Effects of boxing on force characteristics in the upper extremities in people with Parkinson's disease compared to healthy younger and healthy older adults

by

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ABSTRACT

Due to the nature of Parkinson's disease (PD), force output characteristics of the muscles may become impaired in people with PD. Forced exercise and power-based resistance training exercise are trending modalities used to attenuate the physiological effects of PD on muscle activity as an alternative to pharmaceutical and surgical treatments. The objective of this study is to assess the extent to which effects of an acute session of boxing on the muscle activity in the upper extremities of persons with PD compared to healthy older adults (HOAs) and healthy younger adults (HYAs).

Ten participants with PD, fourteen HOAs, and twelve HYAs were recruited for this study. Electromyography (EMG) was used to assess muscle activity in the upper extremities during elbow flexion and extension at a fast and self-selected pace pre and post an acute boxing session. Peak amplitude, time of onset to peak amplitude, and time of peak amplitude to offset were measured.

Results from this study suggest that boxing may influence EMG patterning characteristics in persons with PD alone and compared to HOAs and HYAs. Results have shown main effects after an acute session of boxing, primarily in the muscle activity of the triceps. Results have also shown an interaction effect among PD, HOAs, and HYAs in triceps muscle activity after an acute session of boxing. Future research is needed to determine the efficacy of a boxing program on motor symptom impairment in persons with PD and potential long-term therapeutic benefits.

CHAPTER 1. LITERATURE REVIEW

Introduction

Well-being is becoming a top priority among older generations. This is in part due to the increased cost of pharmaceuticals, hospital visits, surgeries, and patient care. Another driving force behind many older adults to live a healthier lifestyle is an increase in life expectancy. The benefits of maintaining an active, healthy lifestyle far outweigh the costs of health risks associated with sedentary behavior, especially when healthier lifestyle changes are made at early age. These benefits can even extend to older adult populations with existing health conditions.

Parkinson’s disease (PD) is among the top age-specific neurodegenerative diseases surfacing in the older adult population. The loss of dopaminergic neurons within the basal ganglia, characteristic of PD, causes inhibition of motor initiation and control and negatively affects skeletal muscle force output characteristics. The associative cardinal symptoms of PD are resting tremor, postural instability, rigidity, and bradykinesia. These symptoms, along with a reduced scaling of force, can lead to inactivity, inability to perform activities of daily living, and may contribute to more serious, life-threatening injuries such as hip fractures from falls. With PD, force development utilizing the physiological aspects of the sport of boxing and combined power training regimens may potentially delay the progression of motor impairments. A combined boxing and power training program may lead to improved force output characteristics, which may provide a more stable foundation for performing activities of daily living, increase levels of physical activity and reduce the risk of injury.

Indeed, boxing has become a popular form of exercise for persons with PD. Research has shown that exercise is beneficial for persons with PD and may delay the progression of the disease. However, the literature supporting the use of boxing remains limited. There is a need to fully understand the effects of boxing, a power-based activity, on motor symptoms in people with PD. Thus, the purpose of this study is to determine the effects of boxing and additional power training adaptations on force output characteristics in the upper extremities of persons with PD. It is hoped that the findings of this project will aid in the evidenced-based establishment of boxing as an effective physical activity for persons with PD to delay the progression of the disease.

Parkinson's Disease

PD is an age-specific, progressive neurodegenerative disorder caused by the loss of dopaminergic neurons in the basal ganglia. PD has a widespread neuropathology with several molecular mechanisms that evidence suggests contribute to PD motor symptoms. The accumulation of Lewy bodies and neurites, abnormal alpha-synuclein protein aggregate deposits and extensions, in subcortical areas of the brain are a pathological hallmark of PD onset (Ross & Poirier, 2004). Under pathological conditions, a genetic mutation in SNCA (a gene encoding for alpha-synuclein) causes alpha-synuclein proteins to undergo misfolding, leading to an accumulation of protein aggregates that promote dopaminergic cell death and subsequent site-specific degeneration (Stefanis, 2012; Moussaud, et al., 2014). Exposure to environmental toxins, such as herbicides and pesticides, has also been linked to an inhibition of mitochondrial complex I that can lead to neurodegeneration within the brain (Dawson and Dawson, 2003). Defects in mitochondrial complex I lead to impairments in oxidative phosphorylation, resulting in an increase in oxidative stress, or an overproduction of free radicals. Excess free radicals are damaging to cellular components such as lipids, proteins and DNA, causing cell death and neurodegeneration (Lobo, Patil, Phatak, & Chandra, 2010; Guo, Sun, Chen, & Zhang, 2013).

Cell death within in the basal ganglia leads to an imbalance of activity that ultimately impacts motor control. The classical view, or rate model, of the basal ganglia suggests that there are two pathways—direct (D1) and indirect (D2)—that mediate motor control (Albin, Young, & Penney, 1989). Both pathways begin in the substantia nigra pars compacta and pars reticulata and extend via dopaminergic neurons into the striatum, comprised of the caudate and the putamen. The D1 (direct) pathway projects to the globus pallidus internal via gamma-aminobutyric acid (inhibitory) producing neurons. The D2 (indirect) pathway projects to the globus pallidus external via gamma-aminobutyric acid producing neurons, then into the subthalamic nucleus via gamma-aminobutyric acid producing neurons, and finally into the globus pallidus internal via glutamate (excitatory) producing neurons. Both pathways project to the thalamus via gamma-aminobutyric acid producing neurons, and finally project to the motor cortex (mostly the supplementary motor area) via glutamate producing neurons. The direct pathway is responsible for initiating an increase in muscle activity, while the indirect pathway is responsible for inhibiting muscle activity. The balance between both pathways in the basal ganglia allows for control of movement initiation and inhibition.

In PD, it has been proposed that a loss of dopaminergic neurons in the striatal pathway between the substantia nigra pars compacta and the striatum alter the balance between the D1/D2 pathways. This imbalance leads to an upregulation of the activity in the indirect pathway, which is thought to underlie hypokinetic motor symptoms such as resting tremor and rigidity, and a downregulation in activity of the direct pathway, which is thought to underlie hyperkinetic motor symptoms such as bradykinesia and akinesia (DeLong, 1990). Specifically, the lack of input from the substantia par compacta into the striatum leads to an increase in activity of the inhibitory connection between the striatum and the globus pallidus external, causing a decrease in inhibitory activity to the subthalamic nucleus, and an increase in excitatory activity to the globus pallidus internal. The connection between the striatum and the globus pallidus internal is also diminished, decreasing inhibitory activity. Adaptations in both pathways contribute to an increase in inhibitory activity between the globus pallidus internal, decreasing the strength of the excitatory pathway between the thalamus and the cortex. Given that the pathways between the clusters of nuclei in the basal ganglia are reciprocal, the 'rate-model' reasoning behind the motor symptoms of PD described above is not entirely correct. Explanations that are more plausible are from the idea that the pathways in the basal ganglia function via synchronized oscillatory activity, and that PD is a result of alterations in the synchrony of this oscillatory activity within both the basal ganglia and motor cortex (Brown, 2006; Wichmann & DeLong, 2006; DeLong & Wichmann, 2007).

Force Characteristics and Muscle Patterns in PD

Force characteristics of interest during muscle contraction in PD encompass variables such as rate of force production, peak force generation, and response time to force initiation and peak force development. Corcos, Chen, Quinn, McAuley, and Rothwell (1996) conducted a study observing the relationship between strength and rate of force generation, and the effects of medication on force generation variables. Torque during isometric contraction was examined in participants with PD at maximal elbow flexion and elbow extension on and off medication. There was a significant decrease in muscle strength during extension and a decrease in rate of force generation when participants were off medication compared to when participants were on medication. This suggests a correlation between muscle strength and force development.

Stelmach, Teasdale, Phillips, and Worringham (1989) examined force production characteristics of the upper extremity maximal flexor force in participants with PD compared to

HOAs and HYAs. The focus of this study was to examine differences in force-time curves. Results show that the PD group exhibited a higher number of irregularities associated with movement initiation and force control during production compared to their healthy counterparts. Participants with PD also exhibited significantly slower times to peak force generation, lower rates of force development and decreased peak force. Stelmach and Worringham (1988) examined isometric force production of the upper extremity in most affected side of participants with PD compared with the non-dominant side of age-matched controls. Although accuracy of force production during the target force level task was not different in the PD group compared to control group, mean time to peak force development and contraction duration was greater in participants with PD. Significantly lower rates of force development were also observed in the PD group versus the control group. Thus, these results suggest that the timing of force development in persons with PD is impaired and can result in performance decrements in various motor tasks.

Studies examining grip strength and fine motor skills in participants with PD have also shown impairments in force production. Neely and colleagues (2013) asked participants to complete two grip tasks using a modified grip while holding a custom grip apparatus that housed a force transducer to detect force output. Maximal voluntary contraction and two tasks involving visually cued target amplitudes were completed. One visually cued task involved matching force output to the same target amplitude over a series of cues and the other visually cued task involved matching two different target amplitudes. Participants were to contract for a period of 2 seconds and then relax for 1 second; this cycle was repeated for a set number of pulses in a given amount of time. Participants with PD experienced a slower rate of force development and subsequent relaxation time between pulse compared to healthy subjects. Participants with PD also shown a decreased mean maximum voluntary contraction and a mean force output compared to healthy subjects.

Jordan, Sagar and Cooper (1992) also examined maximum grip strength, isometric reaction time and force generation and release in participants with PD on medication, de novo participants, and healthy controls. Force was measured using a hand grip dynamometer, and participants were instructed to grip the device with maximal effort as quickly as possible when an auditory cue was presented. Force was maintained until a second auditory cue was administered at which time participants released the grip as quickly as possible. There was a significant difference in isometric reaction time, force generation time, and force release time between both groups with PD (de novo and on medication) and controls. The PD groups exhibited slower times in all three categories; however, maximum grip strength among all groups did not differ significantly.

Thus, these studies suggest that force output characteristics in people with PD are impaired. Specifically, slower rates of force development, decreased peak force amplitudes, and increased duration of muscle contractions were shown. These alterations in force output characteristics may have implications for functional mobility. For example, accurate timing and peak force is needed to maneuver around obstacles and maintain balance, thereby preventing slips and falls. With slower rates of force development or decreases in peak force amplitudes as in PD, even small changes in balance and coordination could lead to a fall and injury.

Electromyography and PD

Electromyography (EMG) is a common, non-invasive research tool used to observe patterns of force production in the muscle during movement. Studies investigating EMG burst patterns consistently found differences in muscle activity in participants with PD compared to healthy adults. Berardelli, Dick, Rothwell, Day, and Marsden (1986) examined EMG activity in wrist flexor muscles in participants with PD during wrist flexion movements through different ranges (degrees) of motion with and without a load. Participants with PD completed the task while on and off levodopa treatment. Results show an increased number of EMG bursts, decreased movement speed and contractile amplitude, and smaller EMG burst amplitudes on medication. Compared to healthy subjects, participants with PD showed lower peak velocity with and without load. However, despite differences in EMG burst quantity, participants with PD were able to modulate amplitude and duration of initial muscle contraction to match movement size and additional load like healthy subjects. These results suggest that people with PD can modulate the amount of force required to complete a motor task, but the underlying muscle activation remains impaired.

Similar findings have been shown for elbow flexion and grip force. Benecke, Rothwell, Dick, Day, and Marsden (1987) examined muscle activity during elbow flexion and grip force in participants with PD on and off medication and healthy controls. Movements were either completed separately (simple task) or simultaneously (complex task). Results show multiple bursts of EMG activity during elbow flexion in PD participants while off medication compared to PD participants on medication during the simple task. Reduced phasic activity during the grip task was also shown for PD participants when both on and off medication compared to healthy subjects. Movement time during elbow flexion was slower in PD participants off medication compared to PD participants on medication, and slower overall in participants with PD compared to healthy adults. Finally, the duration of isometric contraction during the grip task was longer in

PD participants off medication compared PD participants on medication, and longer in PD participants in general, compared to healthy adults. These studies suggest that participants with PD show a delayed response time for muscle contraction initiation, increased EMG burst durations, and decreased EMG burst amplitudes. These impairments in muscle activity shown with EMG, especially changes in burst activity, may have an impact on functional motor skills.

Research has shown that EMG burst characteristics can be indicative of force production characteristics. EMG burst durations are longer during slower movements and shorter during high velocity movement. EMG burst amplitude is larger during movements that require a greater force amplitude (Mustard & Lee, 1987). Finally, an increased number of EMG bursts during muscle contraction are associated with greater levels of fatigue during movement (Enoka & Duchateau, 2008). Thus, examining EMG burst patterning in participants with PD may be an objective measurement of changes in force output due to a treatment or exercise intervention.

Treatments for PD

There is no cure for PD. Currently, common treatments for PD include Levodopa, a central nervous system agent that acts as a dopamine precursor and is converted into dopamine once it passes the blood-brain barrier, and deep-brain stimulation (DBS), a surgical procedure that interrupts abnormal oscillatory signaling patterns between neurons in the brain causing motor symptoms thereby lessening symptom severity. Although these treatments temporarily alleviate the severity of many motor symptoms, there are many additional symptoms that do not respond to these treatments as well as numerous side effects. These treatments are a costly means of temporary treatment and may affect one individual with PD much differently than another (Shobha, Hofmann, & Shakil, 2006). According to a cost-analysis by Pietzsch, Garner and Marks

(2016) based on a 2014 national average, total cost of DBS implantation (generator, leads and physician fees) was $33,319 ± 30%. Additional fees may include cost of DBS-related infections ($23,441 ± 30%), DBS device complications ($15,902), DBS explanation ($4,918), DBS neurostimulator replacement procedure ($26,653), and pre-operative assessment and work-up for DBS ($432). Huse and colleagues (2005) determined the 2002 total health care costs of PD burden per capita to be $23,101, with $3,366 attributed to prescription drugs. Kowal, Dall, Chakrabarti, Storm, and Jain (2013) determined the estimated 2010 medical cost for the PD community to be $22,129 per capita, with $3,780 attributed to retail prescriptions. While these treatments are standard in the care of PD, recent research has supported the inclusion of daily exercise to delay the progression of the disease.

Exercise and PD

Many forms of exercise have been recommended for people with PD. Research has shown benefits from treadmill training to tai chi (Miyai, et al., 2000; Miyai, et al., 2002; Herman, Giladi, Gruendlinger, & Hausdorff, 2007; Hackney & Earhart, 2008; Li, et al., 2012; Gao 2014). However, some of the most promising work has been in exercise that includes a focus on force characteristics. Alberts and colleagues (2016) show that forced exercise (operationally defined as a mechanically augmented aerobic-based exercise used to reach a rate of exertion beyond what is voluntarily preferred by the participant) and pharmaceutical therapies used to treat the severity of motor symptoms in people with PD utilize similar pathways. Nine PD participants partook in a forced exercise intervention consisting of 40-minutes of assisted cycling to reach a pedaling rate between 80-90 revolutions per minute based on their target heart rate zone (65-80% of maximal heart rate). Functional MRI scans were collected in a randomized order when patients were off their medication, on their medication, and off their medication following an acute session of forced exercise. The forced exercise and drug therapy produced comparable improvements in PD symptoms as well as similar activation patterns in the functional MRI scans. These results suggest that exercise that targets force development may be beneficial for persons with PD.

Paul, Canning, Sherrington, and Fung (2012) assessed power in the leg extensors of persons with PD. The researchers concluded that muscle strength, bradykinesia, and rigidity were associated with reduced muscular power, but not resting tremor. Ni and colleagues (2016) measured the effects of a power-based resistance training program on bradykinesia and muscle characteristics (one repetition maximum and peak power) in participants with PD. The training program consisted of two sessions of power-based resistance exercise, with additional balance and agility training per week, for three months. The power training program resulted in a significant reduction in bradykinesia of the upper and lower extremities and a significant increase in both one-repetition maximum and peak power compared to the control group. By adapting resistance training methods for older adults with PD using power training techniques and lighter, safer loads, muscular force production may be increased and lead to an improvement in activity of daily living performance and reduced risk of fall-related injuries.

King and Horak (2009) offer a guide to developing a progressive exercise program that targets motor skills to improve and maintain mobility in people with PD. Motor symptoms associated with PD that affect mobility include rigidity, bradykinesia, freezing, inflexible program selection, impaired sensory integration, and reduced executive function and attention. King and Horak provide several agility exercise programs, one of which is boxing. Boxing contributes to improving mobility by reinforcing motor skills such as anticipatory postural adjustments and postural corrections, fast arm and foot motions, backward walking, timing, and sequencing actions. These actions counteract motor symptoms affecting mobility. Three levels of progressions are given for task categories: 1) plane of movement, working from lateral stances to pivoting to walking backwards around an obstacle, 2) speed, gradually increasing the speed of punches thrown and the duration for which they are thrown, and 3) dual-task tasking, requiring throwing punches, naming the punches being thrown, and completing cognitive tasks while throwing combinations of punches. A length of 60 minutes for an appropriate exercise program was also suggested. Thus, previous research supports the position that boxing combined with power training may be an alternative form of therapeutic physical activity that may positively affect the motor symptoms of PD.

Aging and Muscle: Power Training in Older Adults and PD

Age-related loss in muscle mass is attributed to factors such as a decrease in muscle fibers, decrease in muscle fiber size, and degeneration of the neuromuscular junction resulting in the inability to properly recruit muscle fibers (Luff, 1998). These factors are associated with a loss in muscle strength and the incapacity to generate muscle force, which may lead to a higher risk of fall-related injuries. Mobility and the ability to perform activities of daily living may also be impacted by a loss of muscle strength in older adults. Lexell and Downham (1992a) examined the mean area and proportion of fast-twitch (type II) muscle fibers of the vastus lateralis muscle in post-mortem, healthy men ages 15-83 years. Mean area in type II fibers was significantly smaller in older men compared to mean area in slow twitch (type I), and there was a strong concurrent relationship between the mean area and the proportion of type II fibers. These results suggest that there is a decrease in type II muscle fibers with age, potentially affecting the ability to perform tasks that require type II muscle fiber activation such as climbing stairs or standing from a chair.

Type II muscle fibers generate more instantaneous force at a faster contraction speed and a higher conduction velocity than type 1 muscle fibers. Type II fibers are also recruited typically during short duration activities that require immediate force production such as rising from a chair or climbing stairs (i.e. activities of daily living). Studies have examined the effects of power training compared to strength training on functional performance in older adults. Power training resulted in a significant improvement in physical functioning and completion of functional tasks compared to strength training (Miszko, et al., 2003; Henwood, Riek, & Taaffe, 2008). Another study examined the optimal loading for power training and the researchers concluded that improvements in peak muscle power can be acquired through light (20% of 1RM), moderate (50% of 1RM), and heavy (80% of 1RM) resistances (de Vos, 2005). These results suggest that incorporating power training adaptations into a daily exercise routine can have a positive effect on activity of daily living performance in older adults. Thus, given the decline of force output in persons with PD, power training may hold promise as an effective exercise intervention.

Power training methods are used to induce greater force output with higher rates of force development in athletic and sports performance. Hakkinen, Kraemer, Newton, and Alen (2001) studied changes in EMG activity and force production characteristics in the knee extensor muscles after a 6-month exercise program designed to address components of both strength and power. Participants included middle-aged men and women (M40, W40) as well as older men and women (M70, W70). Participants followed a progressive full-body training protocol incorporating strength training (total body) and power training (lower body only) based on their 1RM performance. Participants began performing the exercises at loads of 50-70% of their 1 RM for 3-4 sets of 15 repetitions for the first two months. By months three and four, the load had increased to 50-60% and 60-70% of the maximum and 50-60% and 70-80% of the maximum, respectively. Participants then performed the exercise at loads of 70-80% of their 1 RM for 3-6 repetitions per set and loads of 50-60% of their 1 RM for 8-12 repetitions per set for the latter two months. There was an increase in maximal isometric strength and 1 RM strength in M70 (27 ± 17 and 21 ± 9%; $p< 0.001$) and W70 (26 ± 14 and 31 ± 14%; $p< 0.001$) in the knee extensors after the 6-month training protocol. There was also a significant increase in percentage of explosive strength in M70 (21 ± 24%; $p < 0.05$) and W70 (22 ± 28%; $p < 0.05$).

Caserotti, Aagaard, Larsen, and Puggaard (2008) investigated the effects of an explosive-style, heavy-resistance training regimen on force production characteristics in two age categories of older adults (60, 80 years-of-age). The exercise protocol required participants to partake in a progressive 12-week, twice per week, program that catered to strength and power development using ballistic movements and heavy loads corresponding to 75-80% of their 1RM. Peak force, rate of force development, and impulse during maximal velocity contractions of their dominant leg were collected. Significant differences post-testing were seen within treatment group and between treatment groups and control groups for both age groups in peak force (p-values = 0.005), rate of force development (p-values = 0.005) and impulse (p-values = 0.005), and jump height (p = 0.048). These results suggest that power-style training methods increase activity in the target muscle group as well as multiple force output characteristics during motor tasks.

Wallerstein and colleagues (2012) studied neuromuscular adaptations after strength and power training programs were administered to an older adult population. The 16-week strength and power programs incorporated the same exercises, but the sets and repetitions of the exercises performed, as well as the percentage of the 1RM, were adjusted to meet appropriate strength or power training protocols. The exercises included horizontal leg press, bilateral knee flexion, unilateral hip extension, plantar flexion in the horizontal leg press, lat pull-down, upright row. The set, repetition, and load percentages were adjusted every two weeks. For the first two weeks, the load was set at 70% for 2 sets of 10 repetitions and 30% for 3 sets of 7 repetitions for strength and power training, respectively. The load percentage was increased by 5% for the next two weeks with the set and repetition scheme kept unchanged. A similar protocol was applied to weeks 5 through 16. Strength measurements were taken with leg and chest press 1RM tests, and power measurements were taken with maximum voluntary ramp and ballistic isometric contractions. EMG activity, electrical mechanical delay, and rate of torque development of the vastus lateralis and vastus medialis muscles were collected. Peak torque values from both the ramp voluntary isometric contractions and the ballistic voluntary isometric contractions increased significantly in both the power and strength training groups with no changes observed in the control group. Rate of torque development improved in all groups from baseline measurements. Electrical mechanical delay decreased significantly in both the power and strength groups albeit only in the vastus lateralis muscle. No changes were seen in the control group. Thus, strength training and power training were both similarly effective at improving dynamic and isometric strength in the lower body, increasing the cross-sectional area of the quadriceps muscles, and decreasing delay of the vastus lateralis muscle.

Indeed, the American College of Sports Medicine (ACSM) recommends specific resistance principles to tailor a progressive program towards appropriate muscular power and force development. To optimize fast contractile velocities during training, ACSM recommends resistance loading with 30-60% of a subject's one repetition maximum encouraging an emphasis on fast velocity of muscular contraction during movement execution (Kraemer, et al., 2002). Motions should be ballistic in nature. Novice exercisers should perform 3-6 repetitions of movement for 3-6 sets with 2-3 minutes of rest between sets. Power training should be carried out 2-3 days per week. ACSM also recommends starting with multi-joint movements when training for muscular power. While these recommendations may be appropriate for healthy populations, additional considerations are needed when working with persons with PD. Activities that are novel and engaging are essential. Boxing may be one such exercise intervention that is novel and engaging while incorporating aspects of power training and enhancing force output.

Boxing as Force Training

Boxers train to manipulate the body to produce maximal force output with minimal effort. A common misconception in boxing is that the greater the weight of the boxer, the more punch force the boxer will produce. Pierce and colleagues (2006) measured punch force in boxers during a live, professional boxing bout as opposed to force delivered in a laboratory setting. By measuring punch force in a live setting, boxers cannot take the time to appropriately prepare their bodies and properly set up their punches to deliver maximal punch force. Thus, measurements in a laboratory setting could potentially overestimate the actual delivered force during a live setting.

Results show no significant relationship between the boxer's weight and mean punch force, indicating that higher mass does not necessarily mean greater force will be delivered upon execution and subsequent impact. Out of the six professional bouts recorded, the weight classes through which the greatest force was delivered via punch were the light welterweight class (61.7 kg, 62.3 kg) and the cruiserweight class (80.5 kg, 82.0 kg). Mack and colleague (2010) analyzed hand velocity and acceleration, as well as lower body force, power and torque during a boxing punch to determine the association between the pre-impact force development and force output.

Punch force was determined from a dominant-hand straight punch and a dominant-hand hook punch. Although correlations between lower body forces and punch force ($p<0.05$) and correlations between hand velocity and punch force ($p<0.001$) were significant. Correlations between lower body forces and punch force exhibited lower values for the straight and hook punch ($R^2 = 0.099$, $R^2 = 0.103$) compared to the values for hand velocity and straight and hook punch forces ($R^2 = 0.391$, $R^2 = 0.380$). These results suggest that hand velocity provides a better indication of punch force than the generation of lower body forces, which could possibly be due to ineffective transfer of force from the lower to the upper body given the test was conducted on amateur boxers as opposed to professional boxers. Thus, these studies suggest that upper extremity velocity training with boxing may be an advantageous mechanism to improve force output in people with PD.

PD and Boxing

There is very little information on the effects of boxing with PD as few studies have been conducted. Combs and colleagues (2011) studied the effects of multiple boxing sessions on short and long-term changes in balance, mobility, gait, and quality of life in people with PD. Subjects participated in a community-based boxing program, Rock Steady Boxing, that offers a boxing program specifically catering to people with PD. Baseline testing took place for 7 participants with PD before they began the boxing program. Post-testing took place one week after completion of a 12-week program, and at 24 and 36 weeks regardless of continued program participation. The program included a 20-minute warm-up of breathing and stretching exercises, followed by 45- to 60-minutes of circuit-style exercises for functional training, endurance and boxing-specific drills for 3 minutes of activity interspersed with 1 minute of rest. The program concluded with a 15- to 20- minute cool down period of breathing and stretching exercises.

Program design remained consistent throughout 12-weeks, but exercises were varied weekly. The Functional Reach Test, Berg Balance Scale and Activities-specific Balance Confidence Scale were collected. All subjects increased distance for the Functional Reach Test by the 24th week, all subjects maintained or increased scores for the Berg Balance Scale at the 12- and 24-week test, and 5 out of the 6 subjects maintained or increased scores on the Activities-specific Balance Scale at the 24- and 36-week test. Timed "Up and Go" Test, Six Minute Walk Test and gait speed were also collected. All subjects decreased time on the Timed "Up and Go" Test by the 36th week, all subjects increased distance walked during the Six-Minute Walk Test by the 36th week, and all subjects increased gait speed by the 24th week. No p-values were recorded in the case series, so it is unsure as to whether the improved performance was significant.

Combs and colleagues (2013) compared the effects of a boxing style group activity program to a traditional group activity program in people with PD. Thirty-one participants were either assigned to the boxing program or the traditional program. The boxing program included stretching, boxing activities incorporating footwork and heavy bag drills, resistance exercises, and aerobic activity. The traditional program included stretching, resistance exercises, aerobic activity and balance training. Each program consisted of twenty-four to thirty-six, 90-minute sessions over the span of 12 weeks. Pre- and post-intervention tests included Berg Balance Scale, Activities-specific Balance Confidence Scale, Timed Up and Go Test, Dual Timed Up and Go, Gait Velocity, and Six-minute Walk Test. The boxing group showed significant improvements of performance in all tests except the Activities-specific Balance Confidence Scale (p-value 0.624). The traditional group also showed significant improvements in performance on all tests except Gait Velocity and Six-minute Walk Test (p-values 0.140, 0.807). There was only one between-group difference. Results show that the traditional group had greater improvement on the

Activities-specific Balance Confidence Scale (p-values 0.015). Thus, measures of gait and balance were no more improved for the boxing group than the traditional group.

While both studies suggest that there may be promise in using boxing as an exercise strategy for persons with PD, there are many limitations to consider. Neither of the studies involved the use of EMG to collect data on muscle activity in targeted muscle group's pre- and post-boxing session, nor were force output characteristics considered in data collection. Thus, there are no physiological explanations as to why boxing may be beneficial. Although functional tasks were measured pre- and post-treatment, data from the first study was not analyzed, so no supportive evidence can justify changes in functional task performance scores after treatment. The exercise program from the first study also involved boxing-specific activities but did not describe the activities. Finally, the second study involved boxing activities as well as resistance and aerobic activities in the treatment group and showed no advantages of boxing over a traditional exercise group. Thus, the inclusion of resistance and aerobic activities with boxing limited the interpretation of how boxing training may affect functional task performance. Consequently, there is a large gap in the literature regarding the use of boxing as exercise for persons with PD.

Statement of Purpose

The purpose of this study is to determine the extent to which a boxing program improves muscle activity in people with PD compared to healthy older adults and healthy younger adults. To address this purpose, the following specific aims are proposed:

Aim 1: To determine the effects of a single boxing session on muscle activity in people with PD.

Hypothesis for Aim 1: An acute session of boxing will improve timing and amplitude of the bicep brachii and triceps brachii muscle in EMG muscle activity.

Aim 2: To determine the effects of a single boxing session on muscle activity in people with PD compared to healthy older adults and healthy young adults.

Hypothesis for Aim 2: The greatest change in muscle activity will occur in persons with PD. Healthy older adults will also show improvement in timing and amplitude of the bicep brachii and triceps brachii muscle in EMG muscle activity, but not to the same degree as those with PD. Muscle activity in healthy young adults will not change.

The inclusion criteria for healthy adult participants in this study are 1) age between18 and 85, 2) no neurological impairment or disease, 3) ability to complete a 45-minute boxing training session.

By determining the efficacy of a boxing program on muscular activity in people with PD, boxing programs may be considered an inexpensive and alternative treatment option. This study will also contribute towards advancing knowledge on the therapeutic effects of boxing programs in people with PD.

CHAPTER 2. EMG PATTERNING OF BICEPS BRACHII IN PEOPLE WITH PARKINSON'S DISEASE PRE AND POST-ACUTE BOXING SESSION COMPARED TO HEALTHY OLDER AND YOUNGER ADULTS

Abstract

Due to the nature of Parkinson's disease (PD), force output characteristics of the muscles may become impaired in people with PD. Forced exercise and power-based resistance training exercise are trending modalities used to attenuate the physiological effects of PD on muscle activity as an alternative to pharmaceutical and surgical treatments. The objective of this study is to assess the extent to which effects of an acute session of boxing on the muscle activity in the upper extremities of persons with PD compared to healthy older adults (HOAs) and healthy younger adults (HYAs).

Ten participants with PD (69.7 ± 5.2), fourteen HOAs (65.0 ± 5.7), and twelve HYAs (22.8 ± 2.9) were recruited for this study. Electromyography (EMG) was used to assess muscle activity in the upper extremities during elbow flexion and extension at a fast and self-selected pace pre and post an acute boxing session. Peak amplitude, area under the curve, time of onset to peak amplitude, and time of peak amplitude to offset were measured.

Results show a significant main effect of condition (pre vs post) for peak amplitude to offset in the triceps brachii ($F(1) = 5.869$; p = 0.046) in people with PD for fast arm movements and a significant main effect of condition for peak amplitude in the triceps brachii ($F(1) = 7.079$; p = 0.045) and peak to offset in the triceps brachii ($F(1) = 7.512$; p = 0.029) for self-paced arm movements. Results show a significant main effect of condition for peak to offset in the triceps brachii ($F(1) = 8.181$, p = 0.009) in people with PD, HOA, and HYA for fast arm movements on the right side and a significant main effect of condition for peak to offset in the bicep brachii ($F(1)$

= 4.256, p = 0.018) and peak amplitude in the triceps brachii (*F(*1) = 4.587, p = 0.042) in people with PD, HOA and HYA for self-paced arm movements on the right side.. An interaction effect was also shown for peak to offset in the triceps brachii (p = 0.002) but post hoc comparisons did not show significance.

Results from this study suggest that boxing may influence EMG patterning characteristics in persons with PD alone and compared to HOAs and HYAs. Results have shown main effects after an acute session of boxing, primarily in the muscle activity of the triceps. Results have also shown an interaction effect among PD, HOAs, and HYAs in triceps muscle activity after an acute session of boxing. Future research is needed to determine the efficacy of a boxing program on motor symptom impairment in persons with PD and potential long-term therapeutic benefits.

Introduction

Research has shown that exercise and physical therapy can benefit persons with Parkinson's disease (PD), and combat symptoms not alleviated by medicine or surgery. Physical therapy recommendations for exercise that aim at improving PD symptoms are dependent on the staging of disease progression relative to the Hoehn and Yahr classification (Keus, Bastiaan, Hendriks, Bredero-Cohen, 2007). Early stage (stage 1-2.5 classification) therapy protocols aim to prevent inactivity, fear to move or fall, and preserve physical capacity. Mid-stage (stage 2-4 classification) therapy protocols focus on specific problem areas relative to disease such as transfers, body posture, reaching and grasping, balance and gait. Late stage (stage 5 classification) persons are typically wheelchair bound and heavily medicated, so the objective for therapy is to preserve vital functions and prevent complications. Therapeutic protocols developed in accordance with phase-dependent needs components that incorporate and/or target cueing, cognitive movement strategies, balance training, and physical capacity training. Moreover, Horak and King (2009) suggest that the development of a sensorimotor agility program targeting parkinsonian constraints that affect mobility would also be potentially beneficial. Therapeutic boxing includes many of these recommended components, and may be beneficial to persons with PD.

Current evidence-based exercises or physical activities that benefit PD include treadmill walking, tai chi, visual and auditory cued gait training, and forced aerobic exercise such as cycling (Thaut, et al., 1996; Miyai, et al., 2000; Miyai, et al., 2002; Protas, et al., 2005; Herman, Giladi, Gruendlinger, & Hausdorff, 2007; Nieuwboer, et al., 2007; Hackney & Earhart, 2008; Li, et al., 2012; Gao, 2014; Alberts, et al., 2016). These exercise modalities and physical activity protocols have shown benefits in ameliorating the severity of common motor symptoms with PD related to issues such as gait freezing, balance, and dynamic mobility. However, King and Horak (2009) suggested that the incorporation of boxing movements specifically targets anticipatory postural adjustments, postural corrections, fast arm and foot motions, backward walking, timing, and sequencing actions. These would benefit PD-related mobility constraints such as freezing, bradykinesia, inflexible program selection and sequential coordination, and reduced executive function and attention. Thus, therapeutic boxing may be an appropriate exercise to include for persons with PD, but research on boxing in PD is limited.

There have been few studies on the use of boxing as an alternative therapeutic tool for physical activity aimed at improving motor symptoms associated with neurodegenerative or movement disorders. Combs and colleagues (2011) studied the effects of a 12-week boxing-style physical activity program on a battery of functional measures in people with PD. After 12 weeks, results showed improvements in balance and gait. Combs and colleagues (2013) conducted an additional study comparing the efficacy of a boxing-style physical activity program with a traditional physical activity program. Results were promising, but limitations must be considered. There are not any studies on boxing and the effects it may have on underlying neuromuscular or skeletomuscular activity in persons with PD.

ACSM guidelines for force training encompass high velocity during movement to induce greater contractile force operations of the skeletal muscle fibers (Kraemer, et al., 2002). Boxing incorporates upper extremity, high-velocity movements during punching mechanics with light loading, suggesting that boxing may induce changes in neuromuscular activity. Persons with PD showed slower rates of force development, decreased peak force amplitudes, and increased duration of muscle contractions (Berardelli, Dick, Rothwell, Day, and Marsden, 1986; Benecke, Rothwell, Dick, Day, and Marsden 1987).However, several studies on the effects of power-based resistance training in PD showed reduction of bradykinesia, improved physical functioning, and improved neuromuscular adaptations such as rate of force development, peak force, and force production capacity (Hakkinen, Kraemer, Newton, and Alen, 2001; Misko, 2003; de Vos, 2005; Kyrolainen, et al., 2005; Henwood, Riek, & Taaffe, 2008; Caserotti, Aagaard, Larsen, and Puggaard, 2008; Wallerstein, et al., 2012). Thus, this suggests that even though neuromuscular activity may be impaired in persons with PD, power-based exercise, such as boxing, has the potential to target these impairments. With PD, force development utilizing the physiological aspects of the sport of boxing combined with power training regimens may potentially delay the progression of motor impairment. A combined boxing and power-training program may lead to improved force output characteristics which may provide a more stable foundation for performing activities of daily living, increase levels of physical activity, and reduce the risk of injury.

Electromyography (EMG) burst characteristics can be indicative of force production characteristics. EMG burst durations are longer during slower movements and shorter during high velocity movement. EMG burst amplitude is larger during movements that require a greater force amplitude (Mustard & Lee, 1987). An increased number of EMG bursts during muscle contraction are associated with greater levels of fatigue during movement (Enoka & Duchateau, 2008). Moreover, EMG has been used to assess the effects of explosive, high-velocity resistance training regimens on neuromuscular adaptations. Hakkinen, Kraemer, Newton, and Alen (2001) studied changes in EMG activity and force production characteristics in the knee extensor muscles after a progressive 6-month strength and power exercise program in middle aged and older adults. There was an increase in maximal isometric strength and 1 RM strength in older adult males and females in the knee extensors after the 6-month training protocol. There was also a significant increase in percentage of explosive strength in older adult males and females.

Caserotti, Aagaard, Larsen, and Puggaard (2008) investigated the effects of an explosive-style, heavy-resistance training regimen on force production characteristics in two age categories, 60 and 80 years, of older adults. The exercise protocol was a progressive 12-week, twice per week, program that catered to strength and power development using ballistic movements and heavy loads corresponding to 75-80% of the participant’s 1RM. Significant increases were observed in both age groups in measures of rate of force development, maximal isometric voluntary muscle strength, impulse, height and muscle power during countermovement jumps, and the unilateral leg extension.

Wallerstein and colleagues (2012) studied neuromuscular adaptations after a progressive, 16-week strength and power training programs were administered to an older adult population. Strength measurements were taken with leg and chest press 1RM tests, and power measurements were taken with maximum voluntary ramp and ballistic isometric contractions. EMG activity, electrical mechanical delay, and rate of torque development of the vastus lateralis and vastus medialis muscles were collected. Peak torque values from both the ramp voluntary isometric contractions and the ballistic voluntary isometric contractions increased significantly in both the power and strength training groups with no changes observed in the control group. Rate of torque development improved in all groups from baseline measurements. Electrical mechanical delay decreased significantly in both the power and strength groups albeit only in the vastus lateralis muscle. No changes were seen in the control group. Thus, examining EMG burst patterning in participants with PD may be an objective measurement of changes in force output due to therapeutic boxing.

The objectives of this study were 1) to determine the effects of an acute boxing session on the muscle activity in the upper extremities of persons with PD and to determine the contribution of aging to changes in muscle activity after an acute session of boxing. EMG was used to measure muscle activity before and after one session of boxing training in persons with PD, HOAs, and HYAs. We hypothesized that an acute session of boxing would improve timing and amplitude of the biceps brachii and triceps brachii muscle. We also hypothesized that the largest changes in muscle activity would occur in persons with PD. HOAs would also show improvement in timing and amplitude of the biceps brachii and triceps brachii muscle, but not to the extent as those with PD. Muscle activity in HYAs would not change.

Methods

Participant Demographics

Data were collected from 36 participants, including 10 people diagnosed with PD [mean age = 69.7 ± 5.2; female (4), male (6)], 12 healthy age- and sex-matched younger adults [mean age = 22.8 ± 2.9; female (5), male (7)], and 14 healthy sex-matched older adults [mean age = 65.0 ± 5.7; female (6), male (8)] (Table 2.1). HOA were recruited through verbal and personal announcements during operating hours in the Exercise Clinic, an on-campus adult fitness program sponsored by the Kinesiology Department at Iowa State University. Participants with PD were recruited during a boxing outreach group for persons with PD. HYA were volunteers in the boxing outreach group.

The inclusion criteria for HOA and HYA participants in this study: 1) were between the ages of 18 and 85; 2) had no neurological impairment or disease, 3) could complete a 45-minute boxing training session, and 4) for HOAs only, must be currently participating in the Iowa State University Exercise Clinic and have obtained a physician's signature on the physician's awareness form. The inclusion criteria for participants with PD in this study were: 1) clinical diagnosis of PD using the UK PDS Brain Bank Criteria (Clarke et al, 2016); 2) be between

Table 2.1 Participant Demographics

Participant	*Age*	*Gender*	*Handedness*	*Ethnicity*	*Education (years)*	*MAS*	*Disease Duration (years)*	*Boxing Duration (months)*
PD_01	73	Male	Right	Caucasian	23	Left	11	14
PD_02	62	Male	Right	Asian	24	Left	2	13
PD_03	68	Male	Right	Caucasian	17.5	N/A	1	7
PD_04	65	Female	Right	Caucasian	16	Left	4	6
PD_05	65	Female	Right	Caucasian	18	Right	0.25	3
PD_06	75	Female	Right	Caucasian	16	Left	10	24
PD_07	78	Male	Right	Caucasian	24	N/A	2	18
PD_08	74	Male	Right	Caucasian	20	Right	3	18
PD_09	67	Male	Right	Caucasian	16	Left	6	36
PD_10	70	Female	Right	Caucasian	16	Left	16	36
HYA_01	22	Male	Right	Caucasian	16	NA	NA	NA
HYA_02	21	Female	Right	Caucasian	16	NA	NA	NA
HYA_03	22	Female	Right	Caucasian	16	NA	NA	NA
HYA_04	21	Male	Right	Caucasian	16	NA	NA	NA
HYA_05	22	Female	Right	Caucasian	16	NA	NA	NA
HYA_06	24	Male	Right	Caucasian	18	NA	NA	NA
HYA_07	27	Female	Left	Asian	22	NA	NA	NA
HYA_08	20	Female	Right	Caucasian	14	NA	NA	NA
HYA_09	21	Male	Right	Caucasian	15	NA	NA	NA
HYA_10	21	Male	Right	Caucasian	16	NA	NA	NA
HYA_11	30	Male	Left	Caucasian	16	NA	NA	NA
HYA_12	23	Male	Right	Caucasian	17	NA	NA	NA
HOA_01	71	Female	Right	Caucasian	18	NA	NA	NA
HOA_02	52	Female	Right	Asian	20	NA	NA	NA
HOA_03	64	Female	Right	Caucasian	16	NA	NA	NA
HOA_04	57	Female	Right	Caucasian	18	NA	NA	NA
HOA_05	65	Female	Right	Caucasian	16	NA	NA	NA
HOA_06	67	Male	Right	Caucasian	19	NA	NA	NA
HOA_07	69	Male	Right	Caucasian	19.5	NA	NA	NA
HOA_08	64	Male	Right	Caucasian	16	NA	NA	NA
HOA_09	65	Male	Right	Caucasian	14	NA	NA	NA
HOA_10	65	Male	Right	Caucasian	16	NA	NA	NA
HOA_11	72	Female	Right	Caucasian	22	NA	NA	NA
HOA_12	59	Male	Left	Caucasian	24	NA	NA	NA
HOA_13	70	Male	Right	Caucasian	18	NA	NA	NA
HOA_14	70	Male	Right	Caucasian	20	NA	NA	NA

the ages of 40 and 85; 3) previous or current participation in the boxing outreach program at Iowa State University, and 4) have a stable regimen of antiparkinsonian medication for the 30 days prior to study participation. Exclusion criteria for all participants will include a Mini-Mental State Examination score less than 24 (Folstein, Folstein, & McHugh, 1975). Demographic and disease information was collected, and this information is shown in in Table 2.1. Length of participation time in the boxing outreach program was also recorded for all participants with PD. Participants with PD were on medication for the duration of the study.

Intervention overview

Participants were asked to complete a single, acute session of boxing training with data collections before and after the session. The boxing session was led by a USA Boxing certified boxing coach. Each session included a brief warm-up for the upper body using lightweight dumbbells, followed by agility and footwork drills. Next participants performed shadow boxing, individualized pad work. Finally, participants engaged in a cool-down portion that involved static stretching of major muscle groups. Each boxing session was approximately 45-minutes. (Table 2.2).

Pre/post-testing

A Likert fatigue scale from 0 to 10 was administered pre- and post-boxing session prior to data collection to control for the effect of fatigue. Muscle activity from contraction during vertical elbow flexion and extension was collected in the long head of the biceps brachii and the long head of the triceps brachii before and after an acute boxing session. EMG activity was collected via surface electrodes placed on the biceps brachii and the triceps brachii of the both arms. The participant was asked to perform flexion and extension at the elbow joint to induce contraction in both muscle groups of each arm at a self-selected pace and as fast as possible. The movement was demonstrated, and participants were instructed to perform elbow flexion and extension through the full range of motion with their palms facing up and their elbow in a fixed position at their side during the movement task. The length of each trial during data collection was five seconds. Multiple trials were completed until reaching approximately twenty EMG bursts per condition. Self-paced and fast movements per arm were randomized.

Table 2.2 *Description and purpose of drills in boxing session as it relates to PD.*

Exercise	Movement Description	Movement Impact
Upper Body Dumbbell Warm-up	Lightweight dumbbells (each exercise performed for 10 repetitions): internal and external rotation with 90-degree elbow flexion, shoulder abductions with 90-degree elbow flexion, front and lateral raises, military press, bent-over row, chest press at 45-degree angle away from horizontal, elbow flexion, elbow extension	Increase range of motion about the shoulder joint, increase blood flow to muscle supporting shoulder joint, shoulder injury prevention during boxing performance
Footwork Drills	Assume boxing stance, make a 'square' formation on the floor in boxing stance, respond to command "switch" (change direction), for 3, 2-minute rounds	Lower extremity multi-directional agility, cardiovascular stimulus, reactive response mechanisms, lower extremity impact
Shadowboxing	Number sequence established with correlation to boxing punch, instructor calls out number to which participants respond verbally and physically with number and associated punch at an explosive velocity in an open chain kinetic motion (participant is stationary), for 3, 2-minute rounds	Memory recall, high-velocity muscular contractions in the upper extremities, dual-tasking, verbal engagement for muscles used during respiration and talking
Pad-work	Individualize to participants ability, instructor calls out numbers to which participants respond to visual target with mitt wearing boxing gloves through closed chain kinetic motion (participant is stationary), for 3, 2-minute rounds	Memory recall, high-velocity muscular contractions in the upper extremities, hand-eye coordination development
Cool-down	Static-passive stretching technique for all major muscle groups used during boxing session (stretches held for 15 seconds)	Venous return of blood to resting organs, injury prevention

EMG data processing

EMG outcome measures include peak amplitude, area under the curve, time of onset to peak amplitude, and time of peak amplitude to offset. EMG (Delsys Trigno) was recorded from surface electrodes placed over the belly of the biceps brachii and the belly of the triceps brachii on both the right and left extremity using The Motion Monitor™ software and sampled at 2000 Hz. A low pass filter at 500 Hz, a high pass filter at 1 Hz, and a notch filter at 60 Hz were applied. The raw signal was DC-corrected, full-wave rectified, and smoothed using a root-mean-square envelope of 50 ms. The EMG signal was manually inspected for artifacts which resulted in a total of 2,386 flexion and extension trials available for statistical analysis. Peak amplitude, area under the curve (AUC), time of onset to peak amplitude (TTP), and time of peak amplitude to offset (PTO) were calculated from the resulting curve for both muscle groups. Peak amplitude was obtained as the peak in EMG activity. AUC was calculated using the trapezoidal rule. For TTP, the duration of the EMG activity from time to onset to time of peak amplitude was calculated. For PTO, the duration of the EMG activity from time to peak amplitude to time to offset was calculated. Missing data were replaced using substitution of the mean (Roth, Switzer, & Switzer, 1999). Outliers were removed prior to data analysis if data were two standard deviations away from the mean (Selst & Jolicoeur, 1994). Effect sizes were measured using Cohen's *d* to determine the magnitude of any differences between groups.

Statistical analysis

To determine if boxing improved muscle activity in persons with PD, a 2x2 repeated measures analysis of variance (ANOVA) was completed. The within factor was pre- and post-tests and the between factor was the most affected side (MAS) and the least affected side (LAS).

Two participants were removed from the analysis because MAS and LAS were not specified to a single arm. There were 490 trials in the final analysis. To determine the contribution of aging to boxing, a 2x3 repeated measure ANOVA was completed. The within factor was pre- and post-tests and the between factor was group (PD, HOA and HYA). The right side was entered for analyses, and thus only right-handed participants were included in the analysis. Two HYA participants and one HOA were left-handed and were removed. A total of 307 trials were removed as outliers prior to data analysis. Substitution of the mean was used to accommodate missing data sets (Roth, Switzer, & Switzer, 1999). There were 1,896 trials in the final analysis. Separate analyses were completed for the fast and self-paced conditions and for the biceps and triceps muscles. Post hoc comparisons were completed using Tukey's Honest Significant Difference test. Statistical tests were performed in SPSS and set at an alpha level of 0.05.

Exploratory analyses were completed to determine the contribution of fatigue in all groups, and the contribution of boxing training duration and disease duration in participants with PD. A 2x3 repeated measures ANOVA was completed for the reported fatigue outcome measure. The within factor was pre- and post-tests and the between factor was group (PD, HOA and HYA). Post hoc comparisons were completed using Tukey's Honest Significant Difference Test Change score were calculated for the fatigue scores (Post - Pre) and for all muscle activity outcome measures. Pearson correlations were completed between the fatigue change score and all muscle activity change scores, boxing training duration and muscle activity change scores, and disease duration and muscle activity change scores for the PD group only. Four participants were entered for the fatigue analysis, boxing duration, and disease duration analyses. Statistical tests were performed in SPSS and set at an alpha level of 0.05.

Results

EMG Outcome Measures for Changes of Muscle Activity in People with PD

Values for the mean and standard error for fast conditions are represented in Figure 3.1. Results show a significant main effect of condition for PTO in the triceps brachii (*F(1)* = 5.869; *p* = 0.046, *d* = 0.205). No differences for condition were shown for any other outcome measures. For all outcome measures, there was no main effects for MAS and LAS and no interaction effects (Table 3.1, 3.2, and 3.3).

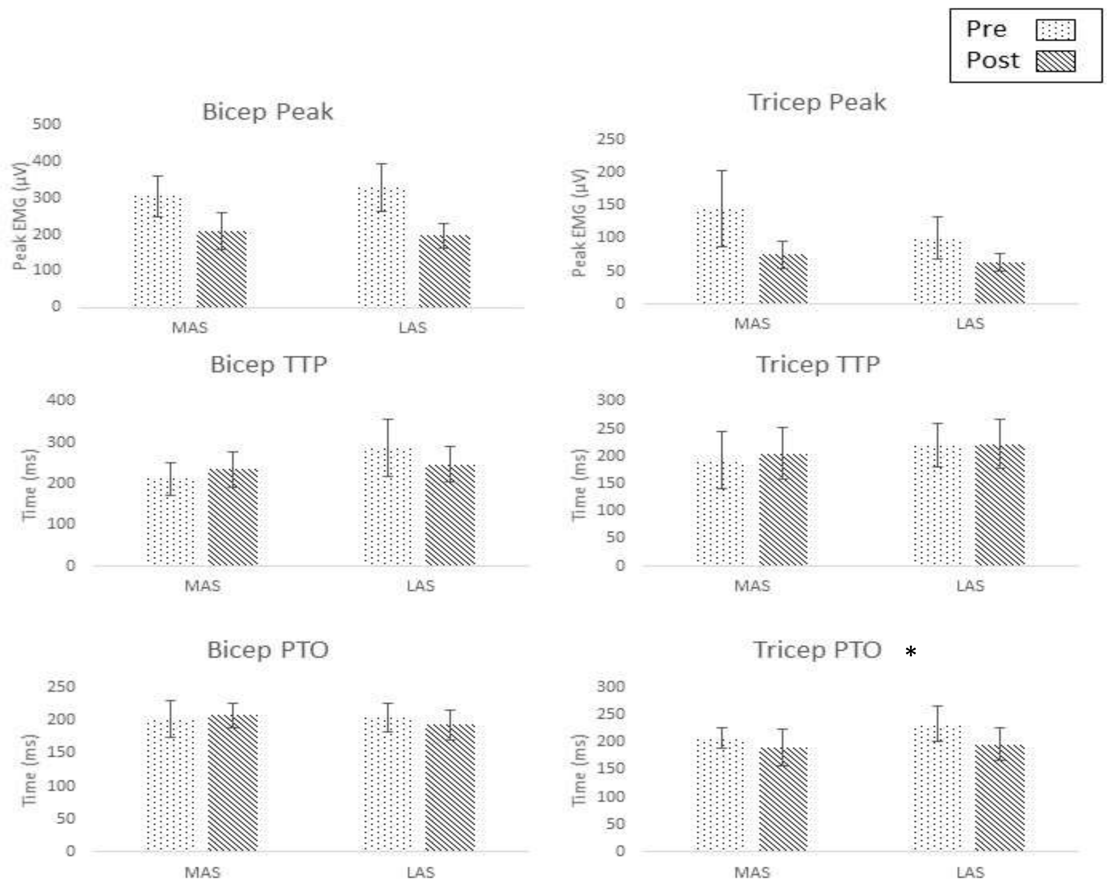

Figure 3.1 Mean values with standard error for most affected side (MAS) pre-post compared to least affected side (LAS) pre-post fast conditions in PD for the biceps brachii and the triceps brachii.

Table 3.1 Main Effects for Pre-Post in Fast Conditions for PD

Outcome Measure	***F***	**df**	***p***
Peak Bicep	5.557	1	0.065
TTP Bicep	1.965	1	0.204
PTO Bicep	0.369	1	0.563
Peak Triceps	1.615	1	0.273
TTP Triceps	0.827	1	0.393
PTO Triceps	5.869	1	0.046*

* *p-value < 0.05*

Table 3.2 Main Effects for MAS-LAS in Fast Conditions for PD

Outcome Measure	***F***	**df**	***p***
Peak Bicep	0.383	1	0.563
TTP Bicep	0.754	1	0.414
PTO Bicep	0.005	1	0.947
Peak Triceps	0.514	1	0.513
TTP Triceps	0.584	1	0.470
PTO Triceps	0.580	1	0.471

Table 3.3 Interaction Effects for Pre-Post and MAS-LAS in Fast Conditions for PD

Outcome Measure	***p***
Peak Bicep	0.127
TTP Bicep	0.317
PTO Bicep	0.894
Peak Triceps	0.533
TTP Triceps	0.756
PTO Triceps	0.318

Values for the mean and standard error for self-paced conditions are represented in Figure 3.2. Results show a significant main effect of condition for peak amplitude in the triceps brachii (*F(1)* = 7.079; *p* = 0.045, *d* = 0.749) and PTO in the triceps brachii (*F(1)* = 7.512; *p* = 0.029, *d* = 0.642). No differences in condition were shown for any other outcome measures. For all outcome measures, there were no main effects for MAS and LAS and no interaction effects (Table 3.4, 3.5, and 3.6).

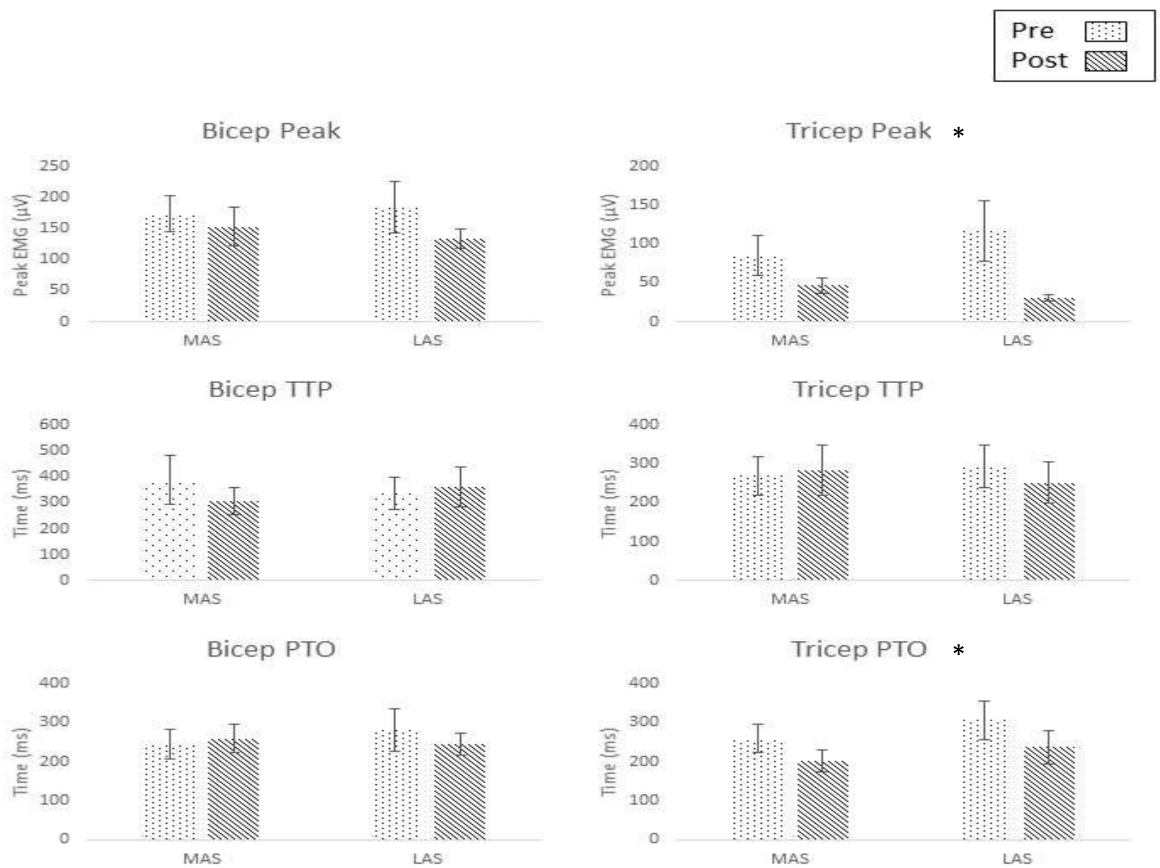

Figure 3.2 Mean values with standard error for most affected side (MAS) pore-post compared to least affected side (LAS) pre-post self-paced conditions in PD for the biceps brachii and the triceps brachii.

Table 3.4 Main Effects for Pre-Post in Self-paced Conditions for PD

Outcome Measure	***F***	**df**	***p***
Peak Bicep	1.703	1	0.240
TTP Bicep	1.944	1	0.206
PTO Bicep	0.141	1	0.719
Peak Triceps	7.079	1	0.045*
TTP Triceps	0.827	1	0.393
PTO Triceps	7.512	1	0.029*

* *p-value < 0.05*

Table 3.5 Main Effects for MAS-LAS in Self-Paced Conditions for PD

Outcome Measure	***F***	**df**	***p***
Peak Bicep	0.079	1	0.789
TTP Bicep	0.006	1	0.942
PTO Bicep	0.095	1	0.767
Peak Triceps	0.163	1	0.703
TTP Triceps	0.584	1	0.470
PTO Triceps	4.665	1	0.068

Table 3.6 Interaction Effects for Pre-Post and MAS-LAS in Self-Paced Conditions for PD

Outcome Measure	***p***
Peak Bicep	0516
TTP Bicep	0.327
PTO Bicep	0.432
Peak Triceps	0.992
TTP Triceps	0.756
PTO Triceps	0.901

EMG Outcome Measures for Changes in Muscle Activity in People with PD Compared to HOA and HYA

Values for the mean and standard error for fast right conditions are represented in Figure 3.3. Statistical analysis shows a significant main effect of condition for PTO in the triceps brachii (*F(1)* = 8.181, *p* = 0.009, *d* = 0.465). There was no main effect of condition for any other outcome measures. For all outcome measures, there were no main effects for group and no interaction effects (Table 3.7, 3.8, and 3.9).

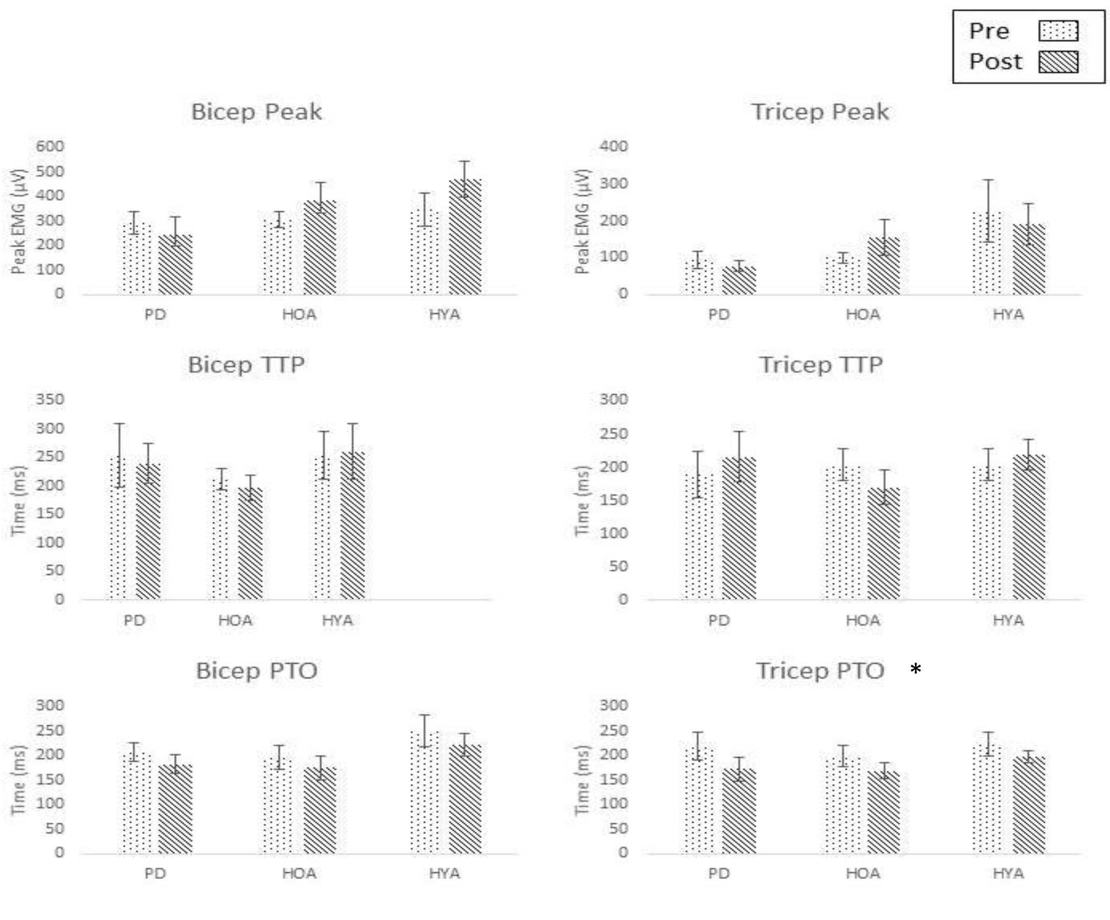

Figure 3.3 Mean values with standard error for fast right conditions in people with PD (PD), healthy older adults (HOA) and healthy younger adults (HYA) for the biceps brachii and the triceps brachii.

Table 3.7 Main Effects for Pre-Post in Fast Conditions

Outcome Measure	***F***	**df**	***p***
Peak Bicep	0.123	1	0.729
TTP Bicep	1.468	1	0.239
PTO Bicep	2.700	1	0.115
Peak Triceps	0.247	1	0.624
TTP Triceps	0.094	1	0.726
PTO Triceps	8.181	1	0.009*

** p-value < 0.05*

Table 3.8 Main Effects for Group (PD, HOA, and HYA) in Fast Conditions

Outcome Measure	***F***	**df**	***p***
Peak Bicep	1.156	2	0.243
TTP Bicep	0.462	2	0.636
PTO Bicep	0.049	2	0.952
Peak Triceps	1.813	2	0.188
TTP Triceps	0.176	2	0.839
PTO Triceps	0.039	2	0.920

Table 3.9 Interaction Effects for Pre-Post and Group in Fast Conditions

Outcome Measure	***p***
Peak Bicep	0.864
TTP Bicep	0.633
PTO Bicep	0.900
Peak Triceps	0.486
TTP Triceps	0.067
PTO Triceps	0.831

Values for the mean and standard error for self-paced right conditions are represented in Figure 3.4. A significant main effect for condition was shown for PTO in the bicep brachii (*F(1)* = 4.256, *p* = 0.018, *d* = 0.224) and peak amplitude in the triceps brachii (*F(1)* = 4.587, *p* = 0.042, *d* = 0.497). No main effect of condition was shown for any other outcome measure. For all outcome measures, there were no main effects of group. An interaction effect was shown for PTO in the triceps brachii (*p*=0.002); however, post hoc analyses show no significant differences. No other interaction effects were shown for any other outcome measure (Table 3.10, 3.11, and 3.12).

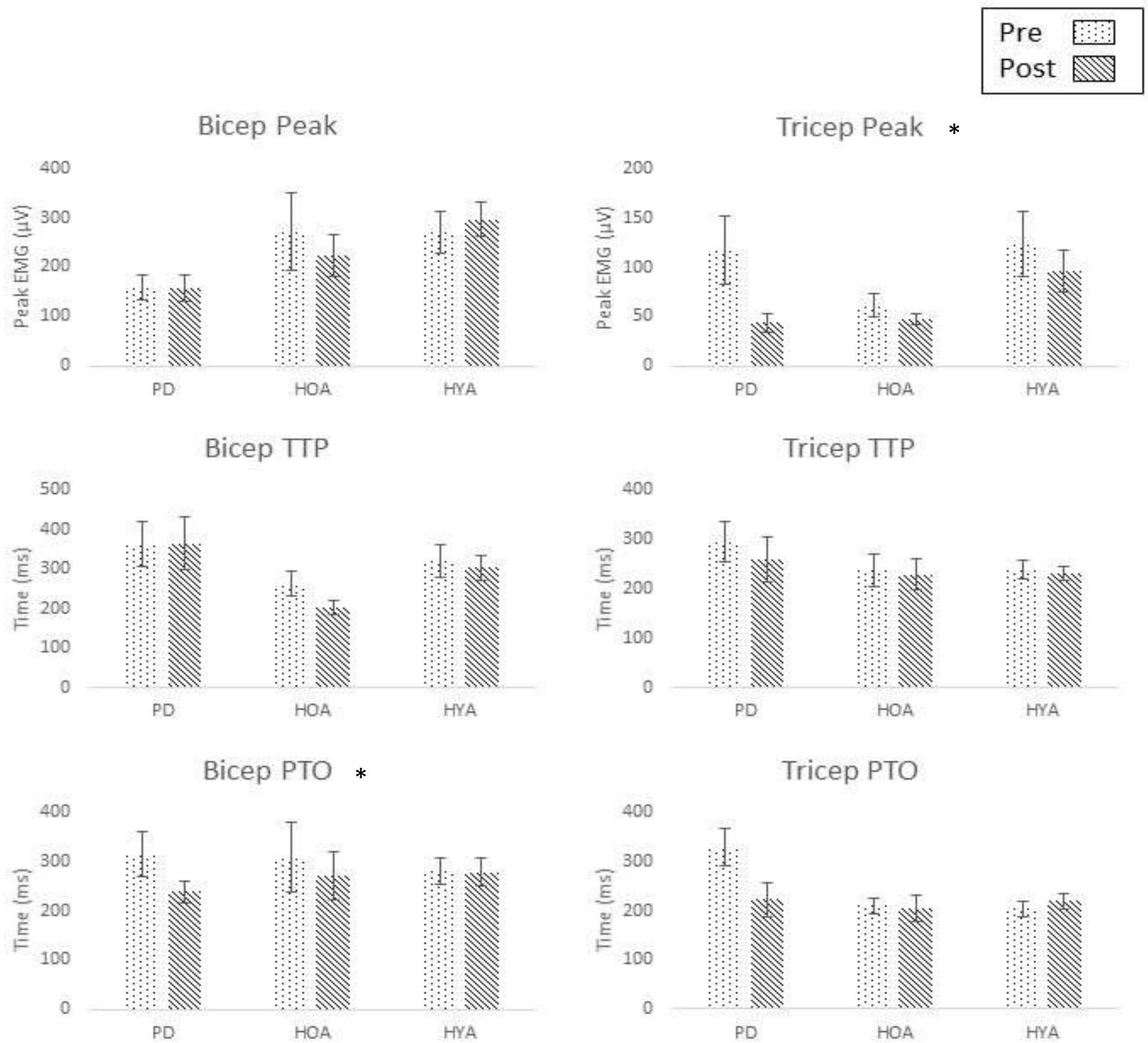

Figure 3.4. Mean values with standard error for self-paced right conditions in people with PD (PD), healthy older adults (HOA) and healthy younger adults (HYA) for the biceps brachii and the triceps brachii. *(* p-value<0.05).*

Table 3.10 Main Effects for Pre-Post in Self-paced Conditions

Outcome Measure	***F***	**df**	***p***
Peak Bicep	0.494	1	0.488
TTP Bicep	1.843	1	0.187
PTO Bicep	4.256	1	0.018*
Peak Triceps	4.587	1	0.042*
TTP Triceps	0.640	1	0.431
PTO Triceps	4.256	1	0.050

* *p-value < 0.05*

Table 3.11 Main Effects for Group (PD, HOA, and HYA) in Self-Paced Conditions

Outcome Measure	***F***	**df**	***p***
Peak Bicep	1.667	2	0.209
TTP Bicep	2.130	2	0.140
PTO Bicep	0.111	2	0.895
Peak Triceps	1.099	2	0.349
TTP Triceps	0.048	2	0.953
PTO Triceps	0.592	2	0.561

Table 3.12 Interaction Effects for Pre-Post and Group in Self-Paced Conditions

Outcome Measure	***p***
Peak Bicep	0.433
TTP Bicep	0.257
PTO Bicep	0.224
Peak Triceps	0.452
TTP Triceps	0.616
PTO Triceps	0.002*

* *p-value < 0.05*

Exploratory Analyses for Fatigue, Boxing Training Duration, and Disease Duration

Values for the mean and standard error for pre-test, post-test, and change scores for the Likert fatigue scale are listed in table 3.13. There was a main effect of condition (pre vs. post) ($F(1)$) = 30.044, $p < 0.001$). There was no main effect of group ($F(1) = 3.103$, $p = 0.061$). An interaction effect was shown ($F(2) = 3.18$, $p = 0.034$); however, post hoc analyses show no significant differences (Table 3.14).

Table 3.13 Mean and SE for Likert Fatigue Scale

Group	Pre	Post	Change
PD	2 ± 1	4 ± 1	2 ± 0
HOA	1 ± 0	2 ± 0	1 ± 1
HYA	0 ± 0	3 ± 1	3 ± 1

Table 3.14 Main and Interaction Effects for Likert Fatigue Scale

Effects	*F*	df	*p*
Pre-Post	30.044	1	0.000*
Group	3.103	1	0.061
Pre-Post * Group	3.18	2	0.034*
* *p-value < 0.05*			

There were no significant correlations shown between fatigue, duration of boxing training (months), and disease duration (years) and all muscle activity outcome measures in the MAS and LAS for both fast paced and self-paced conditions in people with PD (Table 3.15, 3.16, 3.17 and 3.18).

Table 3.15 Correlation between Fatigue, Boxing Duration and Disease Duration in People with PD for Fast MAS Conditions

Outcome Measure	***Fatigue***		***Boxing (mo)***		***Disease (yr)***	
	R	***p***	***R***	***p***	***R***	***p***
Peak Bicep	-0.608	0.392	-0.840	0.160	-0.666	0.334
TTP Bicep	-0.938	0.062	-0.613	0.387	0.026	0.974
PTO Bicep	-0.607	0.393	-0.262	0.738	-0.528	0.472
Peak Triceps	0.997	0.003*	0.383	0.617	-0.150	0.850
TTP Triceps	-0.266	0.734	-0.956	0.044*	-0.369	0.631
PTO Triceps	-0.425	0.575	0.456	0.544	0.958	0.042*

* *p-value < 0.05*

Table 3.16 Correlation between Fatigue, Boxing Duration and Disease Duration in People with PD for SP MAS Conditions

Outcome Measure	***Fatigue***		***Boxing (mo)***		***Disease (yr)***	
	R	***p***	***R***	***p***	***R***	***p***
Peak Bicep	-0.032	0.968	-0.683	0.317	0.035	0.965
TTP Bicep	0.917	0.083	0.654	0.346	0.004	0.996
PTO Bicep	-0.646	0.354	-0.121	0.879	-0.386	0.614
Peak Triceps	-0.047	0.953	0.307	0.693	0.918	0.082
TTP Triceps	0.214	0.786	0.866	0.134	0.175	0.825
PTO Triceps	0.097	0.903	0.963	0.037*	0.557	0.443

* *p-value < 0.05*

Table 3.17 Correlation between Fatigue, Boxing Duration and Disease Duration in People with PD for Fast LAS Conditions

Outcome Measure	***Fatigue***		***Boxing (mo)***		***Disease (yr)***	
	R	***p***	***R***	***p***	***R***	***p***
Peak Bicep	-0.459	0.505	-0.666	0.334	0.217	0.783
TTP Bicep	0.825	0.175	0.799	0.201	0.324	0.676
PTO Bicep	-0.203	0.797	-0.945	0.055	-0.371	0.629
Peak Triceps	0.335	0.665	0.675	0.325	0.880	0.120
TTP Triceps	0.125	0.875	-0.089	0.911	0.602	0.398
PTO Triceps	-0.596	0.407	-0.926	0.074	-0.595	0.405

Table 3.18 Correlation between Fatigue, Boxing Duration and Disease Duration in People with PD for SP LAS Conditions

Outcome Measure	***Fatigue***		***Boxing (mo)***		***Disease (yr)***	
	R	***p***	***R***	***p***	***R***	***p***
Peak Bicep	-0.680	0.320	-0.569	0.431	-0.605	0.395
TTP Bicep	-0.897	0.103	-0.479	0.521	-0.284	0.716
PTO Bicep	0.890	0.110	0.121	0.879	-0.559	0.441
Peak Triceps	0.337	0.663	-0.298	0.702	-0.948	0.052
TTP Triceps	-0.376	0.624	-0.928	0.072	-0.250	0.750
PTO Triceps	0.892	0.108	0.525	0.475	0.307	0.693

Discussion

This study is the first to examine the effects of an acute session of boxing on muscle activity in persons with PD. Results from this study show no statistical difference in peak amplitude after a session of boxing for people with PD. However, there was a main effect of condition for time from peak to offset in the triceps brachii during fast movement and peak amplitude and time from peak to offset in the triceps brachii during self-paced movement. Results also show no statistical difference in peak amplitude and burst duration after a session of boxing for HOAs and HYAs and there were no differences between people with PD, HOAs, and HOAs; however, there was a main effect of condition for time from peak to offset in the triceps brachii during fast movement, a main effect of condition for peak amplitude of the triceps brachii and time from peak to offset in the biceps brachii during self-paced movement.

Main effects are present only in the muscle activity of the triceps, specifically time from peak to offset and peak amplitude. Punching mechanics in boxing rely heavily on triceps and biceps contraction. As the punch is thrown outward, the triceps contract; as the punch is retracted, the movement is reliant on the contraction of the biceps. Often in the sport of boxing, there is a greater emphasis on the movement of the punch being thrown out as opposed to being drawn back to its original position. This could explain why main effects were seen in primarily in triceps outcome measures. In particular, the results of this study showed a significant decrease in peak amplitude of the triceps during self-paced movements. A decrease in peak amplitude after a session of boxing could also be indicative of increased efficiency with use, as peak amplitude is typically higher with a larger amount of force generation required to complete a movement or with an increase in fatigue. Given the task during data collection was elbow flexion and extension with no resistance, a decrease in peak amplitude suggests less force is required to perform the movement. Our results also showed a significant decrease in time from peak to offset. This may suggest that engagement of the muscle encourages a greater effect of efficiency during muscle contraction thereby reducing time from peak to offset or the relaxation of a muscle after contraction. Interestingly, these same patterns of significance were seen for the HOA and HYA groups. This suggests that changes in muscle activity after boxing may be due to the intervention rather than age or disease.

There was a lack of significance for many outcome measures across all groups. This contrasts with previous research. Previous research incorporated some type of resistance into the assigned power- and strength-based protocols. Hakkinen, Kraemer, Newton, and Alen (2001), and Kyrolainen and colleagues (2005), and Caserotti, Aagaard, Larsen, and Puggaard (2008) found changes in EMG activity and force output characteristics, specifically an increase in EMG activity, peak force and rate of force development, in older adults after strength and power-based training resistance programs over an extended period of time. In contrast, the boxing program implemented in this study focused solely on high-velocity movements with little to no resistance. This could affect changes in muscle activity due to the lack of a stressor to induce progressive neuromuscular adaptation and explain the lack of differences in the other outcome measures.

The results of this study show no differences between groups. Berardelli, Dick, Rothwell, Day, and Marsden (1986) and Benecke, Rothwell, Dick , Day, and Marsden (1987) compared EMG activity in people with PD and healthy older adults, showing that people with PD had an increased number of EMG bursts, smaller burst amplitudes, and longer burst durations during wrist flexion and elbow flexion, respectively. Population bias could also contribute to the lack of differences observed in muscle activity across groups. People with PD recruited for this study were functioning at a high-level, not using any assisted devices, most were in early stage development for PD, and they actively participate in other exercise groups offered through the university on a weekly basis. Ergo, there was a possibility that the participation in the boxing outreach group prior to the acute intervention or the level of severity of the disease in people with PD had corrected the expected usual deficit. Data were also collected while participants with PD were on medication, which could contribute to a lack of significance for outcome measures in EMG activity. Indeed, Berardelli, Dick, Rothwell, Day, and Marsden (1986) and Benecke, Rothwell, Dick, Day, and Marsden (1987) observed a decrease in movement speed, contractile amplitude, and EMG bursts while participants with PD were off medication. Benecke, Rothwell, Dick, Day, and Marsden (1987) observed an increase in movement time while participants were on medication and reduced phasic activity and slower movement times during elbow flexion in people with PD compared to healthy older adults.

The HOA group was also highly active which may have contributed to the lack of difference between this group and the HYA group. The participants in the HOA group exercise attend an exercise clinic thrice weekly, an hour per session, through which they can target several areas of physical fitness including muscular strength and endurance via resistance training and cardiovascular endurance via cardiovascular equipment. The HOA group recruited for this study are unique and could therefore also be considered a special population. The HOAs and HYAs were novel to the boxing intervention, while the PD group had been practicing prior to the study (Table 2.1). So, the lack of difference between groups may also be because PD had already learned the movements incorporated into the intervention, while HOAs and HYAs learned the movements at the time of intervention. Nonetheless, there were no differences between the PD and HOA group. Thus, the results of this study suggest that aging may not affect the acute changes in muscle activity after one session of boxing in active participants.

There are other factors that may have influenced the results, such as fatigue: there was a main effect for fatigue across all groups. However, there was a lower report of fatigue in the HOA group compared to the HYA and PD groups. This could be due to maintenance of physical fitness from regular attendance at the on-campus exercise clinic, which offers an hour-long class, three times per week. Moreover, HYAs typically exhibited a higher rate of exertion during the administered boxing session compared to the HOA and PD groups. Previous research has shown that fatigue impacts muscle activity. Dimitrova and Dimitrov (2003) showed EMG amplitude characteristics can increase during fatigue. Thus, fatigue may contribute to the changes in muscle activity shown in this study, especially for persons with PD. However, there is a lack of significant correlation between the fatigue and muscle activity. This is likely due to low power (only 4 participants). Yet, the correlation was relatively high, suggesting that with more participants, significance may be reached. Continued research is needed to fully determine the influence of fatigue on muscle activity after boxing in persons with PD.

Lack of significance in many of the outcome measures could be attributed to the study duration (one acute session), as short-term effects may not influence changes in muscle activity as strongly as long-term effects observed by Hakkinen, Kraemer, Newton, and Alen (2001), Caserotti, Aagaard, Larsen, and Puggaard (2008), and Wallerstein and colleagues (2012). Hakkinen, Kraemer, Newton, and Alen (2001) observed a significant increase in torque and EMG activity in the knee extensor muscles of older adults after two months of a strength and power-training program. Caserotti, Aagaard, Larsen, and Puggaard (2008) observed significant increases in peak force and impulse, and significant decreases in rate of force development in 60- and 80-year old adults after twelve weeks of an explosive, heavy resistance protocol. Wallerstein and colleagues (2012) observed significant increases in in peak torque and rate of torque development, and a decrease in electrical mechanical delay in older adults after sixteen weeks. Research in PD has shown similar findings. Longer training times result in people with PD have contributed to reduced bradykinesia and increased peak power (Ni, Signorile, & Balachandran, 2016). Results from this study suggest an inverse correlation in TTP of the triceps and length of participation in boxing. Thus, continuous participation may contribute to better efficiency of motor unit recruitment during muscle contraction.

Limitations

There may have been complications during EMG measurements with conductance and tissue composition. The area on which the EMG surface electrodes were placed were cleaned although the amount of fat free mass comparative to fat mass, specifically over the triceps brachii in older adults, could have affected surface electrode conductance during data collection. Muscular contractions during elbow flexion and extension may have been inconsistent due to non-fixed range of motion movements during data collection. However, we instructed participants to perform elbow flexion and extension through the full range of motion with their palms facing up and their elbow in a fixed position at their side during the movement task. Fast conditions during muscular contraction may have increased noise during EMG collection given EMG sensors were non-invasive, surface electrodes and high-velocity movements could create a greater amount of perturbations. However, we did inspect the EMG data for artifacts and removed outliers.

Conclusion

Results from this study suggest that boxing may influence EMG patterning characteristics in persons with PD alone and compared to HOAs and HYAs. Results have shown main effects after an acute session of boxing, primarily in the muscle activity of the triceps. Results have also shown an interaction effect among PD, HOA, and HYA in triceps muscle activity after an acute session of boxing. Future research is needed to determine the efficacy of a boxing program on motor symptoms in persons with PD and potential long-term therapeutic benefits.

CHAPTER 3. SUMMARY

Summary

Due to a loss of dopaminergic neurons in the basal ganglia caused by Parkinson's disease (PD), the inhibition of motor initiation and control have a detrimental effect on the characteristics of skeletal muscle activity. The primary motor symptoms of PD include bradykinesia, postural instability, rigidity, and bradykinesia. The negative effects of PD on movement that induce these symptoms can become problematic during mid- to late-stage disease and reduce quality of life and activities of daily living performance. Pharmaceuticals and surgery are commonly used to alleviate the severity of the motor symptoms in PD; however, exercise and physical therapy can benefit those with PD in order to combat the motor symptoms not mitigated by medicinal treatments or surgical procedures.

Physical therapy recommendations aim to improve PD symptoms relative to the stage of disease progression. The inherent goal of physical therapy protocols is the prevention of inactivity, compensation for balance and gait perturbations common in people with PD, postural stability and transfer tasks, reaching and grasping, and the preservation of physical capacity to prolong independence. Exercise, specifically forced exercise and resistance-based exercise with high-velocity movements (i.e. power training), has been shown to improve the force output characteristics during motor tasks and activities of daily living performance in people with PD.

King and Horak (2009) developed a sensorimotor agility program to delay mobility disability in people with PD. Their program includes a variety of progressive exercises including tai chi, kayaking, boxing, Pilates, lunges, and an agility course that evoke movement patterns to improve mobility. Boxing exercises incorporated into the program include high-velocity contractile punching mechanics and agility work to induce anticipatory postural adjustments, postural correction, fast arm and foot motions, backwards walking, timing and sequencing actions. However, there is currently no evidence-based research to support the efficacy of this program.

There are very few studies assessing the effects of a boxing program and motor skill training for people with PD. Combs and colleagues (2011) studied the effects of a 12-week boxing-style physical activity program on a battery of functional measures in people with PD. After 12 weeks, results showed improvements in balance and gait. Combs and colleagues (2013) conducted an additional study comparing the efficacy of a boxing-style physical activity program with a traditional physical activity program. The boxing program included stretching, boxing activities, resistance exercises, aerobic activity, and balance training. The traditional program included stretching, resistance exercises, aerobic activity, and balance training. Results from this study show an improvement in balance and gait measures in both groups albeit measures were no more improved for the boxing group compared to the traditional group.

The exercise program implemented in this study used boxing style drills, only (see Table 2.1). The boxing program included agility drills using the typical boxing stance and footwork mechanics to target gait, balance, and lower body coordination to target gait shuffling, a common PD constraint. The boxing program also included cued shadowboxing and individualized mitt work to evoke high-velocity contractions of the muscles in the upper extremities and to encourage rhythmic and reciprocal movements to target PD constraints such as rigidity and bradykinesia. King and Horak (2009) support the use of fast, large movements to target rigidity, bradykinesia, and freezing to assist in delaying mobility disability.

The purpose of this study was to provide preliminary data in order to determine the efficacy of a boxing program on muscle activity in people with PD compared to HOAs and HYAs. EMG data on muscle activity was collected before and after an acute session of boxing on the upper extremities of people with PD, HOAs, and HYAs. Results from this study showed main effect differences after a session of boxing in people with PD in the triceps during fast and self-paced conditions. Results from this study also showed significant main effect and interaction effect differences in muscle activity after an acute session of boxing compared to HOAs and HYAs, primarily in the triceps muscle. There were many other components in the boxing training that may have additional beneficial effects for persons with PD.

Further research is necessary to determine the efficacy of a boxing program to target and improve motor and non-motor symptoms in people with PD. Utilization of boxing and boxing-related protocols can be modified to target a variety of PD constraints such as rigidity, postural instability, gait perturbations, and bradykinesia. Boxing techniques, applicable within a fitness or therapeutic setting, have the capacity to incorporate several exercise principles highlighted by King and Horak (2009) to maintain mobility such as trunk rotations, rhythmic and reciprocal movements, task sequencing, kinesthetic awareness, large and fast movement, and dual-tasking. The boxing program implemented in this study emphasis agility training; future research could investigate the effects of boxing specific agility drills on balance and gait in people with PD. The boxing program also requires dual motor-cognitive sequencing and memory recall during shadowboxing: a number is assigned to each individual punch, where participants are required to respond with the designated punches to a number sequence provided by the instructor as a combination. Upon responding with punches, participants are also required to verbally repeat the number sequence as loudly as possible, encouraging utilization of muscles that affect speech and swallowing in people with PD. Future research could study the effects of the modified shadowboxing protocols on cognitive functioning and swallow and speech muscle impairment in people with PD. Finally, task sequencing and hand-eye coordination during motor tasks such as pad work that enforces quick, reactive responses to a visual cute (mitt) could be targeted in future research. Boxing also has the potential to contribute to qualitative measurements from non-motor symptoms associated with PD such as stress, anxiety, depression, executive functioning, memory, and fatigue. Boxing is a sport, when applied within a fitness setting, typically associated with stress-relief while deriving physiological benefits from the intensity of the session and the quality of the unique style of physical activity. Boxing can be implemented through group-style fitness sessions to encourage comradery and frequent exposure to social environments. Boxing can also be used in home as an inexpensive fitness tool to target a range of physical and motor fitness components. Boxing is an upcoming modality in which several populations can participate and derive enjoyment.

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