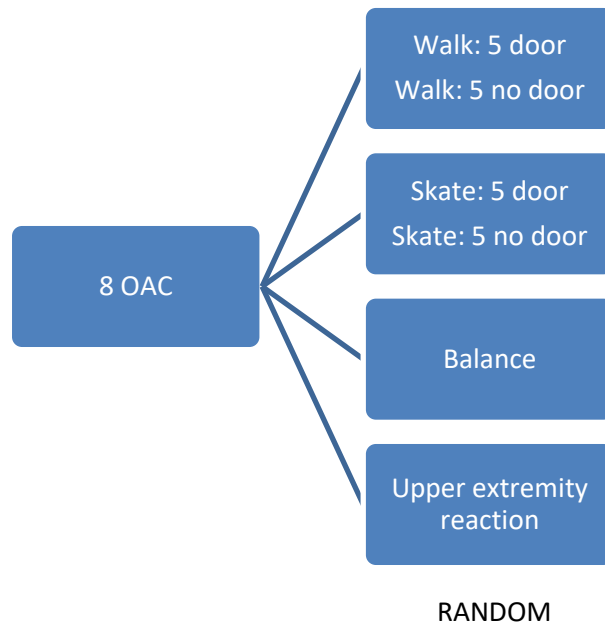
took place. Immediately after skating, participants repeated dryland post- tests (Fig. 3.1.a). OAC took part in one set of skating trials, walking trials, balance trials and upper extremity impulse testing in randomly assigned blocks. We predicted that ice skating would make no significant changes to the assessed parameters for OAC as they suffered no gait impairments and would already be at the 'ceiling' of their gait function for the tested parameters, so repeat testing was not performed (Fig. 3.1.b). Findings from balance tests and upper extremity reaction trials have been reported elsewhere (Doan et al, 2016; Bartoszyk, Bruin, Brown, & Doan, 2015).

Skating trials took place on open ice, and participants did not have assistance of boards or other stopping aids. Pathway markers were placed two meters apart for a distance of twelve meters. Participants were informed that half of the trials would have a doorway (220cm x 82 cm) (Fig. 3.2.a) and that half of the trials would have no doorway present (Fig. 3.2.b), and the order of the door and no door trials would be randomly presented. Individuals were instructed to skate at self- selected pace from the start to the end of the pathway. At the end of the pathway they could turn as desired and return to the starting position. Breaks were provided at the participant's request. The doorway consisted of the frame only, with the bottom portion having no material obstruction. Each side of the doorway was mounted on a wheeled platform so that the door could be moved in and out of the testing pathway based on trial randomization.

Walking trials took place in available space at the ice skating arena, and all participants wore their own everyday shoes. A twelve meter pathway was marked with cones spaced two meters apart (Fig. 3.3.a and 3.3.b). The same instructions that were given for skating were given for walking. All skating and walking trials were recorded from a sagittal view with a digital video recorder (JVC GC- PX100B, JVC, KENWOOD Corporation, USA).



(a)



(b)

Figure 3.1. Experimental design. Protocol testing order for PLwPD (a) and OAC (b)

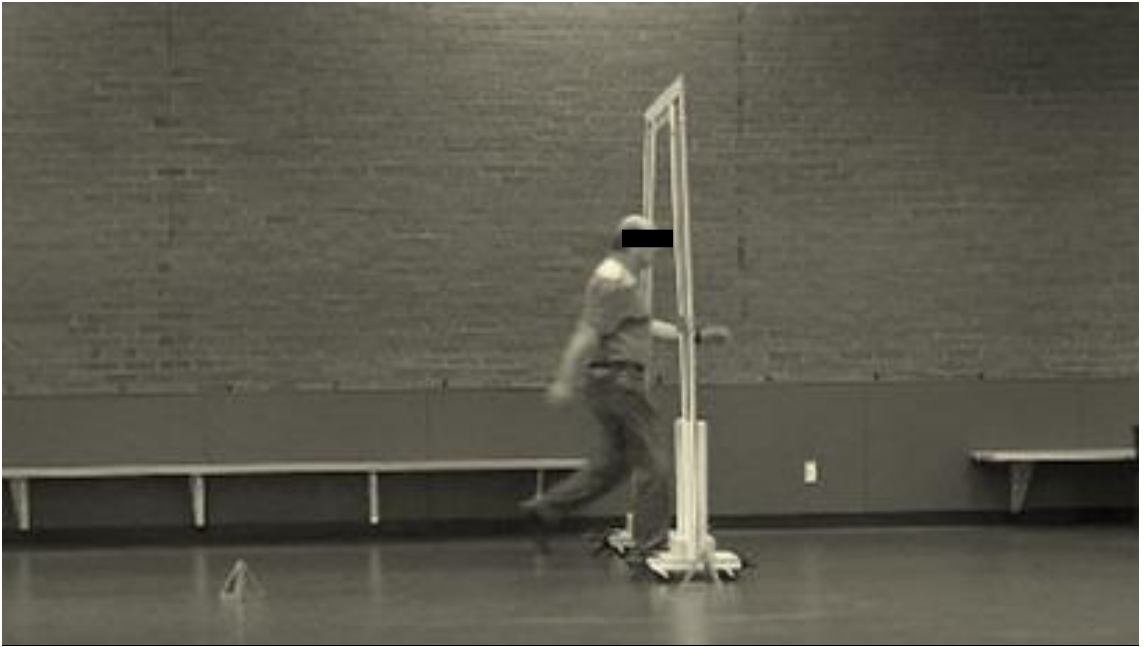
(a)



(b)



Figure 3.2. SKATE trial execution. Example of skating trials by a subject from the PD group. (a) is skating trial with door and (b) is skating trial with no door.



(a)



(b)

Figure 3.3. WALK trial execution. Example of walking trials by a subject from the PD group. (a) is walking trial with door and (b) is walking trial with no door.

3.2.3. Analysis

Videos were organized into trials and desampled into individual frames using Windows Movie Maker© (Microsoft, Seattle, Washington, USA). Segment endpoints were hand digitized frame by frame using Image J© (National Institute of Health, Bethesda, Maryland, USA). Digitized endpoints were positioned at the right ear, right hip, right hand, left hand, right knee, left knee, right heel, right toe, left heel and left toe (Fig. 3.4). When the left hand was hidden by the body this marker was also assigned to the right hip. Pixel coordinate information for each trial was imported into an Excel© (Microsoft, Seattle, Washington, USA) spreadsheet. Calculations of spatiotemporal parameters of locomotion were performed for each trial then averaged for each individual in each locomotion type. For trials with a doorway present there were two different value sets calculated (Fig. 3.5.). One value set is for the entire trial of door and no door, and the other has two phases, these being the frames before and after the door (B & A DOOR) and the frames one step from to one step beyond the doorway (DURING DOOR). Parameters of interest were average and maximum horizontal step length, maximum arm swing amplitude, average and maximum horizontal locomotion velocity, and percentage of time spent in double limb support. See formulas in Appendix A.

IBM SPSS Statistics 24 © was used for all statistical processing. There were three main questions tested. The first question was if there was a difference in locomotion between door and no door trials, which was assessed using a 2 x 2 x 2 ANOVA comparing group (PLWPD and OAC) by locomotion type (WALK and SKATE) by context (DOOR and NO DOOR). The second question was if there was a phase difference within door trials, which was assessed using a 2 x 2 x 2 ANOVA comparison of group (PLWPD and OAC) by locomotion type (WALK and SKATE) by phase (B & A DOOR and DURING DOOR). The third question was if there were walk post- skate changes amongst PLWPD, which was assessed using a 2 x 2 ANOVA of locomotion type (WALK

PRE SKATE and WALK POST SKATE) and context (DOOR and NO DOOR). To further determine door effect differences a second 2 x 2 ANOVA was performed comparing locomotion time (PRE WALK and POST WALK) and phase (B & A DOOR and DURING DOOR) amongst PLwPD. Level of significance was determined to be $p = .1$. The positive nature of exercise led to choosing a less sensitive restriction on Type I error. Exercise has well- established general health benefits that would occur following skating even if specific benefits prove false.

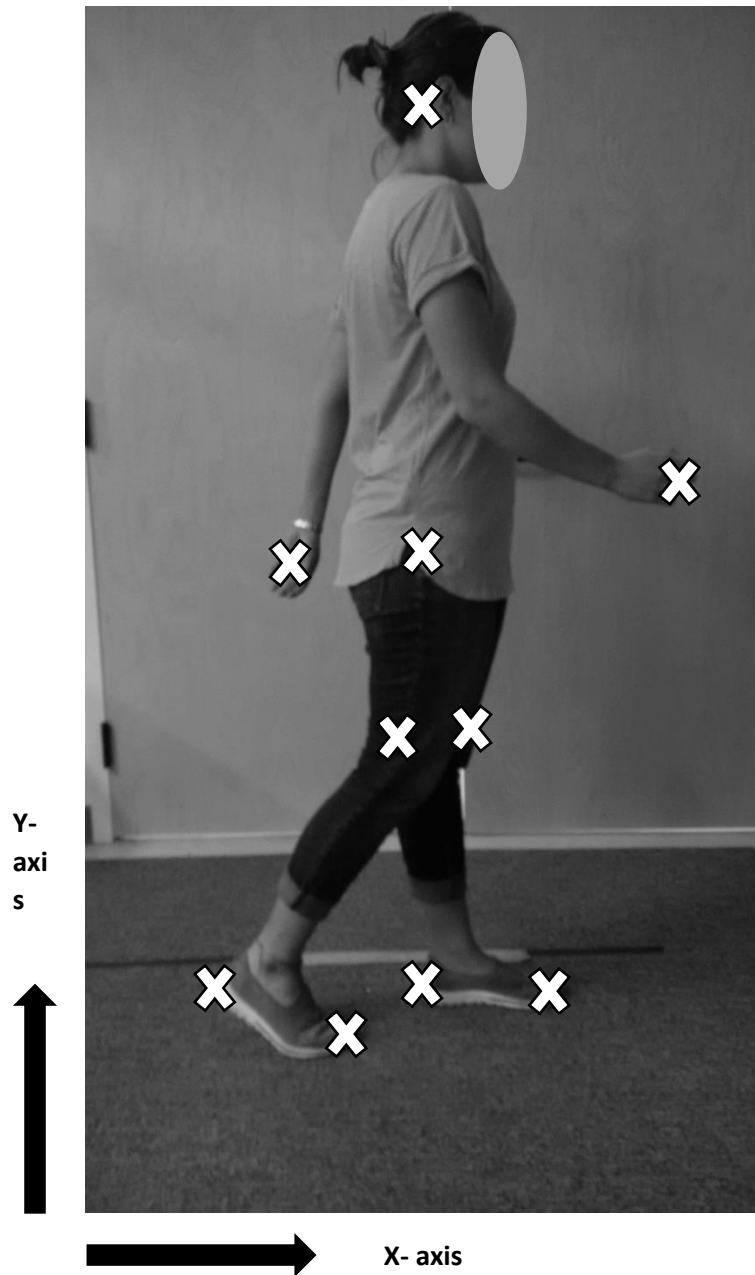


Figure 3.4. Segment endpoints. Reproduction of Image J © segment endpoint digitization over right ear, right hand, left hand, right hip, right knee, left knee, right heel, right toe, left heel, and left toe. These markers provided the coordinates used for calculations of average and maximum horizontal stride length, maximum arm swing average across both arms, average and maximum horizontal velocity, and percentage of time spent in double limb support.

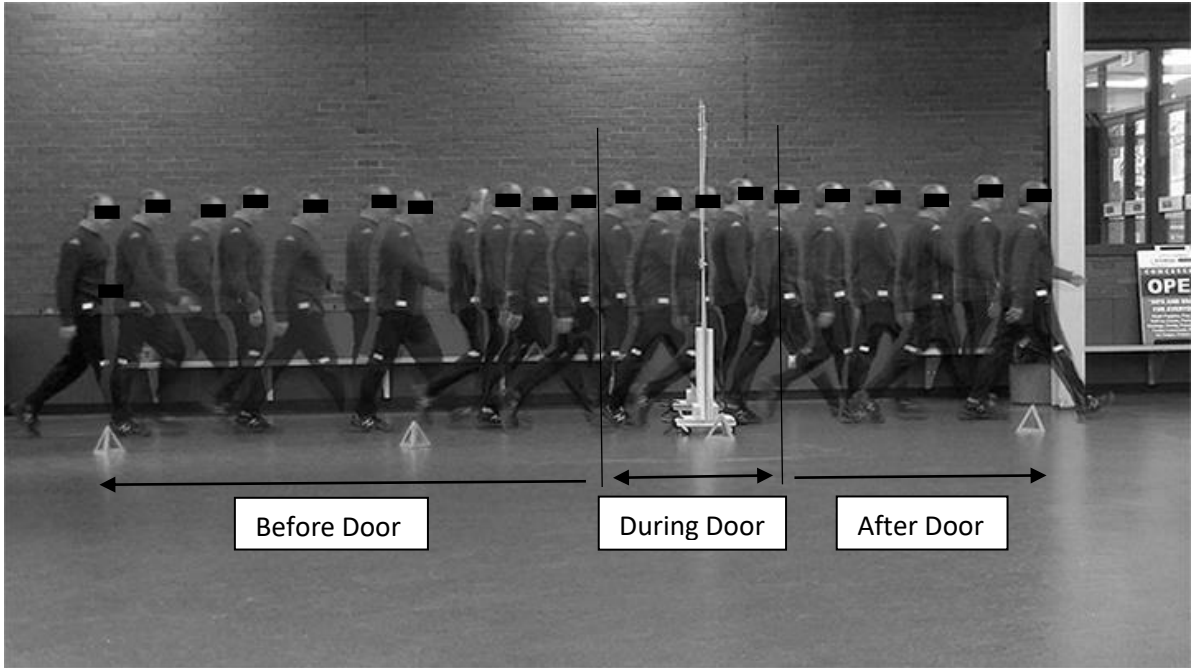


Figure 3.5. Segmentation of B & A DOOR and DURING DOOR. Depiction of area used for B & A DOOR data and DURING DOOR data.

3.3. Results

All participants were able to complete all trials. There was one fall amongst the PLwPD, one fall amongst the OAC, and one fall amongst the experimenters. There were no injuries resulting from these falls. There were no missing data, and no evidence of skewness, kurtosis, or outliers. As Mauchly's test for sphericity was significant, the Geisser- Greenhouse correction was used for all ANOVA's, with follow- up post- hoc testing using the Bonferroni procedure.

3.3.1. PLwPD and OAC WALK PRE SKATE and SKATE through doorway

3.3.1.1. Door versus no door

Comparison of PLwPD WALK PRE SKATE and SKATE and OAC WALK and SKATE trials showed significant main effects for group [$F(1, 19) = 6.280, p = .002, \text{partial } \eta^2 = .729$], locomotion [$F(1, 19) = 57.171, p < .001, \text{partial } \eta^2 = .961$], context [$F(1, 19) = 2.438, p = .080, \text{partial } \eta^2 = .511$], and group x locomotion [$F(1, 19) = 3.528, p = .024, \text{partial } \eta^2 = .602$].

Between- subjects group significance was for the variable of double stance support time (DSST) (Fig. 3.6.), with PLwPD spending significantly more time in DSST [$F(1, 19) = 18.546, p < .001, \text{partial } \eta^2 = .494$]. No other variables yielded significance: maximum horizontal step length [$F(1, 19) = .863, p = .364, \text{partial } \eta^2 = .043$] (Fig. 3.7.a), average horizontal step length [$F(1, 19) = 1.535, p = .231, \text{partial } \eta^2 = .075$] (Fig. 3.7.b), maximum horizontal velocity [$F(1, 19) = 2.322, p = .144, \text{partial } \eta^2 = .109$] (Fig. 3.8.a), average horizontal velocity [$F(1, 19) = 2.739, p = .114, \text{partial } \eta^2 = .126$] (Fig. 3.10.) (Fig. 3.8.b), or maximum arm swing [$F(1, 19) = .088, p = .771, \text{partial } \eta^2 = .005$] (Fig. 3.9.).

Follow- up comparison on the within- subject factor of locomotion revealed significance for all factors. During SKATE trials there was significantly more time spent in DSST [$F(1, 19) =$

14.583, $p = .001$, $partial \eta^2 = .434$] (Fig. 3.6.), and both maximum horizontal step length [$F(1, 19) = 32.569$, $p < .001$, $partial \eta^2 = .632$] (Fig. 3.7.a) and average horizontal step length [$F(1, 19) = 77.189$, $p < .001$, $partial \eta^2 = .802$] (Fig. 3.7.b) were shorter during SKATE. Maximum horizontal velocity [$F(1, 19) = 147.16$, $p < .001$, $partial \eta^2 = .886$] (Fig. 3.8.a), average horizontal velocity [$F(1, 19) = 159.925$, $p < .001$, $partial \eta^2 = .894$] (Fig. 3.8.b), and maximum arm swing [$F(1, 19) = 10.901$, $p = .004$, $partial \eta^2 = .365$] (Fig. 3.9.) were significantly greater during SKATE as compared to WALK.

Follow-up comparison of context showed that maximum horizontal step length [$F(1, 19) = 3.400$, $p = .081$, $partial \eta^2 = .152$] (Fig. 3.7.a) and average horizontal step length [$F(1, 19) = 11.740$, $p = .003$, $partial \eta^2 = .382$] (Fig. 3.7.b) were significantly greater in NO DOOR trails. No other variables were significant: DSST [$F(1, 19) = 2.708$, $p = .116$, $partial \eta^2 = .125$] (Fig. 3.6.), maximum horizontal velocity [$F(1, 19) = .720$, $p = .407$, $partial \eta^2 = .036$] (Fig. 3.8.a), average horizontal velocity [$F(1, 19) = .261$, $p = .615$, $partial \eta^2 = .014$] (Fig. 3.8.b), or maximum arm swing [$F(1, 19) = .018$, $p = .894$, $partial \eta^2 = .001$] (Fig. 3.9.).

Comparison of interaction for group x locomotion showed significance for the variable of DSST [$F(1, 19) = 8.186$, $p = .010$, $partial \eta^2 = .301$] (Fig. 3.6.), maximum horizontal step length [$F(1, 19) = 5.263$, $p = .033$, $partial \eta^2 = .217$] (Fig. 3.7.a) and average horizontal step length [$F(1, 19) = 3.185$, $p = .090$, $partial \eta^2 = .144$] (Fig. 3.7.b). Further follow-up comparison by splitting the group factor showed that PLWPD had significantly greater DSST [$F(1, 12) = 19.853$, $p = .001$, $partial \eta^2 = .623$] during SKATE than during WALK (Fig. 3.6.), and greater maximum horizontal step length [$F(1, 12) = 27.699$, $p < .001$, $partial \eta^2 = .698$] (Fig. 3.7.a), and average horizontal step length [$F(1, 12) = 51.237$, $p < .001$, $partial \eta^2 = .810$] during WALK than SKATE (Fig. 3.7.b). OAC had significantly greater maximum horizontal step length [$F(1, 7) = 41.152$, $p < .001$, $partial \eta^2 = .855$] (Fig. 3.7.a) and average horizontal step length [$F(1, 7) = 75.858$, $p < .001$, $partial \eta^2 = .916$]

(Fig. 3.7.b) during WALK. No other parameters were significant: maximum horizontal velocity [$F(1, 19) = 1.033, p = .322, \text{partial } \eta^2 = .144$] (Fig. 3.8.a), average horizontal velocity [$F(1, 19) = .600, p = .448, \text{partial } \eta^2 = .031$] (Fig. 3.8.b), or maximum arm swing [$F(1, 19) = .773, p = .390, \text{partial } \eta^2 = .039$] (Fig. 3.9.).

3.3.1.2. Before and after door versus during door phase

The ANOVA for group (PLWPD and OAC) by locomotion (WALK and SKATE) by phase (B & A DOOR and DURING DOOR) to determine performance differences showed that there were main effects for group [$F(1, 19) = 8.885, p < .001, \text{partial } \eta^2 = .792$], locomotion [$F(1, 19) = 53.402, p < .001, \text{partial } \eta^2 = .958$], phase [$F(1, 19) = 25.450, p < .001, \text{partial } \eta^2 = .916$], group x locomotion [$F(1, 19) = 3.427, p = .027, \text{partial } \eta^2 = .595$], and locomotion x phase [$F(1, 19) = 5.491, p = .004, \text{partial } \eta^2 = .702$].

Between- subjects follow- up for group showed that PLWPD spent a significantly greater amount of time in DSST than OAC [$F(1, 19) = 13.438, p = .002, \text{partial } \eta^2 = .414$] (Fig. 3.10.), and that PLWPD had a significantly lower average horizontal velocity than OAC [$F(1, 19) = 2.072, p = .083, \text{partial } \eta^2 = .150$] (Fig. 3.12.b). No other parameters were significantly different between groups: maximum horizontal step length [$F(1, 19) = .605, p = .446, \text{partial } \eta^2 = .150$] (Fig. 3.11.a), average horizontal step length [$F(1, 19) = 1.607, p = .220, \text{partial } \eta^2 = .078$] (Fig. 3.11.b), maximum horizontal velocity [$F(1, 19) = 2.729, p = .115, \text{partial } \eta^2 = .126$] (Fig. 3.12.b), or maximum arm swing [$F(1, 19) = .023, p = .882, \text{partial } \eta^2 = .001$] (Fig. 3.13.)

Follow- up comparison of locomotion factors showed that DSST [$F(1, 19) = 12.495, p = .002, \text{partial } \eta^2 = .397$] (Fig. 3.10.) was significantly greater during SKATE trials. Maximum horizontal step length [$F(1, 19) = 41.527, p < .001, \text{partial } \eta^2 = .686$] (Fig. 3.11.a) and average horizontal step length [$F(1, 19) = 53.071, p < .001, \text{partial } \eta^2 = .736$] (Fig. 3.11.b) were greater

during WALK trials. Maximum horizontal velocity [$F(1, 19) = 161.753, p < .001, \text{partial } \eta^2 = .895$] (Fig. 3.12.a), average horizontal velocity [$F(1, 19) = 149.225, p < .001, \text{partial } \eta^2 = .887$] (Fig. 3.12.b), and maximum arm swing [$F(1, 19) = 4.591, p = .045, \text{partial } \eta^2 = .195$] (Fig. 3.13.) were all greater during SKATE trials.

Follow-up comparison for phase showed that DSST [$F(1, 19) = 3.344, p = .083, \text{partial } \eta^2 = .150$] (Fig. 3.10.) was greater DURING DOOR as compared to B & A DOOR for both PLwPD and OAC. Maximum horizontal step length [$F(1, 19) = 6.520, p = .019, \text{partial } \eta^2 = .255$] (Fig. 3.11.a) and maximum horizontal velocity [$F(1, 19) = 18.054, p < .001, \text{partial } \eta^2 = .487$] (Fig. 3.12.a) were greater B & A DOOR, and average horizontal velocity [$F(1, 19) = 35.684, p < .001, \text{partial } \eta^2 = .653$] (Fig. 3.12.b) was greater DURING DOOR. No other variables were significant: average horizontal step length [$F(1, 19) = 2.515, p = .129, \text{partial } \eta^2 = .117$] (Fig. 3.11.b), or maximum arm swing [$F(1, 19) = .263, p = .614, \text{partial } \eta^2 = .014$] (Fig. 3.13.).

Comparisons of group x locomotion differences revealed significance for the variables of DSST [$F(1, 19) = 5.308, p = .033, \text{partial } \eta^2 = .218$] (Fig. 3.10.) and maximum horizontal step length [$F(1, 19) = 4.599, p = .045, \text{partial } \eta^2 = .195$] (Fig. 3.11.a). No other variables were significant: average horizontal step length [$F(1, 19) = 2.299, p = .146, \text{partial } \eta^2 = .069$] (Fig. 3.11.b), maximum horizontal velocity [$F(1, 19) = 2.578, p = .499, \text{partial } \eta^2 = .119$] (Fig. 3.12.a), average horizontal velocity [$F(1, 19) = 1.404, p = .251, \text{partial } \eta^2 = .069$] (Fig. 3.12.b), or maximum arm swing [$F(1, 19) = .474, p = .499, \text{partial } \eta^2 = .024$] (Fig. 3.13.). Within-group comparison showed that PLwPD and OAC both had significantly greater maximum horizontal step length [$F(1, 12) = 33.560, p < .001, \text{partial } \eta^2 = .737, F(1, 7) = 30.914, p = .001, \text{partial } \eta^2 = .815$, respectively] during WALK compared to SKATE (Fig. 3.11.a). PLwPD had significantly greater DSST [$F(1, 12) = 15.126, p = .002, \text{partial } \eta^2 = .558$] during SKATE, whereas OAC had no significant difference for this variable [$F(1, 7) = 3.423, p = .107, \text{partial } \eta^2 = .328$] (Fig. 3.7.).

Locomotion x phase was significant for the variables of DSST [$F(1, 19) = 3.222, p = .089, \text{partial } \eta^2 = .145$] (Fig. 3.10.), maximum horizontal step length [$F(1, 19) = 6.322, p = .021, \text{partial } \eta^2 = .250$] (Fig. 3.11.a), and average horizontal velocity [$F(1, 19) = 13.5181, p = .002, \text{partial } \eta^2 = .416$] (Fig. 3.12.b). Follow-up comparison was performed using pairwise t-test. DSST in SKATE B & A DOOR and DURING DOOR were both greater than WALK during the same phases of the trial [$t(20) = -4.436, p < .001$ and $t(20) = -2.754, p = .012$ respectively]. Furthermore, DSST DURING DOOR in SKATE was the greatest of all conditions [$t(20) = -2.040, p = .055$] (Fig. 3.10.). Maximum horizontal step length pairwise t-test comparisons revealed that WALK B & A and DURING DOOR were significantly greater than both SKATE B & A and DURING DOOR [$t(20) = 5.984, p < .001$ and $t(20) = 6.253, p < .001$ respectively], while SKATE B & A DOOR maximum horizontal step length was greater than SKATE DURING DOOR [$t(20) = 2.644, p = .016$] (Fig. 3.11.a). Average horizontal velocity pairwise t-test showed that SKATE B & A and DURING DOOR were greater than velocities for same phases in WALK average horizontal velocities [$t(20) = -11.672, p < .001$ and $t(20) = -12.218, p < .001$ respectively]. WALK B & A DOOR was greater than WALK DURING DOOR [$t(20) = -1.873, p = .076$] (Fig. 3.12.b). There were no significant differences for the variables of average horizontal step length [$F(1, 19) = 1.465, p = .241, \text{partial } \eta^2 = .072$] (Fig. 3.11.b), maximum horizontal velocity [$F(1, 19) = .025, p = .876, \text{partial } \eta^2 = .001$] (Fig. 3.12.b), or maximum arm swing [$F(1, 19) = .493, p = .491, \text{partial } \eta^2 = .025$] (Fig. 3.13.).

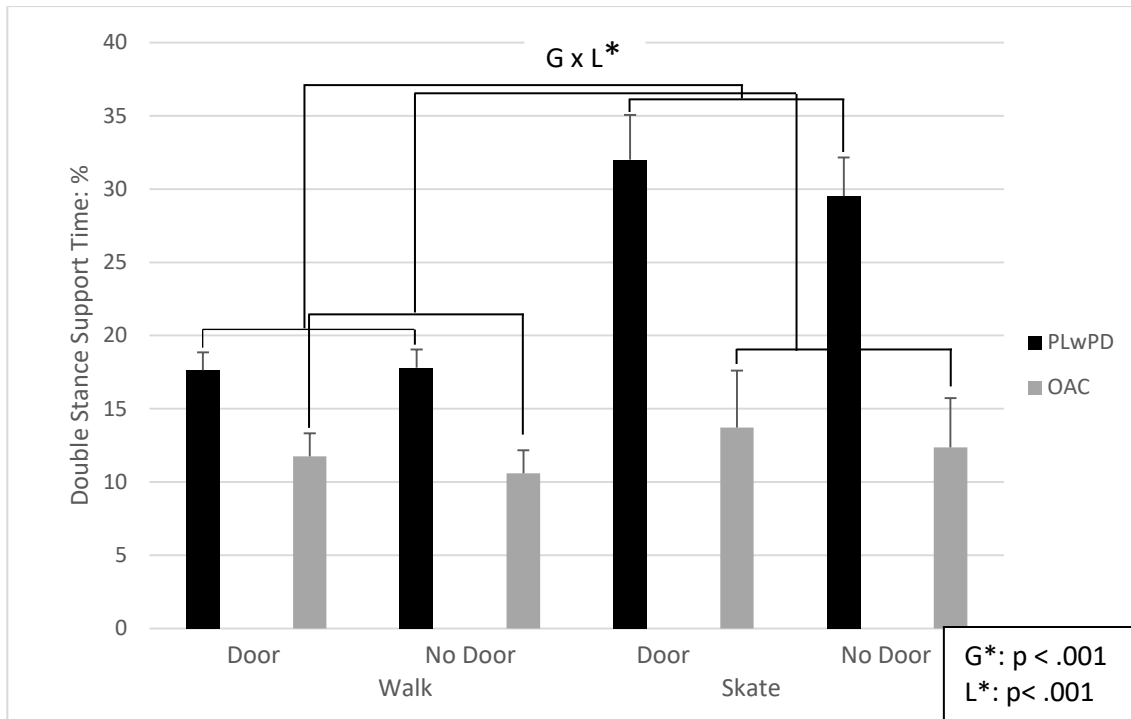
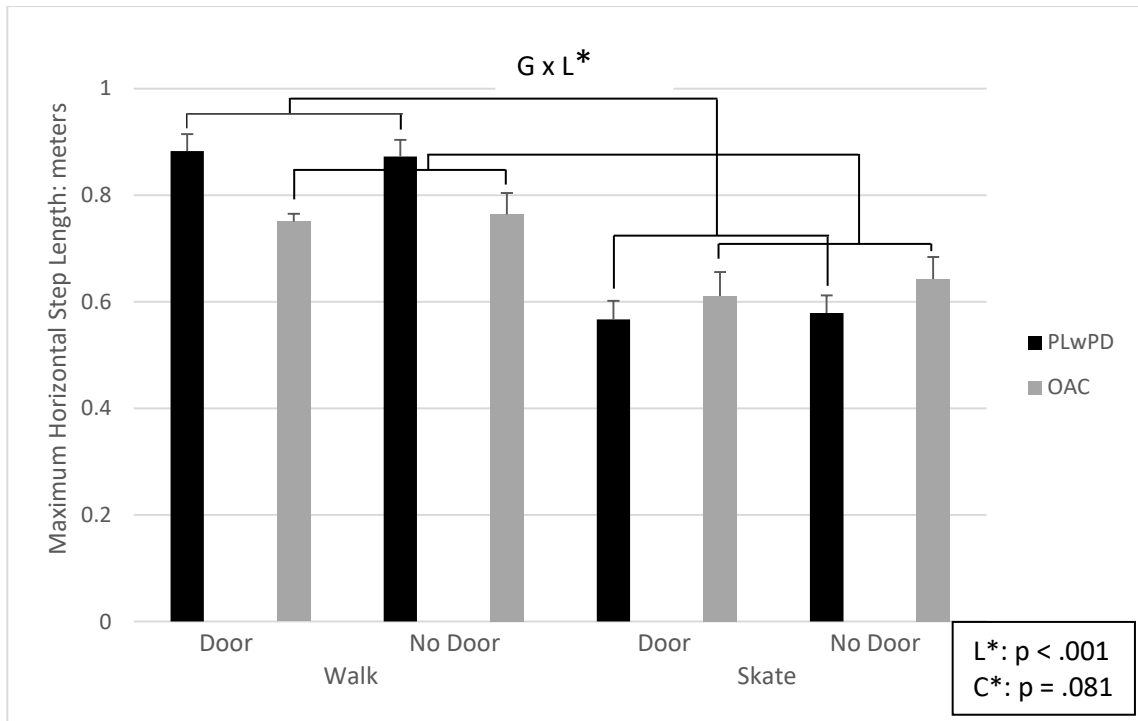
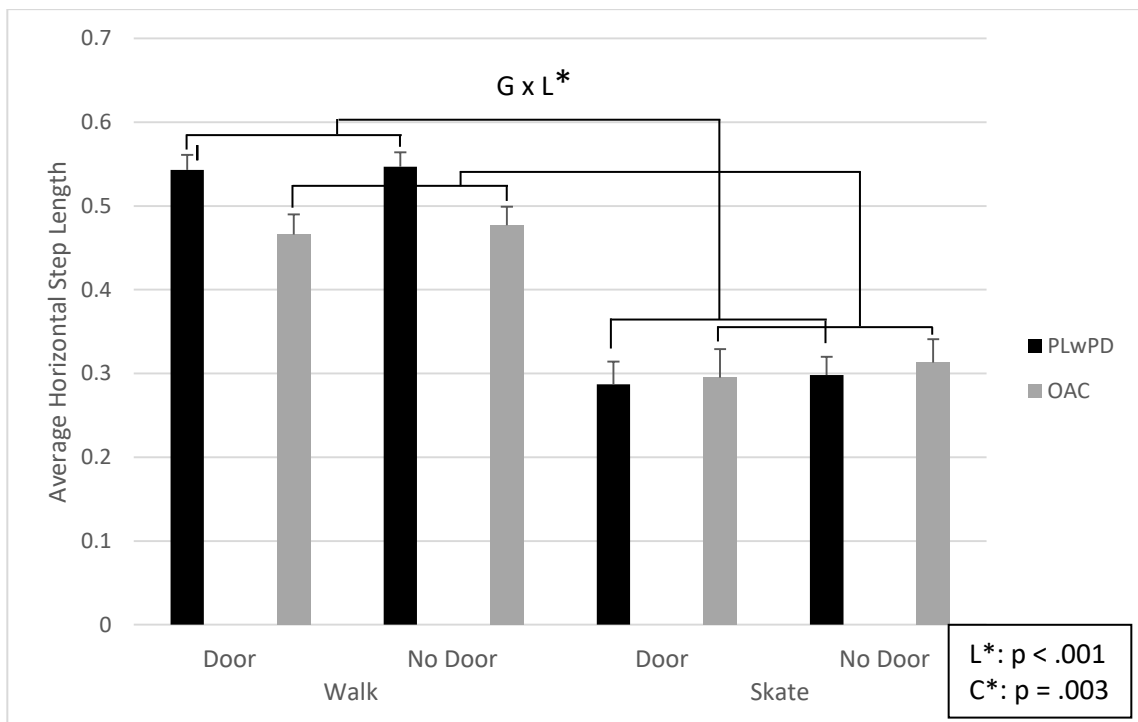


Figure 3.6. DSST percentage of PLwPD and OAC during WALK and SKATE trials. There was an overall group effect (G) of PLwPD spending significantly more time in DSST than OAC [$F(1, 19) = 18.546, p < .001, \text{partial } \eta^2 = .494$]. There was an overall locomotion effect (L) of greater DSST during SKATE than WALK [$F(1, 19) = 14.583, p = .001, \text{partial } \eta^2 = .434$]. There was a significant group x locomotion effect (G x L) effect of PLwPD having greater DSST during SKATE than PRE WALK [$F(1, 19) = 8.816, p = .010, \text{partial } \eta^2 = .301$].

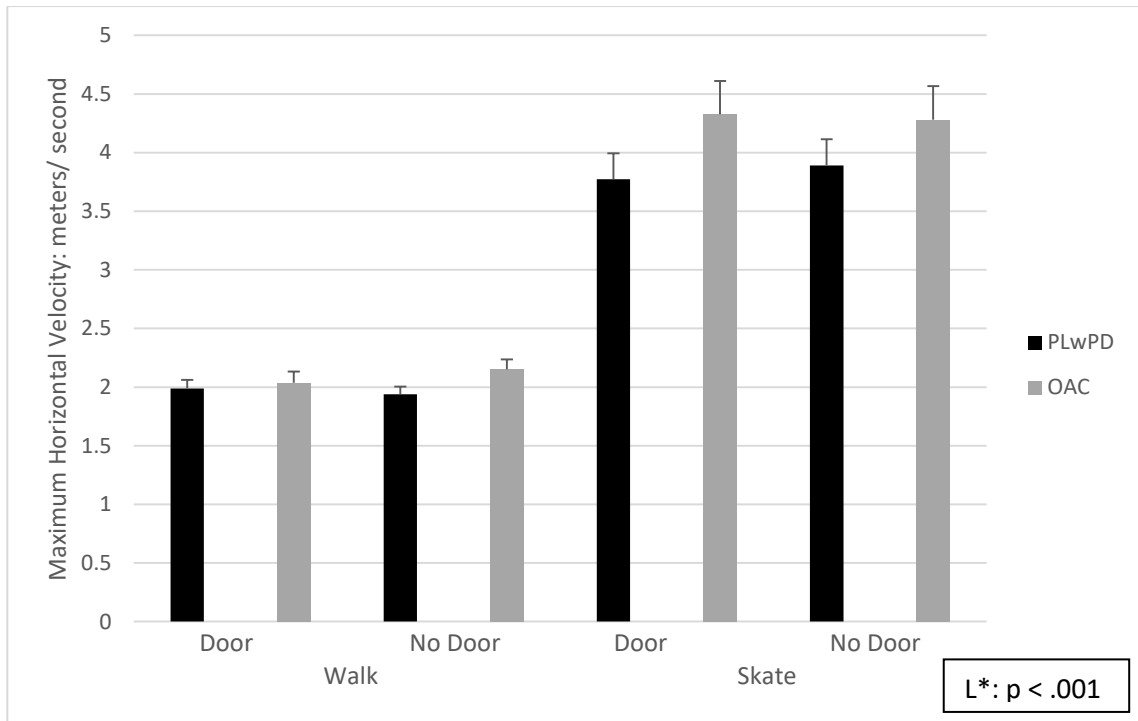


(a)

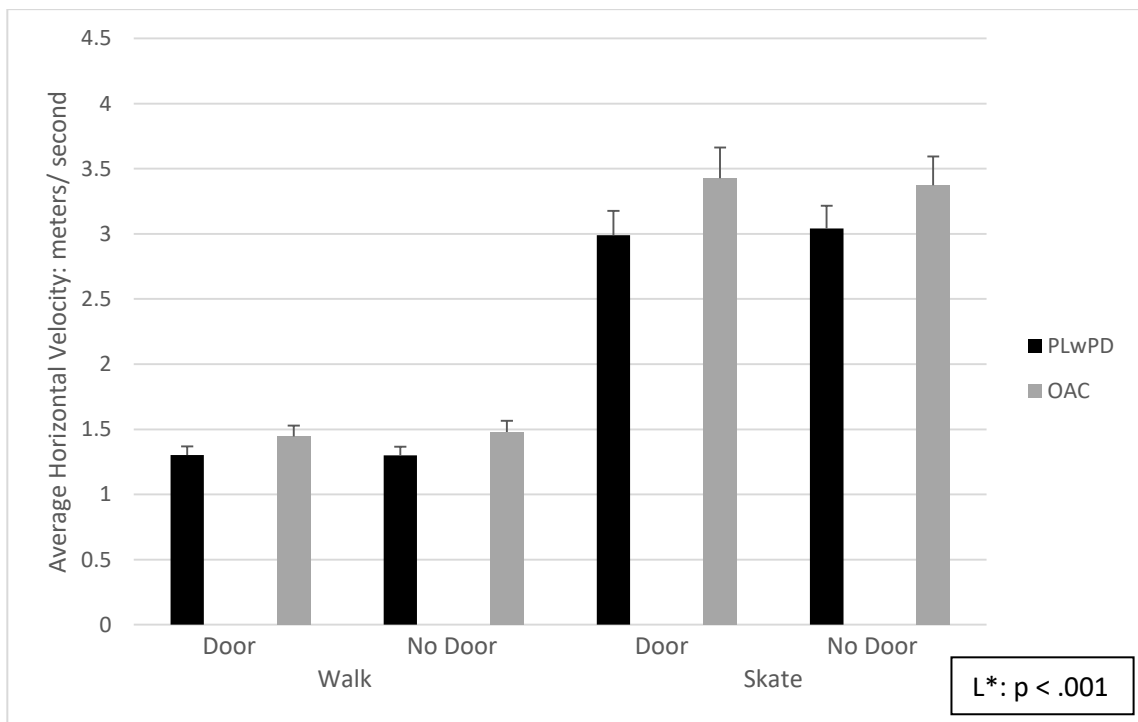


(b)

Figure 3.7. Maximum (a) and average (b) horizontal step length of PLwPD and OAC during WALK and SKATE trials. There was an overall locomotion effect (L) of greater maximum [$F(1, 19) = 32.569, p < .001, \text{partial } \eta^2 = .632$] and average horizontal step length [$F(1, 19) = 77.189, p < .001, \text{partial } \eta^2 = .802$] during WALK trials. There was an overall group \times locomotion effect (G \times L) of PLwPD and OAC having greater maximum [$F(1, 12) = 27.699, p < .001, \text{partial } \eta^2 = .698, F(1, 7) = 41.152, p < .001, \text{partial } \eta^2 = .855, \text{ respectively}$], and average horizontal step lengths [$F(1, 12) = 51.237, p < .001, \text{partial } \eta^2 = .810, F(1, 7) = 75.858, p < .001, \text{partial } \eta^2 = .916, \text{ respectively}$] during WALK trials. There was an overall context effect (C) of greater maximum [$F(1, 19) = 3.400, p = .081, \text{partial } \eta^2 = .152$] and average horizontal velocity [$F(1, 19) = 11.740, p = .003, \text{partial } \eta^2 = .382$] on NO DOOR trials as compared to DOOR trials.



(a)



(b)

Figure 3.8. Maximum (a) and average (b) horizontal velocity of PLwPD and OAC during WALK and SKATE trials. There was an overall locomotion effect (L) of significantly greater maximum [$F(1, 19) = 147.16, p < .001, \text{partial } \eta^2 = .886$], and average [$F(1, 19) = 159.925, p < .001, \text{partial } \eta^2 = .894$] horizontal velocity during SKATE as compared to WALK.

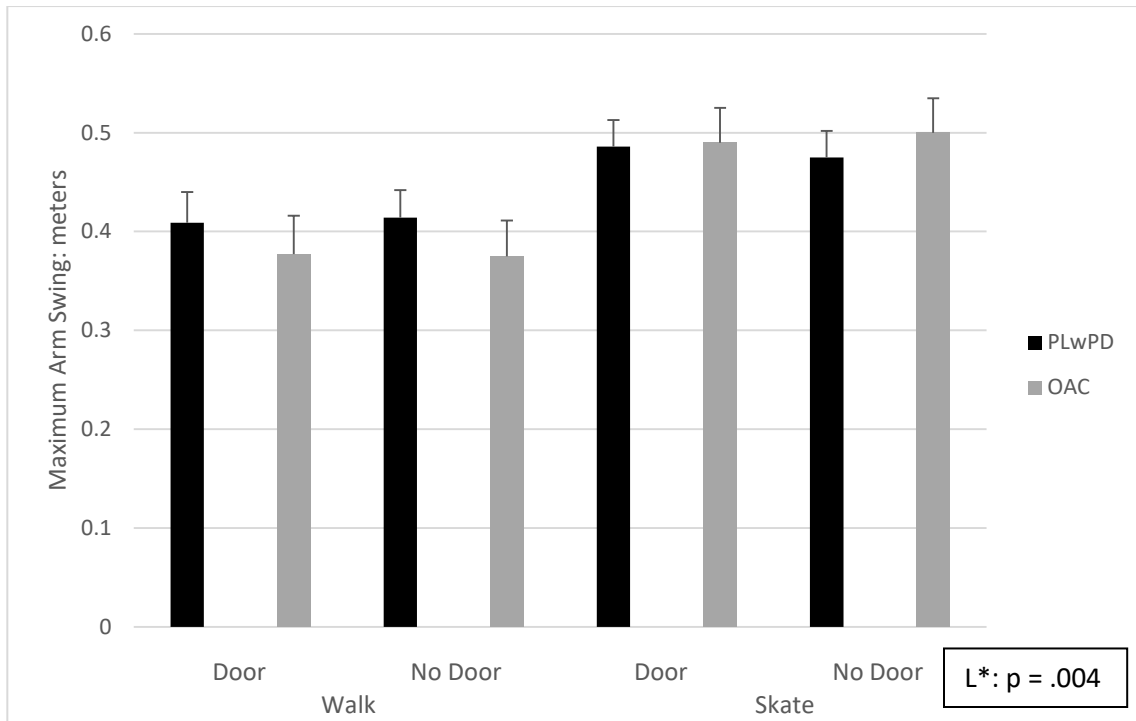


Figure 3.9. Maximum arm swing of PLwPD and OAC during WALK and SKATE trials. There was an overall locomotion effect (*L*) of significantly greater arm swing [$F(, 19) = 10.901, p = .004, \text{partial } \eta^2 = .365$] during SKATE trials as compared to WALK trials.

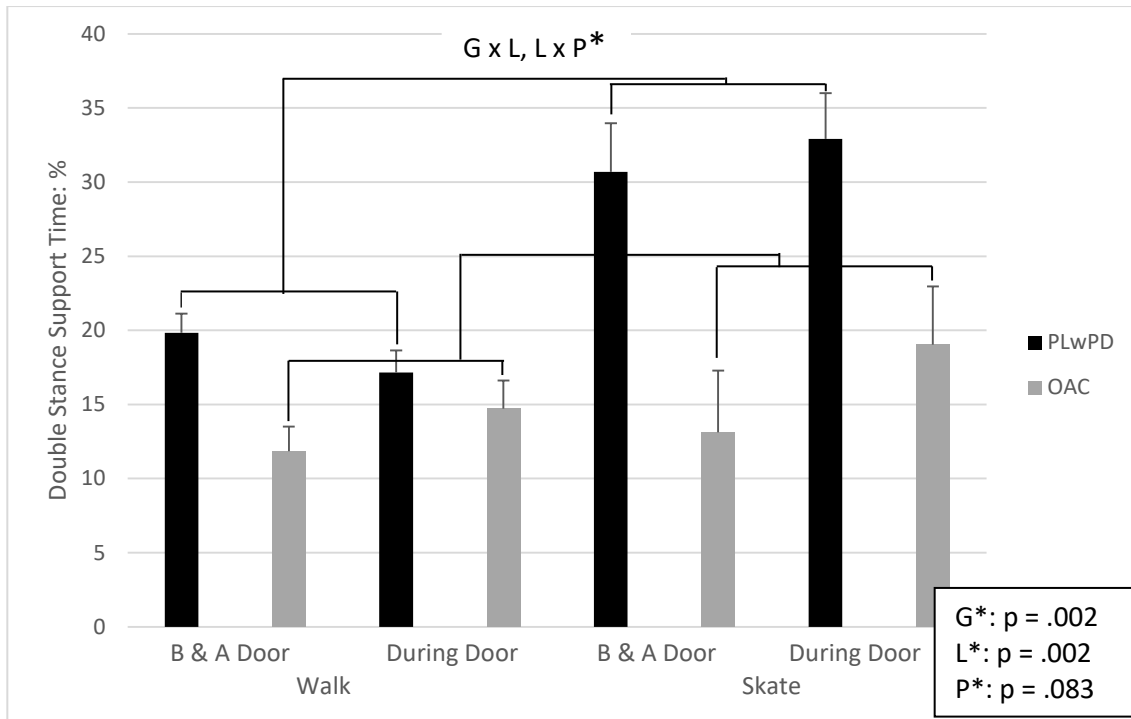
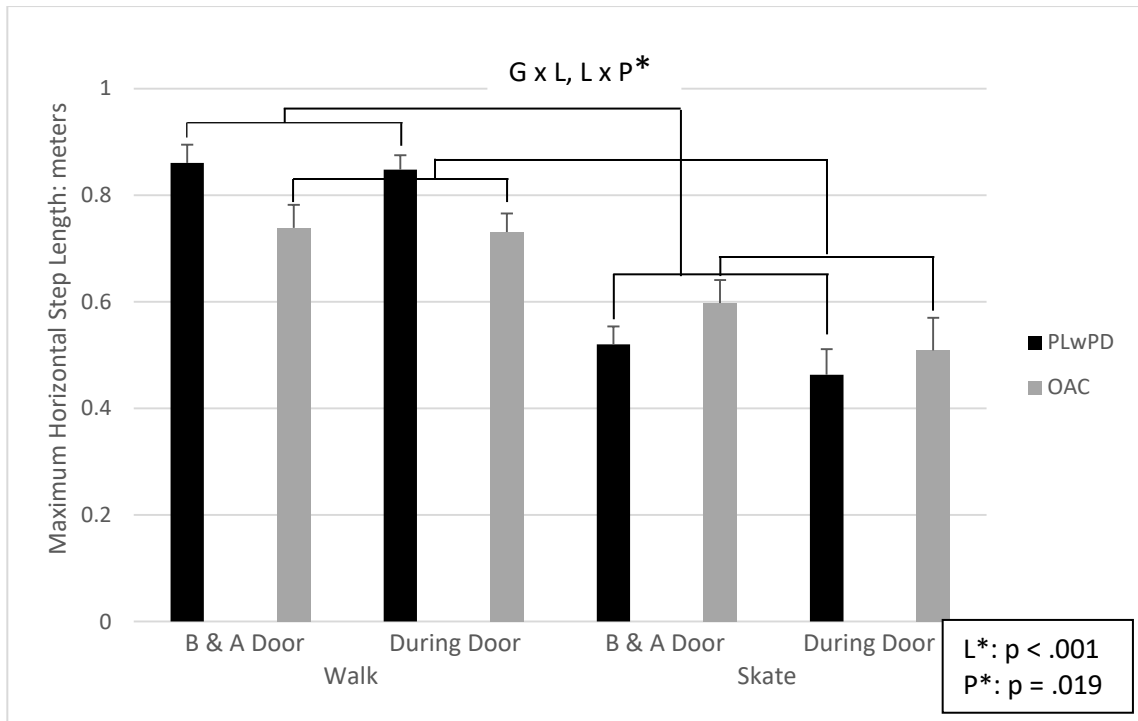
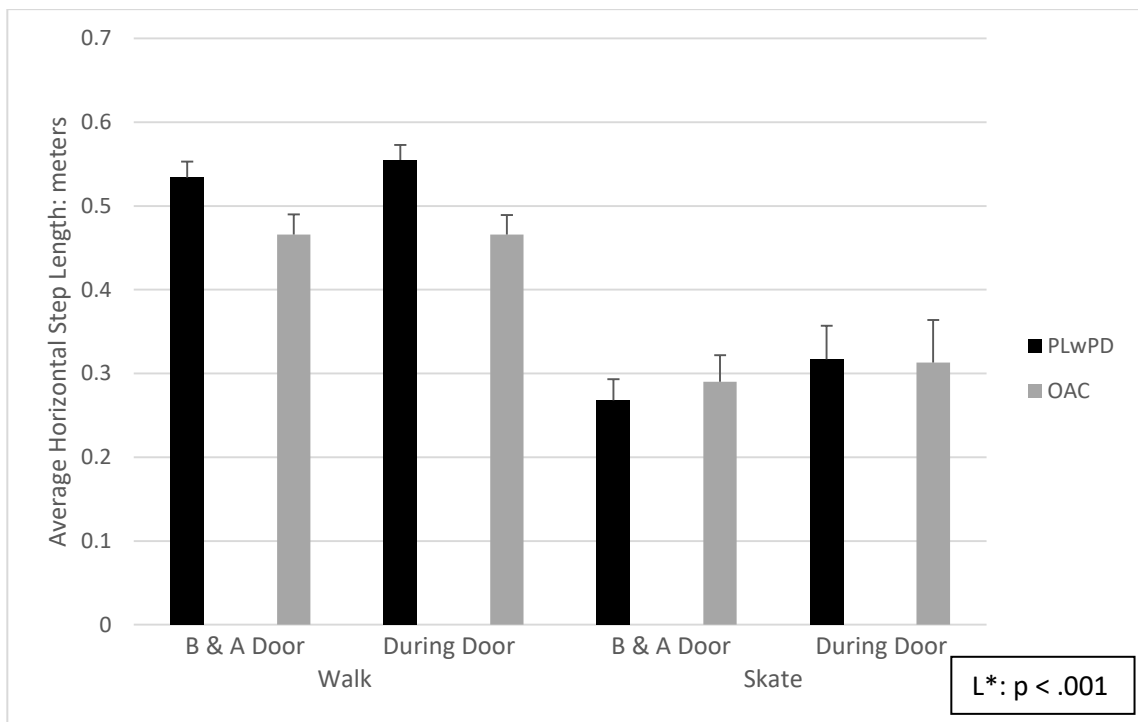


Figure 3.10. DSST percentage of PLwPD and OAC for DOOR trails during WALK and SKATE. There was an overall group effect (G) of PLwPD having greater DSST than OAC [$F(1, 19) = 13.438, p = .002, \text{partial } \eta^2 = .414$]. There was an overall locomotion effect (L) of SKATE being significantly greater than WALK [$F(1, 19) = 12.495, p = .002, \text{partial } \eta^2 = .397$]. There was an overall group x locomotion effect (L x G) of PLwPD having greater DSST [$F(1, 12) = 15.126, p = .002, \text{partial } \eta^2 = .558$] during SKATE, but there was no difference for OAC [$F(1, 7) = 3.423, p = .107, \text{partial } \eta^2 = .328$]. There was an overall phase effect (P) of DSST being significantly greater DURING DOOR as compared to B & A DOOR [$F(1, 19) = 3.344, p = .083, \text{partial } \eta^2 = .150$]. There was an overall locomotion x phase effect (L x P) of SKATE B & A DOOR and DURING DOOR both being greater than WALK during the same phases of the trial [$t(20) = -4.436, p < .001$ and $t(20) = -2.754, p = .012$ respectively]. Furthermore, DSST DURING DOOR in SKATE was the greatest of all conditions [$t(20) = -2.040, p = .055$].

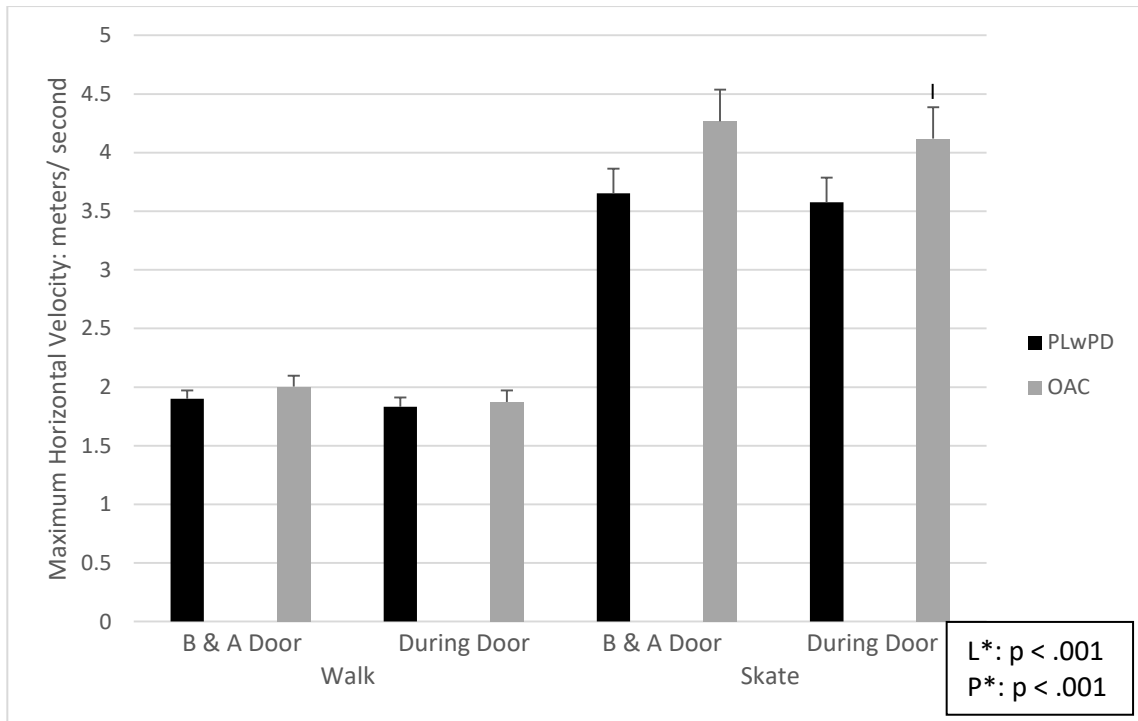


(a)

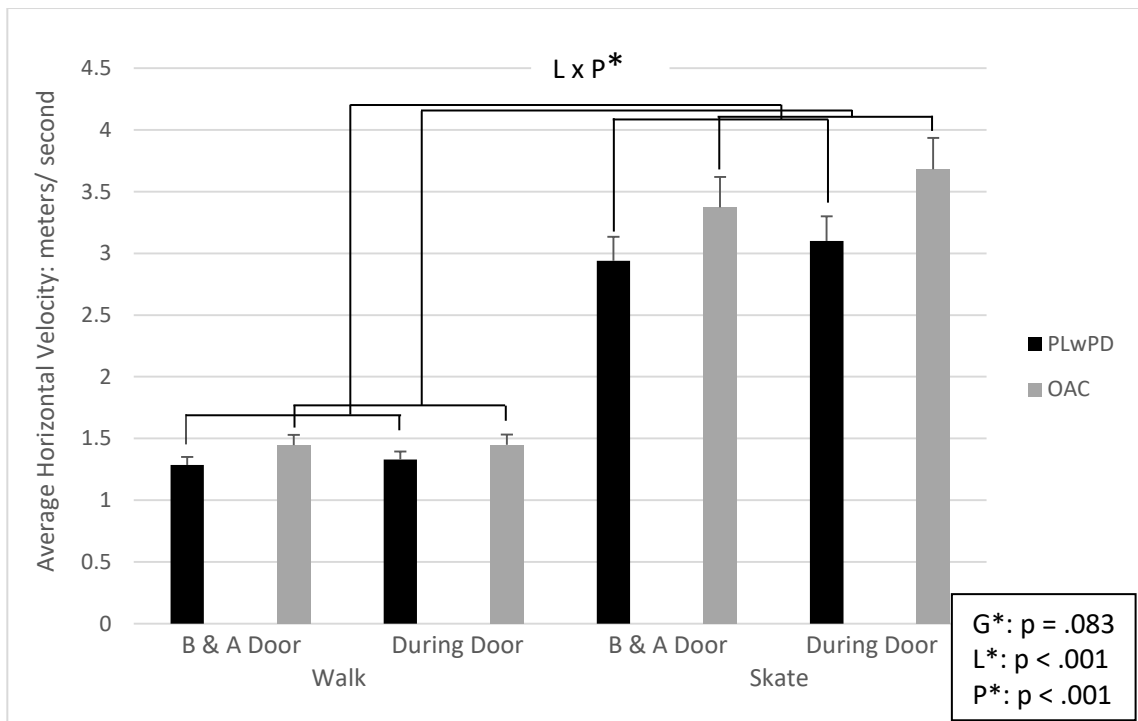


(b)

Figure 3.11. Maximum (a) and average (b) horizontal step length of PLwPD and OAC for DOOR trials during WALK and SKATE. There was an overall locomotion effect (L) of WALK being significantly greater than SKATE for maximum [$F(1, 19) = 41.527, p < .001, \text{partial } \eta^2 = .686$] and average horizontal step length was greater during SKATE [$F(1, 19) = 53.071, p < .001, \text{partial } \eta^2 = .736$, respectively]. There was an overall group x locomotion effect (G x L) of maximum horizontal step length [$F(1, 19) = 6.520, p = .019, \text{partial } \eta^2 = .255$] being greater during WALK for both PLwPD and OAC. There was no significant difference for average horizontal step length [$F(1, 19) = 2.515, p = .129, \text{partial } \eta^2 = .117$]. There was an overall phase effect (P) of increased maximum horizontal step length B & DOOR [$F(1, 19) = 6.520, p = .019, \text{partial } \eta^2 = .255$]. There was no significant difference for average horizontal step length [$F(1, 19) = 2.515, p = .129, \text{partial } \eta^2 = .117$]. There was an overall locomotion x phase effect (L x P) of maximum horizontal step length during WALK B & A DOOR being significantly greater than SKATE B & A DOOR [$t(20) = 5.984, p < .001$], and SKATE DURING [$t(20) = 6.253, p < .001$], SKATE B & A DOOR was greater than SKATE DURING DOOR [$t(20) = 2.644, p = .016$] but was less than WALK DURING [$t(20) = -6.338, p < .001$]. There was no significance for average horizontal step length [$F(1, 19) = 1.465, p = .241, \text{partial } \eta^2 = .072$].



(a)



(b)

Figure 3.12. Maximum (a) and average (b) horizontal velocity of PLWPD and OAC for DOOR trials of WALK and SKATE. There was an overall group effect (G) of OAC having significantly greater average horizontal velocity [$F(1, 19) = 2.072, p = .083, \text{partial } \eta^2 = .150$]. There was no significant difference for maximum horizontal velocity [$F(1, 19) = 2.729, p = .115, \text{partial } \eta^2 = .126$]. There was an overall locomotion effect (L) of maximum and average horizontal velocity being significantly greater during SKATE [$F(1, 19) = 161.753, p < .001, \text{partial } \eta^2 = .895, F(1, 19) = 149.225, p < .001, \text{partial } \eta^2 = .887, \text{ respectively}$]. There was an overall phase effect (P) of maximum horizontal velocity being greater B & A DOOR [$F(1, 19) = 18.054, p < .001, \text{partial } \eta^2 = .487$], and average horizontal velocity [$F(1, 19) = 35.684, p < .001, \text{partial } \eta^2 = .653$] being greater DURING DOOR. There was an overall locomotion x phase effect (L x P) of average horizontal WALK B & A being greater than WALK DURING [$t(20) = -1.873, p = .076$], WALK B & A being significantly less than SKATE B & A [$t(20) = -11.672, p < .001$] and SKATE DURING [$t(20) = -12.770, p < .001$], and SKATE DURING being significantly greater than SKATE B & A [$t(20) = -4.465, p < .001$] and WALK DURING [$t(20) = -12.218, p < .001$]. There was no significant difference for maximum horizontal velocity [$F(1, 19) = .025, p = .876, \text{partial } \eta^2 = .001$].

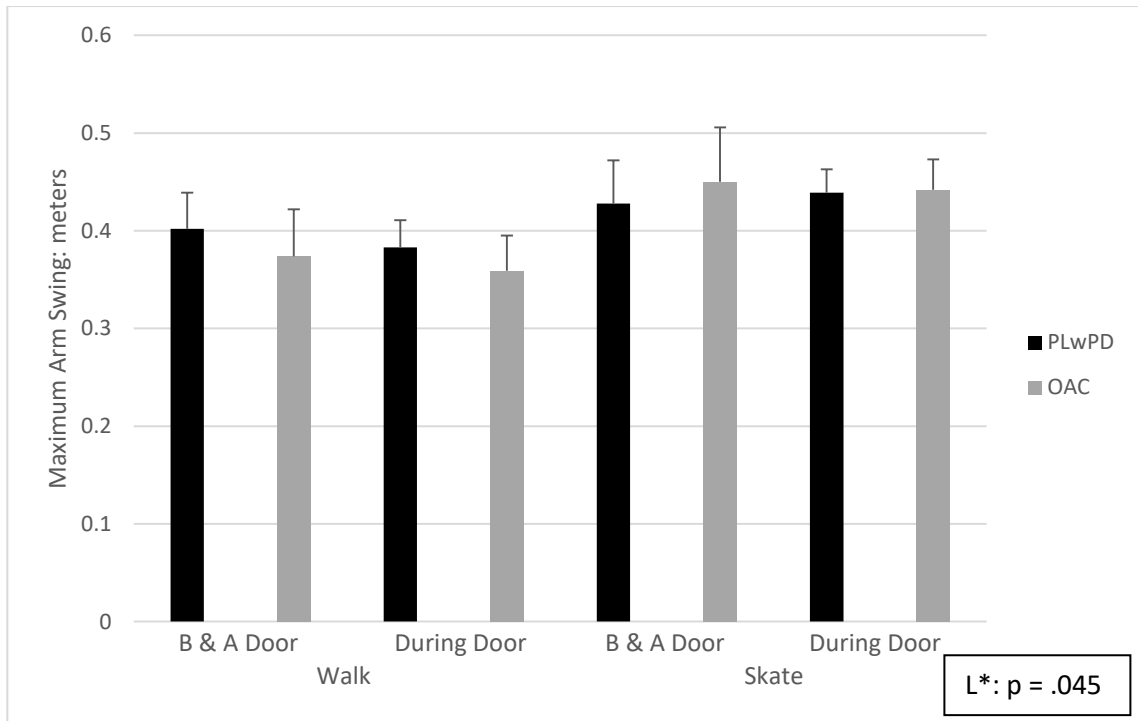


Figure 3.13. Maximum arm swing of PLwPD and OAC for DOOR trials of WALK and SKATE. There was an overall locomotion effect (L) of significantly greater maximum arm swing during SKATE trials as compared to WALK trials [$F(1, 19) = 4.591, p = .045, \text{partial } \eta^2 = .195$].

3.3.2. PLwPD WALK PRE SKATE versus WALK POST SKATE

Comparison of PLwPD WALK PRE and POST SKATE performance kinematics for DOOR and NO DOOR had no significant main effects: locomotion [$F(1, 12) = 2.569, p = .121, \text{partial } \eta^2 = .688$], door presence [$F(1, 12) = 1.398, p = .333, \text{partial } \eta^2 = .545$], or locomotion x door presence [$F(1, 12) = .502, p = .790, \text{partial } \eta^2 = .301$].

The second ANOVA for PLwPD WALK PRE and POST SKATE trials for phase (B & A DOOR and DURING DOOR) had significant main effects of door crossing [$F(1, 12) = 3.923, p = .048, \text{partial } \eta^2 = .771$]. Within- subject comparisons showed that this was for the variable of average horizontal step length [$F(1, 12) = 5.370, p = .039, \text{partial } \eta^2 = .309$] (Fig. 3.14.), which was greater DURING DOOR as compared to B & A DOOR. No other variables were significantly different: DSST [$F(1, 12) = 51.849, p = .129, \text{partial } \eta^2 = .182$], maximum horizontal step length [$F(1, 12) = .642, p = .439, \text{partial } \eta^2 = .051$], maximum horizontal velocity [$F(1, 12) = 1.473, p = .248, \text{partial } \eta^2 = .109$], average horizontal velocity [$F(1, 12) = 1.181, p = .299, \text{partial } \eta^2 = .090$], or maximum arm swing [$F(1, 12) = .427, p = .526, \text{partial } \eta^2 = .034$].

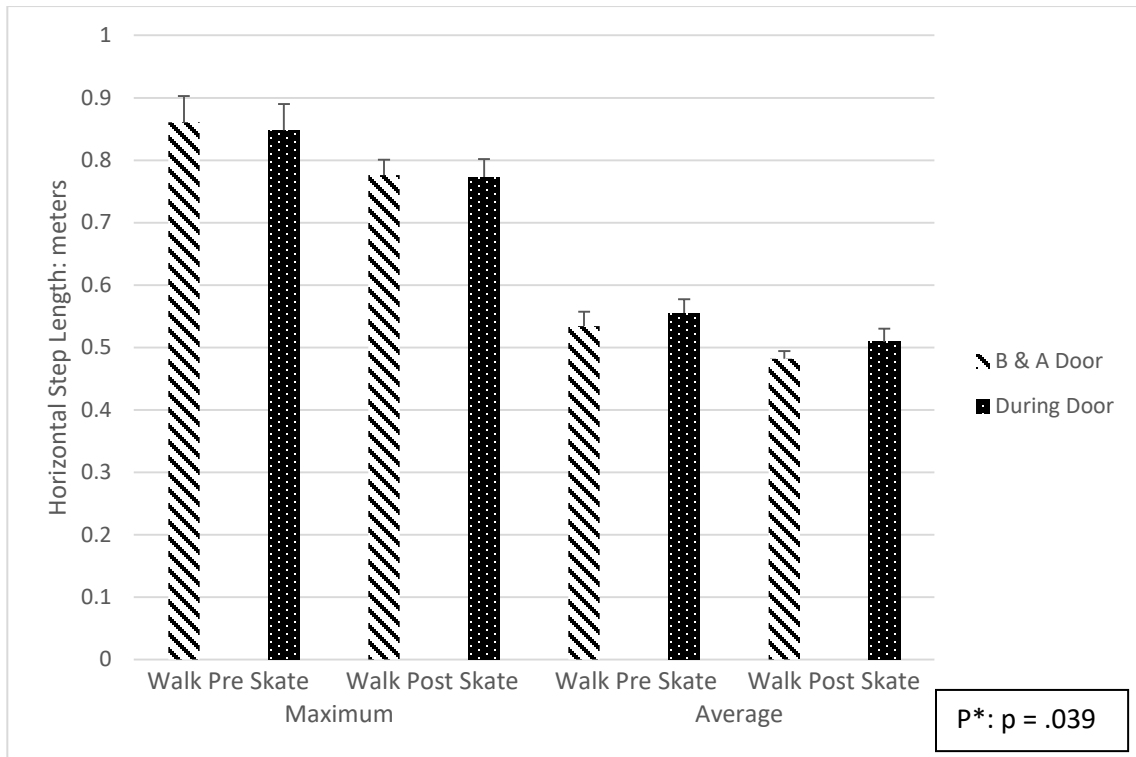


Figure 3.14. Maximum and average horizontal step length of PLwPD for DOOR trials of PRE and POST WALK. There was an overall phase effect (P) of PLwPD having significantly increased average horizontal step length [$F(1, 12) = 5.370, p = .039, \text{partial } \eta^2 = .309$] DURING DOOR as compared to B & A DOOR. Maximum horizontal step length was not significantly different [$F(1, 12) = .642, p = .439, \text{partial } \eta^2 = .051$].

3.4. Discussion

The aim of this study was to examine ice skating and walking kinematics while door crossing, an action known to provoke locomotor deficits amongst many people living with Parkinson's disease (PLwPD). This research was done to determine if paradoxically preserved ice- skating was still present when door crossing, and if ice skating exercise had an immediate positive effect on walking kinematics in the doorway context. Our results showed that both PLwPD and OAC skated towards and through a doorway with similar kinematics. Moreover, during skating trials both PLwPD and OAC had similarly increased double stance support time (DSST), decreased maximum and average horizontal step length, increased maximum and average horizontal velocity, and increased maximum arm swing amplitude compared to walking trials. PLwPD did spend more time in DSST than OAC for either locomotion type. Both groups decreased maximum and average horizontal step length in door trials compared to non- door trials.

Comparing locomotion kinematics between door crossing phases revealed that both PLwPD and OAC made gait alterations when approaching the doorway in either locomotion pattern. Doorway affected walking for both groups- maximum horizontal step length, maximum horizontal velocity, and average horizontal velocity significantly increased before and after door compared to during door crossing. During skating both groups' displayed this same door rushing behavior by having increased maximum horizontal velocity and step length before and after door, but alternatively had increased average horizontal velocity and DSST during door crossing. This strategy may be enabled by both the physical and the neurological mechanics of skating. Participants can use double stance support or gliding as locomotion, and a gliding posture may present less opportunity for physical inference with the narrowed context of the doorway, as gliding reduces the need for lateral striding, and thus decreases the stance width. This locomotor flexibility, specifically the opportunity to select an increased gliding phase with increased

velocity and DSST, may be enabled by the stimulating rapid visual flow of ice skating. In other modalities, visual flow stimulates motor activity and spares directed attention (Azulay et al., 1999; Ehgoetz Martens, Pieruccini-Faria, & Almeida, 2013; Majsak et al., 1998), possibly minimizing the confounding attentional interference of challenging environmental contexts like a doorway. In the current study, PLWPD were challenged while walking towards the doorway, as evidenced by increased DSST, but were enabled in skating to generate higher velocity to travel through the doorway. OAC had no significant difference between walking and skating DSST during door present trials.

Comparison of PLWPD walk trials showed an increase in average horizontal step length during door as compared to before and after door for post walk trials. Increased step length during door crossing may be an indication of improved internal motor pathway activation after one bout of ice- skating.

3.4.1. Attentional demand of visual information

Well- learned motor repertoires like walking are typically internally cued by the basal ganglia and regulated by the supplementary motor area (SMA) (Brotchie, Iansek, & Horne, 1991; Deiber, Ibañez, Sadato, & Hallett, 1996; Jahanshahi et al., 1995; Morris, Iansek, Summers, & Matyas, 1995; Mushiake, Inase, & Tanji, 1991). Imaging studies have shown that PLWPD have decreased activation of the internally cued basal- ganglia- SMA loop, and as a result have impaired gait regulation, as observed in PLWPD baseline walking trials in this study. Imaging studies have also shown that some PLWPD have developed a compensatory strategy to circumvent the impaired internally cued motor pathway by using the externally cued motor pathway. This alternative pathway is largely preserved amongst PLWPD and is driven by directed attention to external visual cues resulting in improved motor actions (Hanakawa, Fukuyama,

Katsumi, Honda, & Shibasaki, 1999; Rascol et al., 1997; Snijders et al., 2011; van der Hoorn et al., 2014). In order for this more preserved pathway to be used, individuals' attention must be directed externally to the cued environment. Many previous studies have shown improved gait parameters with the use of explicit visual cues, like transverse line markings (Azulay et al., 1999, 2006; Hanakawa et al., 1999; Martin, 1967). The presence of the lines perpendicular across a walkway directed attention to the cues, generating cortical activation through the more preserved externally cued areas of the posterior parietal cortex and premotor cortex (Azulay et al., 2006; Hanakawa et al., 1999). A similar stimulation has been postulated during volitional tasks (Asmus et al., 2009; Snijders, Toni, et al., 2011). Voluntary motor actions rely more heavily on external cueing (van der Hoorn et al., 2010), so performing them may increase the reliance on the more preserved external pathway (Majsak et al., 1998). As the inherent nature of these tasks may already draw the attention to the external environment, it has been predicted that naturally- occurring contextual cues may be driving improved motor function in these situations, allowing for improved motor performance (Snijders, Toni, et al., 2011).

Cue attention, however, becomes problematic in the presence of increased, novel, or attention dividing visual cues. Visuomotor processing is impaired in some PLWPD when attentional demand is increased (Cowie et al., 2010; van der Hoorn et al., 2014). An interference effect can take place, which may result in further impairments to motor function (Morris, Iansek, Matyas, & Summers, 1996). This conflict is possibly revealed during door crossing pre- walk trials, evidenced by decreased step length and velocity during door crossing. Conversely, during ice skating door crossing PLWPD did not hesitate but rather made motor adjustments to improve the probable success of doorway crossing, as seen by increased average horizontal velocity and DSST gliding. Skating strides are wider than walking and as such individuals need to assess their ability to fit through the doorway in the different phases of skating. As gliding reduces lateral

width, a gliding posture would provide the least amount of physical interference when passing through the doorway (Bracko, 2004). Participants needed to determine that this was the case and adjust stride so that they could perform a 'hard push' prior to the door, increasing average horizontal velocity, so they had enough momentum to glide through the door, increasing DSST. PLWPD motor adjustments made during ice skating door crossing were similar to OAC, possibly indicating a reduction in attentional interference and improved directed attention to pertinent cues. Generation of an environmentally specific motor plan in response to ecological context may reflect the rise of directed attention. We postulate this may have occurred because when walking PLWPD have been predicted to experience attentional interference which creates a tendency to 'over- react' to visual stimuli. Cowie et al (2010) demonstrated that when PLWPD approach a doorway while walking they make the same gait adjustments as neurotypical individuals, but in an exaggerated fashion. In skating PLWPD and OAC make the same kinematic adjustments to pass through the doorway, but no exaggeration was observed amongst PLWPD. This may have occurred because of the rapid visual flow afforded by ice skating, as rapid visual flow has previously been associated with PK (Azulay et al., 1999; Snijders, Toni, et al., 2011). Skating occurs at a higher velocity than walking, and as such will have more rapid visual flow. This format of visual information may increase attention to visual cues, stimulation from visual cues, or both. This may have occurred through more gaze time being focused at the door and less time directing gaze at other visual stimuli. More gaze time focused on the door may reduce intake and processing resources toward non- door stimuli, allowing for improved motor planning and execution of door crossing, as was seen during ice skating. Although we did not assess gaze patterns in this study previous work has found that increased target gaze amongst PLWPD results in improved door crossing (Beck, Martens, & Almeida, 2015).

3.4.2. Latency of improved motor function

During post- walking trials, as compared to pre- walk, PLWPD had an increase of average horizontal step length during door. PLWPD had no significant difference in gait parameters before and after the door between pre and post- walk trials. We suggest that the attentional demand of the dual task of walking and door planning remained the same during doorway approach, resulting in the same attentional interference as in pre- walk trials. During door crossing there is a reduction in visual information which may have caused a reloading of pathway activation from the external motor pathway to the internal motor pathway. Previous research has shown that immediately post vigorous exercise the basal ganglia and SMA, components of the internal motor pathway, have increased activation (Alberts et al., 2011). The intensity at which skating was performed at may have triggered a similar response, increasing the activation of the basal ganglia and SMA, thus resulting in the improved motor function during door crossing.

This study was limited by selection bias. Pre- enrollment individuals were told that they would be performing ice skating which may have targeted a more active PD population of mild to moderate disease severity. This may have lowered the potential effect of the ice skating as subjects already may have been displaying improved motor performance from other physical activities. Despite the potential 'ceiling effect' of previous physical activity there were still improvements, potentially making this data more translational to future participants that may have higher than typical activity levels. Another limitation was the doorway itself. The doorway structure was just the frame and was not mounted within a wall as most naturally occurring doorways are. This may have altered the attentional demand of external visual stimulation from that of what may be experienced when a doorway is mounted within a wall. However, the same doorway design was used for all trials, and previous research has effectively used a similar design (Cowie et al., 2010). This structure was also deemed appropriate as it allowed for the

doorway to be moved in and out of the pathway so the same visual environment was always used, and allowed for a randomized deliverance of trials. On- site multi- rink testing was another limitation. Instead of in a controlled laboratory setting with a skating treadmill, testing was performed at ice rinks and on the ice. We chose this as skating treadmills alter skating kinematics making direct translation difficult (Nobes et al., 2003). Also, the laboratory will have a different ecological context than ice rinks, which we believe may play an important role in ice skating performance. By performing testing in the natural environment the translation of this data is enhanced for future community- dwelling interventions.

3.4.3. Conclusion

PLWPD are able to ice skate through doorways with decreased hesitation, and possibly decreased attentional interference. This remarkable ability had a carry- over effect of increased average horizontal step length DURING DOOR, which may be an indication of improved neural reloading. Future research should focus on examining the dose response for retention post- ice skating intervention, as well as gaze analysis during ice- skating to determine attentional focus. A neural reloading effect that improves kinematic transitioning when doorway crossing would make ice skating an appealing option for freezing of gait neurotherapy amongst some PLWPD who have previous ice skating experience.

4.0. Discussion

To summarize the main findings of this thesis

4.0.1. People living with Parkinson's disease (PLwPD) can ice skate safely and skillfully, and ice skating could become part of an exercise therapy program

PLwPD who felt they could ice skate safely and skillfully were recruited from 7 Canadian cities. These participants were able to ice skate with similar kinematic characteristics as older adult controls (OAC). Immediately after one session of ice skating, walking parameters improved amongst some PLwPD who had previous experience at ice skating, making ice skating a potential exercise intervention.

4.0.2. PLwPD are able to ice skate through a doorway

PLwPD demonstrated conservative locomotor kinematics when walking through a doorway possibly reflective of sub-threshold freezing. This same cautious behavior was not observed amongst OAC. PLwPD were able to ice skate through a doorway with similar kinematic parameters as OAC. Immediately after ice skating PLwPD were able to walk through a doorway with increased average horizontal step length, making *paradoxical kinesias*, including ecological and vibrant visual flow, a viable paradigm for experimental and clinical examination of freezing of gait.

4.1. Paradoxical kinesia: Ice skating is a paradoxically preserved skill amongst PLwPD

Previous research has shown that when PLwPD are presented with specific sensory stimulations, many are able to perform smooth, skillful motor actions that are paradoxical to their typical movement deficits (Glickstein & Stein, 1991). The landmark study by Martin (1967) elicited paradoxical gait amongst PLwPD by placing transverse lines along a walkway. These visual cues provided PLwPD with immediate kinematic improvements in gait performance. Since this time other experiments have successfully used external cues to elicit enhanced motor performance. Azulay et al (1999) built on the line walking experiments by introducing variable light while walking on the transverse line pathway. Dynamic conditions had uninterrupted 'normal' lighting and static conditions were performed under stroboscopic lighting, creating the appearance that the lines were stationary. Preserved gait occurred during dynamic visual cueing and gait was impaired when cues appeared static (Azulay et al., 1999). Majsak et al (1998) used a ball paradigm where speed of grasp was measured when the ball was stationary and when rolling down a ramp. During static trials PLwPD were slower than controls, but during dynamic visual cue trials of the ball rolling PLwPD produced maximal speeds and movement accuracy comparable to healthy controls (Majsak et al., 1998). More recently, ecological external cues have also been tested. Asmus and colleagues (2009) presented a case study with a 68 year old man with PD who typically experienced strong freezing of gait. A ball attached to a wrist string, simulating a soccer ball, was given to the man as an external cue for steps and movement. The resultant effect was that the patient dribbled the ball skillfully, locomoting forward quickly and capably with no assistance (Asmus et al., 2009). Snijders and Bloem (1999) also had positive results for cycling with a 58 year old man diagnosed, with PD for 10 years, who had severe motor dysfunction. When walking he suffered from freezing and festination, but when mounted on a bicycle he was able to pedal, steer, and negotiate surroundings independently (Snijders &

Bloem, 2010). In both of these cases there was a display of superior motor function when using ecologically valid external cues, compared to their typically impaired state. These improvements in motor performance are believed to occur because the external motor control pathway was stimulated by vibrant, dynamic, familiar visual cues (Hanakawa et al., 1999; Snijders, Toni, et al., 2011).

The basal ganglia are the primary area of neurodegeneration in Parkinson's disease (PD). One of the resultant effects of basal ganglia degeneration is decreased cortical activity during internally cued motor actions (Albin et al., 1989; DeLong, 1990; Samuel et al., 1997), which results in movement deficits (Hausdorff et al., 2003; Hausdorff, Cudkovicz, & Firtion, 1998; Morris, Iansek, Matyas, & Summers, 1996). When the basal ganglia are impaired, the SMA also has decreased activation levels, resulting in movements that have decreased temporal regulation and compromised sequential execution (Cunnington et al., 1995; Mushiake et al., 1991). Motor deficits were evidenced in section 2.3 here, where PLWPD, compared to OAC, had prolonged double stance support time (DSST) and decreased horizontal velocity during baseline walking trials. During ice skating, however, there was an improvement in locomotor performance, with PLWPD making similar decreases to horizontal step length, plus increases to horizontal velocity and arm swing as OAC. Ice skating kinematic similarities between the two groups suggests that ice skating is safe for PLWPD. Motor improvements during skating, compared to walking, also suggest that an alternative cortical pathway may be being accessed by the perceptions of the ecological cues and actions of ice skating. We suggest this pathway may be the external motor pathway, as previous research has shown increased cortical activation in associated areas when visual cues are used (Disbrow et al., 2013; Hanakawa et al., 1999).

The external motor pathway is comprised of the posterior parietal cortex, pre- motor cortex (PMC), and the cerebellum (Hanakawa et al., 1999; Samuel et al., 1997). The external pathway is used during sensory guided actions, such as walking to the beat of a metronome or walking using visual line markings (Hanakawa et al., 1999; Thaut et al., 1996). Activity in the more preserved external motor pathway may be being stimulated during ice skating by the increased visual flow of the ecological and familiar context. Previous research has demonstrated that explicit external cues could generate improved motor function (Azulay et al., 1999; Hanakawa et al., 1999), but the clinical case studies of walking ball dribbling and cycling summarized previously have shown that explicit visual cues may not be necessary. It has been postulated that familiar ecological context may provide cueing that instigates improved motor performance (Snijders et al., 2011). Ecological cueing could apply to ice skating, where the environment and dynamism of the activity may have provided the external cues to prompt the more preserved external pathway to be used, resulting in skillful motor performance.

4.1.1. Ice skating as an exercise intervention for PLwPD

Improved motor execution of the complex task of ice skating may be useful as an exercise therapy, as exercise has been shown to be effective at decreasing motor and non-motor symptoms amongst some PLwPD (Blandy, Beevers, Fitzmaurice, & Morris, 2015; Earhart & Williams, 2012; Hirsch et al., 2003; Sawabini & Watts, 2004). Ice skating exercise therapy may also decrease some problems that plague current therapies, such as poor social interaction, difficulties with accessibility, and the need for skilled instructors (Ellis et al., 2013; Quinn et al., 2010; Ravenek & Schneider, 2009). These problems may be rectified with ice skating, as the nature of ice skating is highly social and interactive, and open to group participation in locations that are often a community hub (Roult et al., 2014). Rinks are also highly accessible in both urban and rural settings in geographically northern nations, which is of pivotal importance as

poor access is one of the key barriers to exercise participation (Roult et al., 2014). In addition, the inherent preservation of ice skating requires previous experience at the skill meaning they may require less instruction, decreasing the instructor cost and the reliance on instructors.

Ice skating also has the potential to be performed at vigorous intensities. Studies in biking have shown that vigorous rates can result in prolonged neurological activation improvements (Alberts et al., 2011). Motor changes subsequent to vigorous cycling effort were first anecdotally recorded after a weeklong tandem charity bike ride across Iowa (Alberts et al., 2011). The intention of the trip was to encourage physical activity, but parallel beneficial results included improvement in handwriting and other PD motor symptoms. Researchers discovered that the tandem pedaling rate during the ride was 40% faster than patient's desired speed. The neurotypical 'captain' set the pace, forcing the PD 'stroker' (rear seat cyclist) to maintain the rate (Alberts et al., 2011). Forced pedaling rate was subsequently reproduced in a laboratory experimental trials, with follow-up fMRI testing showing prolonged improved activation of basal ganglia regions and SMA during an internally cued hand movement task (Alberts et al., 2011). As previously discussed, the basal ganglia and SMA regions are accessed during internal motor pathway stimulated activities (Jahanshahi et al., 1995; van der Hoorn et al., 2010), like walking, meaning that increasing activation of these regions may lead to improvement in gait function. Ice skating performance may have also caused prolonged increased basal ganglia and SMA activation, as the internal cued motor activity of walking was immediately improved post-ice skating. This was seen in Chapter 2 of this thesis, with decreased DSST and increased average horizontal velocity during post skate walking trials amongst PLwPD.

In the biking experiments pedaling rate was augmented by a front seat partner forcing a higher cadence than the participant with PD previously self-selected (Alberts et al., 2011; Ridgel, Vitek, & Alberts, 2009). The cycling rate was chosen based on observation of when symptoms

improved in this population, as higher cadence has been shown to be more beneficial than PD preferred pace (Ridgel, Phillips, Walter, Discenzo, & Loparo, 2015). During ice skating PLWPD were able to self- select a skating pace that was on average 1.16 times faster than their walking pace, which was comparable to the walk to skate increase amongst OAC. Improved post- ice skating gait in Chapter 2 of this thesis demonstrated locomotor improvements, suggesting that PLWPD had chosen a high enough rate of exercise during ice skating to generate prolonged and transferable motor changes. The ability for ice skating to be voluntarily performed and still produce positive motor changes may make ice skating a more feasible exercise modality than forced exercise alternatives, as participants may not require assistance to reach necessary rates for motor changes, thus making the exercise more independent.

4.2. Preserved function: Ice skating through a doorway

In the presence of additional visual cues, such as a doorway, there is an increased demand on the cortical system that may cause attentional interference amongst some PLWPD (Griffin et al., 2011). The external cue draws attention, creating the dual attentional task of conscious control of walking plus attending to locomoting through the geometric confines of a doorway, thus increasing demand on the finite resources of the visuomotor system and ultimately resulting in motor changes in both walking and doorway crossing (Beck et al., 2015; Canning, 2005; Cowie et al., 2010; Hanakawa et al., 1999). It is typical amongst all individuals to make slight motor adjustments when approaching a door to ensure that they will pass through safely, but the experiment in Chapter 3 demonstrated that PLWPD had significant gait changes, beyond those made by OAC. Specifically, while approaching the door PLWPD significantly increased average horizontal step length compared to no door trials, possibly because they did not plan for the door. This increase was followed by highly conservative locomotor kinematics, namely reduction in stride length and velocity, plus prolonged double stance support time (DSST), during door crossing. Significant changes in kinematics during doorway crossing may be because of the increased demand on the finite resources of the cortical system, resulting in poor motor control for the task.

During ice skating door crossing trials PLWPD and OAC had similar kinematic data, specifically increased maximum horizontal step length and average horizontal velocity before entering the door, and increased DSST during the door. As locomotor performance improved for PLWPD during skating door crossing, without changes in door size or distance from walking trials, we suggest that more attentional resources were available to be allocated to the door because less directed attention was required for skating. These improvements may be due to PLWPD being able to use the specific pertinent cues in ice skating to generate typical and consistent

motor behavior appropriate to the environment. PLwPD may be able to generate ice skating with less directed attention because of the ecological context of the environment providing vibrant external cues, as discussed in the previous section, along with the more rapid visual flow generated by skating locomotion. Previous research has linked the skillful movements of *paradoxical kinesia* with the flow of visual cues (Azulay et al., 1999). PLwPD may be vision dominant, having been shown to rely more heavily on visual cues than neurotypicals (Azulay et al., 2006; Demirci, Grill, Mcshane, & Hallett, 1996). Rapid movement increases the flow rate of visual cues, which will increase the intensity of visual information available (Snijders, Toni, et al., 2011). Increased flow may increase activation of the more preserved external motor pathway. Use of a more preserved and efficient pathway may result in more cortical resources being spared for doorway attention, and thus improved motor control when doorway crossing (Azulay et al., 1999; Ehgoetz Martens, Pieruccini-Faria, & Almeida, 2013; Majsak, Kaminski, Gentile, & Flanagan, 1998). This proposed benefit was observed in section 3.3 of this thesis, where PLwPD had similar skating door crossing kinematics as OAC.

4.2.1. Prolonged benefits: Exercise among PLwPD

Exercise has been shown to have many motor benefits for PLwPD, as discussed in section 1.2., including prolonged neuromotor improvements (Alberts et al., 2011; Schenkman et al., 2012). In Chapter 2, where participants completed open, unobstructed skating, post ice skating walking trials had kinematic improvements compared to pre walk. In Chapter 3, where a door was present, there were no significant changes in walking parameters before and after the door, only during door crossing, where there was an increase in average horizontal step length in post walk trials. As stated in section 4.1.1. we suggest that ice skating may have caused a prolonged increase in basal ganglia and SMA activation. These structures are critical components of the internal motor pathway, which has been shown to be used during internally

cued motor activities such as walking (Jahanshahi et al., 1995; van der Hoorn et al., 2014). Since there were no significant changes in kinematics during walk post- skate door approach we are lead to assume that the visual cue of the doorway continues to use the external motor pathway, generating attentional interference during the dual task of walking and doorway planning. Impaired post walking kinematics before and after door crossing may show that improved attentional focus, as seen during ice skating through a doorway, may not be a lasting change while increased activation of the internal motor pathway is. As PLWPD moved from an area of external cueing, before and after the door, to a narrowed area of vision, door crossing, there may have been a redirection from predominately external to internal motor pathway activation (van der Hoorn et al., 2010). As vigorous activity resulting in motor changes has been shown to cause a prolonged increase in the basal ganglia and SMA (Alberts et al., 2011), we suggest that prolonged internal pathway activation during door crossing after ice skating may have accounted for the increase in average horizontal step length.

4.3. Clinical Application

This thesis has shown that ice skating exercise has the potential to be a promising component of a PD treatment plan. Previous work has shown that traditional exercise modalities can be effective at improving PD motor symptoms (Carvalho et al., 2015; Schenkman et al., 2012), but the studies in this thesis are the first to show that ice skating is safe, feasible, and results in immediate kinematic improvements in both unobstructed and obstructed locomotion. Further research is required to determine dose response rates, skating skills, and psychological components that will optimize the effectiveness of ice skating as a widespread intervention for PLwPD, but this thesis provides pilot evidence to support the potential of using ice skating as a neurotherapeutic rehabilitation tool. Ice skating is an appealing intervention option as it addresses many of the issues that other modalities face, mainly accessibility, cost, and social interaction. Ice skating also has the benefit of positive motor changes at self selected speeds, where as other modalities can require augmentation (Ridgel et al., 2009). Further research is required to determine the extent of the motor benefits that can be obtained from ice skating.

4.4. Future Directions

This thesis has shown that ice skating exercise has the potential to be a promising component of the PD treatment plan. Future research should focus on optimizing the rate, duration, and programming of ice skating exercise in order to develop the most effective intervention for prolonged motor benefits. The underlying neuromechanisms should also be investigated, with a focus being placed on attention to and activation from ecological visual stimulation. Isolating different components of the ecological visual stimulation may determine which specific cues are necessary for ice skating *paradoxical kinesis* to occur. Neuroimaging should be applied to verify which neurological structures are being activated during ice skating *paradoxical kinesis*, and how cortical activation changes after ice skating. Identifying underlying neuromechanisms will increase the understanding of how this phenomenon works, which will help with further extrapolation and application. Quantifying cortical changes after ice skating and the protracted benefits will aid in intervention implementation, as well as overall patient treatment planning. If ice skating exercise is able to improve cortical activity and motor symptoms then there is the possibility for reduction in pharmacological intervention and improvement in quality of life.

4.5. Limitations

Self selection bias was a strong limitation in this study. During recruitment, interested individuals were told they needed previous experience at ice skating, and that they would be performing ice skating. The need to actually perform physical activity may have created a bias, leading to an already active population of mild to moderate PD severity to volunteer. Since the recruited PLWPD were likely already physically active, it is not possible to determine that the initial improvements to locomotor parameters were exclusively a product of the experiment, or of physical activity in general.

Field testing may have also limited this study. Data collection was performed on site at multiple rinks. Use of several on site testing locations could have increased the variability of the environment, such as walking trial surface material and slope, ambient noise, lighting, and ice surface inconsistencies. In order to minimize these effects, practice walking and ice skating trials were allowed to familiarize participants with the environment prior to data collection. Laboratory testing could have taken place on a skating treadmill, but skating treadmills alter kinematic characteristics of ice skating, reducing the transference to actual ice skating performance (Nobes et al., 2003). On site testing is more realistic to not only the performance of ice skating, but also the environment that future exercise programs may occur in. Also, being in a laboratory would decrease the ecological context that may help engage the persevered ice skating ability. As we are unsure of the specific environmental cues that stimulate skating ability, reproduction in a laboratory setting would not be possible at this time.

4.6. Conclusion

Ice skating is safe, feasible, and a persistent skill amongst some PLWPD and results in immediate improvements to locomotor parameters in both unobstructed and obstructed situations. Immediate kinematic gait improvements following one session of ice skating makes skating a viable neurotherapeutic intervention, with possible prolonged benefits to walking, freezing of gait, and quality of life amongst people living with Parkinson's disease.

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Appendix A.

x = horizontal

y = vertical

Step length:

$$\left(\sqrt{(\text{left heel } x - \text{right heel } x)^2 + (\text{left heel } y - \text{right heel } y)^2} \right) \times \frac{2}{\text{cone distance}}$$

Right arm swing:

$$\left(\sqrt{(\text{right hand } x - \text{right hip } x)^2 + (\text{right hand } y - \text{right hip } y)^2} \right) \times \frac{2}{\text{cone distance}}$$

Left arm swing:

$$\left(\sqrt{(\text{left hand } x - \text{right hip } x)^2 + (\text{left hand } y - \text{right hip } y)^2} \right) \times \frac{2}{\text{cone distance}}$$

Velocity:

$$\left(\frac{\text{displacement}_{n+1} - \text{displacement}_{n-1}}{\text{time}_{n+1} - \text{time}_{n-1}} \right) \times \left(\frac{2}{\text{cone distance}} \right)$$

Double Stance Support %:

n= 1 to END

IF: $(|\text{right heel } y_n - \text{left heel } y_n| + |\text{right toe } y_n - \text{left toe } y_n|) < 1$

NEXT: count= count + 1

NEXT: $\left(\frac{\text{count}}{\text{END}} \right) \times 100$

Appendix B.

Performing these experiments was very powerful to me as I was able to see the importance, emotion, and impact that physical activity had on people living with Parkinson's disease (PLWPD). Many participants in these studies had not ice skated since their diagnosis and had also eliminated many other physical pursuits. They had many reasons for ceasing activity such as fear of falling, belief they lacked the ability, or lack of encouragement to participate. When first approached for recruitment individuals were excited at the prospect of preserved ability and were willing to try ice skating, despite reluctance by many caregivers. At testing when PLWPD went onto the ice and found that they were able to ice skating I was able to see the power that this sort of work brought into their lives. Many participants were shocked and excited to be able to part take in an activity that they previously loved and thought they would never be able to do again. PLWPD were excited that there was the potential for them to take back some of their power and actively take part in an activity that could potential slow or reduce their symptoms instead of just waiting to take more pills. Seeing the emotion and the functional gains from the actual people that this work could help allowed me to further appreciate the impact that this work can have on the Parkinson's disease population. It made research less abstract and more applicable to everyday life for real people that are struggling with real problems. It has given me an appreciation for the scientific process, where decades of work performed by hundreds of people can come together outside of the lab and create real world applicable interventions to help improve the lives of those around us.