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The Immediate Effect of Rhythm on the Timing of Upper Extremity Movements in Patients with Parkinson's Disease

Erin Mary Keenan
University of Miami, ekeenan826@gmail.com

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THE IMMEDIATE EFFECT OF RHYTHM ON THE TIMING OF UPPER EXTREMITY MOVEMENTS IN PATIENTS WITH PARKINSON’S DISEASE

By
Erin Mary Keenan

A THESIS

Submitted to the Faculty of the University of Miami in partial fulfillment of the requirements for the degree of Master of Music

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the requirements for the degree of
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THE IMMEDIATE EFFECT OF RHYTHM ON THE TIMING OF UPPER
EXTREMITY MOVEMENTS IN PATIENTS WITH PARKINSON’S DISEASE

Erin Mary Keenan

Approved:

Shannon K. de l’Etoile, Ph.D.
Associate Professor of Music Therapy

Terri A. Scandura, Ph.D.
Dean of the Graduate School

Teresa L. Lesiuk, Ph.D
Assistant Professor of Music Therapy

James G. Moore, Ph.D.
Assistant Professor of Physical Therapy
Keenan, Erin Mary (M.M., Music Therapy)
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Parkinson’s disease is a neurodegenerative disease caused by a loss of dopamine-producing neurons in the basal ganglia. Primary motor deficits include resting tremor, bradykinesia, muscular rigidity, and postural instability. Most importantly, patients have difficulty both initiating movements and performing well-timed movements. This study explored the effect of rhythm on the timing of upper extremity movements in patients with Parkinson’s disease. Comparisons were made between an external rhythmic cue, an external rhythmic cue in combination with auditory feedback, and no cue. Fifteen participants performed a simple reaching task in each of the four cueing conditions with the use of an interactive touch table. Condition 1 consisted of no cue. Condition 2 included a metronome set to the participant’s baseline tempo. Condition 3 included a metronome set to the participant’s baseline tempo, and a synthesized tone that occurred as a result of contact with the table. Finally, Condition 4 included no cue, similar to Condition 1. Participants were placed into either a mild/moderate level of impairment group, or a severe level of impairment group. Data were collected for total movement time, initiation time, and delta time for each participant in all four conditions.
Results of the study did not reveal a main effect of condition on total movement time, initiation time or delta time. However, post-hoc pair-wise comparisons revealed significant decreases between Condition 1 and Condition 4, which were both uncued conditions, for both total movement time and delta time. In addition, for total movement time, a significant decrease was found between Condition 2 (external rhythmic cue) and Condition 4 (no cue). An immediate effect of cueing was found for initiation time and delta time, but did not reach a level of significance. An immediate effect of cueing on total movement time was not evident. Overall, from Condition 1 to Condition 2 as well as Condition 1 to Condition 3, initiation time and delta time decreased, but total movement time did not. Further analysis of level of impairment could not be conducted because of the small number of participants in the severe level of impairment group. The results suggest that one auditory cue was not more beneficial than the other for improving total movement time, initiation time, or delta time. In addition, the improvement from Condition 1 to Condition 4 for total movement time and delta time suggests that a practice effect was evident for the participants. The results of the study suggest that long-term training of either auditory cue can be an effective rehabilitation technique for patients with Parkinson’s disease to improve the timing of upper extremity movements.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>LIST OF FIGURES</th>
<th>vi</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
</tbody>
</table>

## Chapter
1. **INTRODUCTION** ................................................................. 1  
   Statement of the Problem ....................................................... 1  
   Need for the Study............................................................... 5  
   Purpose of the Study ............................................................ 7  
2. **REVIEW OF LITERATURE** .................................................... 8  
   The Role of the Basal Ganglia in Movement ................................ 8  
   The Role of the Basal Ganglia in Parkinson’s Disease .................. 15  
   The Role of the Basal Ganglia in the Perception of Rhythm ........... 20  
   The Immediate Effect of Rhythm on Upper Extremity Movement ...... 25  
   Long-Term Training of Upper Extremity Movement with Rhythm ...... 37  
   Summary of Literature Review ............................................... 46  
   Research Questions ................................................................... 49  
3. **METHOD** ............................................................................ 50  
   Participants ............................................................................... 50  
   Materials .................................................................................. 51  
   Equipment .................................................................................. 52  
   Procedure .................................................................................. 53  
   Design and Analysis ................................................................... 56  
4. **RESULTS** ............................................................................ 58  
   Research Question One ............................................................. 60  
   Research Question Two ............................................................. 62  
   Research Question Three ......................................................... 62  
   Additional Descriptive Analysis ............................................... 64  
   Inferential Analysis for Research Questions 1, 2, and 3 ............. 67  
   Level of Impairment ................................................................... 70  
   Research Questions 4, 5, 6, and 7 ............................................. 71  
   Mild/Moderate Level of Impairment ........................................... 71  
   Severe Level of Impairment ....................................................... 74  
5. **DISCUSSION** ....................................................................... 79  
   Review of the Research Questions .............................................. 79
The Effect of Rhythmic Cueing Condition on Total Movement Time, Initiation Time, and Delta Time ................................................................. 79
Level of Impairment ........................................................................... 82
Limitations of the Study ...................................................................... 84
Theoretical Implications ...................................................................... 86
Clinical Implications ........................................................................... 86
Recommendations for Future Research ............................................... 87
Summary and Conclusions ................................................................... 88

REFERENCES .......................................................................................... 90

APPENDICES .............................................................................................. 96
A. CONSENT FORM: PARTICIPATION IN
   THE RESEARCH STUDY ....................................................................... 96
B. PARKINSON’S DISEASE QUESTIONNAIRE ......................................... 98
C. SELF-REPORTED DISABILITY SCALE .................................................. 99
D. SCHWAB AND ENGLAND ACTIVITIES
   OF DAILY LIVING .............................................................................. 101
E. RECRUITMENT FLYER ....................................................................... 102
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>The Basal Ganglia Structures</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>The Nigrostriatal Pathway</td>
<td>11</td>
</tr>
<tr>
<td>2.3</td>
<td>The Basal Ganglia Motor Circuit</td>
<td>14</td>
</tr>
<tr>
<td>3.1</td>
<td>Visual of Targets on the Interactive Touch Table</td>
<td>54</td>
</tr>
<tr>
<td>4.1</td>
<td>Total Movement Time by Level of Severity Across All Conditions</td>
<td>77</td>
</tr>
<tr>
<td>4.2</td>
<td>Initiation Time by Level of Severity Across All Conditions</td>
<td>77</td>
</tr>
<tr>
<td>4.3</td>
<td>Delta Time by Level of Severity Across All Conditions</td>
<td>78</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Demographics of Participants</td>
<td>61</td>
</tr>
<tr>
<td>2</td>
<td>Means and Standard Deviations of Total Movement Time, Initiation Time, and Delta Time for All Participants in Each Condition</td>
<td>63</td>
</tr>
<tr>
<td>3</td>
<td>All Participants When Exposed to All Conditions and the Results for Total Movement Time, Initiation Time, and Delta Time</td>
<td>65</td>
</tr>
<tr>
<td>4</td>
<td>Summary of ANOVA Results for Effect of Condition on Total Movement Time</td>
<td>67</td>
</tr>
<tr>
<td>5</td>
<td>Summary of ANOVA Results for Effect of Condition on Initiation Time</td>
<td>68</td>
</tr>
<tr>
<td>6</td>
<td>Summary of ANOVA Results for Effect of Condition on Delta Time</td>
<td>69</td>
</tr>
<tr>
<td>7</td>
<td>Means and Standard Deviations of Total Movement Time, Initiation Time, and Delta Time for Mild/Moderate Level of Impairment in Each Condition</td>
<td>73</td>
</tr>
<tr>
<td>8</td>
<td>Means and Standard Deviations of Total Movement Time, Initiation Time, and Delta time for Severe Level of Impairment in Each Condition</td>
<td>75</td>
</tr>
</tbody>
</table>
Chapter One

Introduction

Statement of the problem. Parkinson’s disease (PD) is a neurodegenerative disorder that currently affects at least 1 million people in the United States, with 60,000 new cases diagnosed each year (Hou & Lai, 2008; Vernon, 2007). About 2% of older adults over the age of 65 are affected with the disorder. The distinct primary deficits of the disease include resting tremor, bradykinesia, muscular rigidity, and postural instability. Tremor, which is a rhythmic oscillation of a body part, is the cardinal feature of PD and is often the first sign of the disease (Carr & Shephard, 1998). Bradykinesia involves a slowness of movement, while akinesia produces “freezing”, or a cessation of movement. Muscular rigidity prevents adequate range of motion of the arms, legs, trunk and neck.

Postural instability is highly evident during standing and walking, and in combination with poor timing of movement it increases the risk of falling (Carr & Shephard, 1998). Patients also have problems with both initiating movement and continuing an ongoing motor movement. Due to the progressive nature of PD, symptoms worsen over time (Jankovic & Lang, 2008).

PD causes impairments in activities of daily living, such as dressing and eating. In later stages of the disease, the client may experience loss of independence and reduced quality of life. Bradykinesia and akinesia in particular impair the ability to perform tasks such as dressing, fastening buttons, or getting arms into sleeves. If the dominant hand is more affected, upper extremity tasks such as brushing teeth, shaving, or other repetitive movements, are greatly impacted (Jankovic & Lang, 2008).
Automatic movements, including the use of hands to gesture when talking, are minimal. Overall, the activity and magnitude of movements are reduced due to “freezing” episodes.

A further decline in motor functioning can occur if the patient does not maintain normal activity levels (G. Hartley, personal communication, February 26, 2009). In a patient who has decreased motor activity and increased rigidity and stiffness, contractures (i.e., shortening of the muscle) may occur, which can cause deformity. The client will then have additional loss of strength, endurance, and range of motion in the upper extremities. This limited range of motion prevents the PD patient from performing activities of daily living and increases the need for assistance. As the disease progresses, the patient will need a caretaker or family member to provide care. This level of care, combined with medical services, medications, and therapies can cost over $23,101 a year per patient (Hou & Lai, 2008).

Patients with PD benefit from treatment such as physical therapy or occupational therapy. Rehabilitative interventions in physical therapy address deficits such as postural instability, slowness of movement, balance, and gait. Exercising the muscles of the neck, trunk, hips, and shoulders is vital for improving flexibility, strength, and mobility (Cianci, 2007). In occupational therapy, ways to improve functional independence are addressed, such as feeding, dressing, and cooking (Carr & Shephard, 1998). Compensation strategies are also provided for the patient to improve balance or reduce freezing, and the patient is given ways to modify aspects of the home in order to maintain independence (Cianci, 2007). For example, patients can utilize adaptive utensils or button hooks so that the patient is better able to take care of themselves.
In addition to therapies, a common medication for PD is known as levodopa, or L-dopa. Levodopa counteracts the dopamine deficiency in the brain that is associated with PD. The drug can successfully manage the motor symptoms of PD, but has side effects, such as nausea, dyskinesia, and hallucinations (Fitzsimmons, Vernon, & Ward, 2007). In addition, as the disease progresses, nerve terminals in the brain are reduced, which causes a depletion of dopamine that is stored in the nerve terminals. This depletion results in a decreased effect of the drug duration, meaning the patient must receive higher doses of the medication in order to achieve benefits (Hou & Lai, 2008). Due to the progressive nature of the disease and the high costs of medical care and therapies, more effective treatments are needed for patients with PD.

Other avenues need to be investigated to improve upper extremity functioning to maintain independence and quality of life in patients with PD. Research has shown that auditory rhythm can improve upper extremity movement in typical participants, as well as participants with a neurologic disorder, such as stroke or PD. In typically-functioning adults, rhythm enhances movement of the arms due to the decreased variation of muscle activity as well as increased co-contraction of agonist and antagonist muscles (Safranek, Koshland, & Raymond, 1982). Rhythm, especially at a slower tempo, increases the duration of muscle activity, which can enhance the endurance and joint stability of the upper extremities (Thaut, Schleiffers, & Davis, 1991). In addition, rhythm improves timing of the movement, despite spatial demands (Thaut, Brown, Benjamin, & Cooke, 1996).
In participants with a neurological disorder, such as stroke or PD, the addition of rhythm can improve motor control and timing. The immediate effects of rhythm on a simple upper extremity movement have been studied with patients post-stroke. An external cue of a metronome provides a template for when to begin the movement, an endpoint for the movement, as well as guidance for the whole trajectory of the movement (Thaut, Kenyon, Hurt, McIntosh, & Hoemberg, 2002). Research involving participants with PD has also revealed an immediate entrainment effect when the patients are presented with an auditory rhythm. PD patients are able to entrain with an external rhythm with the use of a simple finger-tapping task at their preferred tempo (Freeman, Cody & Schady, 1993). The entrainment ability of a patient with PD provides evidence of brain plasticity and the ability of the central nervous system to compensate for the depletion of dopamine.

For stroke patients, long-term studies have also been conducted using rhythm to increase velocity and decrease variability of upper extremity movements. Schneider, Schnole, Altenmuller, and Munte (2007) utilized auditory feedback from a drum or piano to improve movement timing of the upper extremities. Using an external auditory cue and auditory feedback, Yoo (2009) found a decrease in overall movement timing with stroke patients. Results revealed a decrease in variability of time between targets when patients performed a movement sequence at their preferred tempo.
Results of long-term studies using an external cue with patients with PD have been conflicting. Platz, Brown, and Marsden (1998) did not find a significant decrease in movement timing with auditory cuing in PD patients. del Olmo et al. (2006) concluded that the use of external auditory cue in upper extremity training decreased movement timing variability. However, the studies with patients with PD did not utilize the combination of an external cue with auditory feedback to further enhance movement timing.

**Need for the Study.** This study has both theoretical and practical contributions. Theoretical contributions will enhance the understanding of the perception of rhythm and the effect of an auditory rhythm on upper extremity movements. Practical contributions will provide evidence of the use of an external cue with or without auditory feedback to enhance upper extremity movements in patients with PD.

**Theoretical Contributions.** The findings of this study will contribute to clarifying the immediate effect of rhythm on the timing of upper extremity movements. Rhythm provides structure and organization, which provides a pattern to enhance the timing and accuracy of upper extremity movements (Thaut, 2005). The study will support the link between the perception of rhythmic patterns and the ability to produce a rhythmic movement. The findings will provide further evidence of the biological ability of humans to perceive an auditory rhythmic pattern that influences the internal timekeeper, resulting in rhythmic entrainment.

The results will provide insight into the physiological response of the body to auditory rhythm. The motor system is highly sensitive to auditory stimuli and can influence the timing and control of upper extremity movements (Thaut, Kenyon, Schauer,
& McIntosh, 1999). The addition of an external auditory cue facilitates more regular motor unit recruitment and provides a continuous time reference to perform a well-timed movement. In addition, the auditory feedback can provide information to reinforce the external cue of a metronome, thus further enhancing movement timing. If a metronome plus auditory feedback is most effective in improving movement timing, the results will provide further evidence of the effectiveness of auditory stimuli on motor movements.

**Practical Contributions.** The results of the study will provide scientific evidence to support the use of Therapeutic Instrumental Music Playing (TIMP) with patients with PD (Thaut, 2005). TIMP is a therapeutic intervention used to improve gross and fine motor skills. By playing a musical instrument, a patient can improve the ability to perform functional, everyday movements. With this technique, an external rhythmic cue can be used to assist in the timing of movements.

In TIMP, patients also receive auditory feedback from the instrument when it is played, which gives the patient an opportunity to adjust the movement. An external rhythm decreases the variability of movements, while the rhythm and auditory feedback provide cues to guide the entire movement trajectory. Participants in the study may benefit more from a metronome alone or a metronome combined with auditory feedback. The study will provide insight into which approach is more effective in improving timing of upper extremity movements in PD. Results from this study may have implications for future research. This research might involve repetitive practice of arm movements to enhance movements of everyday life, such as movements required to perform activities of daily living.
The study will provide implications for music therapists as well as physical and occupational therapists who work in the rehabilitation of patients with PD. Depending on the outcome of this study, therapists will be able to use the most appropriate technique, either an external cue alone or an external cue with auditory feedback, to improve timing of upper extremity movements.

**Purpose of the Study.** The purpose of the present study was to examine the immediate effect of an external rhythmic cue with or without auditory feedback on the timing of upper extremity movements in patients with PD.
Chapter Two

Review of Literature

This chapter will review research literature related to the perception of rhythm and the use of rhythm to enhance upper extremity movements in both typically-functioning adults and adult clinical populations. The first section of the chapter will identify the structures of the basal ganglia and the role of the basal ganglia in movement. Next, the role of the basal ganglia in Parkinson’s disease (PD) will be discussed. The third section will explain the responsibility of the basal ganglia in the perception of rhythm. The next section will examine the immediate effect of rhythm on upper extremity movement in both typical and atypical populations. The final section of the chapter will identify the effects of long-term training of upper extremity movements with the use of rhythm in clinical populations. The literature review will provide scientific justification for using an external rhythmic cue with or without auditory feedback to improve the timing of upper extremity movements in patients with PD.

The role of the basal ganglia in movement. The basal ganglia are part of the extrapyramidal motor system, and consist of four structures: two main structures and two related structures. The extrapyramidal system controls motor functions of voluntary movement along with the pyramidal system and cerebellar pathways (Mosley & Romaine, 2004). The first structure of the basal ganglia, the striatum, contains the caudate nucleus, putamen, and nucleus accumbens (Mosley & Romaine, 2004).
The second structure, the globus pallidus, contains the internal segment, external segment, and ventral pallidum. Two related structures considered part of the basal ganglia are the subthalamic nucleus, a structure located beneath the thalamus, and the substantia nigra, which contains the pars compacta and pars reticulata (see Figure 2.1).

In the striatum, the nucleus accumbens contributes to the movement of limbs, the caudate nucleus controls eye movements, and the putamen is related to motor control in the entire body (Cote & Crutcher, 1991). The substantia nigra also assists in voluntary movement and is an important structure responsible for the production of the neurotransmitter dopamine (Mink, 2007). The substantia nigra pars compacta sends dopamine to the striatum, specifically the caudate nucleus via the nigrostriatal pathway. The nigrostriatal pathway is the efferent connection between the substantia nigra and the striatum, and is important for motor control, such as movement of limbs (see Figure 2.2). The striatum has specific dopamine receptors, and depending on which receptors receive adequate levels of dopamine, movement may be inhibited or initiated (Bear, Connors & Paradiso, 2001).

These inhibitory and excitatory functions provide information to other central nervous system structures as to when to inhibit or excite muscles to perform a movement. When dopamine receptors inhibit a muscle contraction, they exert a braking function, and the movement is not produced. If dopamine receptors activate a muscle, the brake will be released, and a voluntary movement can be performed, such as using the arms to reach for an object (Mink, 2007). The braking function also serves to inhibit competing motor patterns by suppressing any unwanted or unnecessary movement. An example of an unwanted movement is the moving of the right arm, when only the left arm is required to perform a task.
Figure 2.2. An image of the nigrostiatal pathway, which projects dopamine from the substantia nigra to the striatum. Retrieved from www.med.upenn.edu/udall/learn.shtml
Another important aspect of movement is the interaction of the basal ganglia with other structures of the central nervous system, which involves input to the basal ganglia and output from the basal ganglia. These interactions enable the execution of automatic movement once the patterns have been learned. An example of an automatic movement is riding a bike or driving a car (Gutman, 2001). To produce an automatic movement, the striatum receives afferent information from cortical structures as well as thalamic and brainstem nuclei (Mink, 2007). The output of the basal ganglia consists of sending dopamine and other neurotransmitters to the primary motor cortex, the somatosensory cortex, the supplementary motor area, the motor nuclei of the brain stem, and the premotor cortex via the thalamus (Cote & Crutcher, 1991).

The thalamus is the relay center of the brain that transports information or neurotransmitters, such as dopamine, to the cortex. The ventral lateral thalamus projects directly to the premotor, or supplementary motor cortex, which assists in movement (Gutman, 2001). The pars reticulata of the substantia nigra as well as the globus pallidus pars interna (GPI) send output to various structures in the central nervous system. This output includes the pedunculopontine tegmental nucleus (PPI), a brainstem structure that is responsible for locomotor control and movement of upper and lower limbs (Mink, 2007).

Input and output mechanisms of the basal ganglia can function as a motor loop. The basal ganglia contain many loops, but an important loop for movement is the cortico-basal ganglia loop (Cote & Crutcher, 1991). This circular loop enables the basal ganglia to receive information about planned movements and motion via the primary motor cortex. The cortico-basal ganglia loop functions as a motor circuit with connections from the motor and somatosensory areas of the cortex going to the basal ganglia and thalamus.
and back to the supplementary and premotor areas of the brain (Cote & Crutcher, 1991). The last destination in the loop is the primary motor cortex, which then projects information down to the spinal cord to produce movement (see Figure 2.3). The cortex is topographically organized, and specific areas of the cortex connect to corresponding parts of the striatum (Cote & Crutcher, 1991). Topographic means that a specific area of the cortex regulates a particular muscle or joint to enable movement. The cortico-basal ganglia loop provides feedback for the planning, programming, and execution of movement (Beatty, 2001).

The basal ganglia do not project directly to the spinal cord, but do communicate with the motor regions of the cortex that will then communicate with the spinal cord (Beatty, 2001). The structures of the basal ganglia regulate muscle tone of agonist and antagonist muscles by sending input via cortical structures to the alpha and gamma motor neurons in the ventral horn of the spinal cord (Gutman, 2001). The input controls muscle tone in the body and impacts movement of both upper and lower extremities.

In summary, human motor function is possible due to the production of dopamine by the substantia nigra, which is then sent to the striatum. The excitatory or inhibitory information is sent from the striatum to the cortex, and depending on which receptors fire, certain areas of the cortex are activated to either produce movement or inhibit movement.
Figure 2.3. A diagram of the basal ganglia structures and the connections to cortical structures, which function as a motor circuit. Adapted from “Modulation of Movement by the Basal Ganglia,” by D. Purves et al., 2001, Neuroscience, p. 392. Copyright 2001 by Sinauer Associates, Inc.
To be clear, dopamine is the key to the initiation and motor planning of movement sent to cortical structures from the basal ganglia (Beatty, 2001). If an inhibitory dopamine receptor puts the “brake” on the movement, the movement will not occur. If an excitatory receptor releases the “brake,” then activation occurs, producing smooth, coordinated movements of limbs, as well as locomotion.

Stereotypic or hard-wired movements, such as swinging of the arms during gait, are also regulated by dopamine functioning in the basal ganglia (Gutman, 2001). The basal ganglia not only regulate automatic movements, but help to produce voluntary movements through connections with cortical areas. The communication between the basal ganglia and cortical areas, primarily the supplementary motor area, is important because this feedback provides information for the planning of sequenced, accurate, and well-timed movements (Cote & Crutcher, 1991). An example of a sequenced movement is reaching for a glass of water, grasping it, and then bringing it to the mouth to drink.

**The role of the basal ganglia in Parkinson’s disease.** Parkinson’s disease is a progressive disorder caused by loss of dopamine producing neurons in the basal ganglia, specifically the substantia nigra (Pearce, 1992). Lewy bodies, or protein deposits, are then present in the substantia nigra in the areas of neuronal degeneration in the basal ganglia (Mosley & Romaine, 2004). The depletion of neurons in the substantia nigra prevents the transportation of dopamine through the nigrostriatal pathways, which connect the substantia nigra and the striatum.
The reduction of dopamine transportation creates a deficiency of dopamine in the striatum, which is responsible for the smoothness and continuity of muscle activity during movement (Swinn, 2005). About 80% of dopamine is lost from the nigrostriatal neurons before clinical signs of Parkinson’s emerge.

The depletion of neurons in the nigrostriatal pathway disrupts neuronal activity between the pathways within the cortico-basal ganglia loop. If the neuronal activity is impaired, the control and initiation of movement will be affected (Pearce, 1992). Due to the decrease in dopamine-producing neurons in the basal ganglia, upper and lower extremity movement is directly affected. A large amount of dopamine is depleted from the putamen, which projects to the substantia nigra, specifically the pars compacta (Pearce, 1992). The reduction of dopamine results in an imbalance between dopamine and acetylcholine, which leads to an abundance of acetylcholine in the striatum. Excessive acetylcholine in the striatum can cause tremors, dyskinesias and rigidity, as well as other muscle-related symptoms of Parkinson’s disease (Mosley & Romaine, 2004).

The primary upper extremity (UE) deficits of patients with Parkinson’s disease are classified as either positive symptoms or negative symptoms (Pearce, 1992). Positive symptoms are behaviors that the patient has no control over, such as tremors or rigidity. Negative symptoms reflect a diminution or loss of normal functions, such as difficulty maintaining an upright posture or a difficulty initiating and performing accurate movements (Pearce, 1992).
A tremor is “an involuntary rhythmic oscillatory movement that results from the alternating and synchronous muscle contractions of reciprocally innervated antagonist muscles” (Weiner & Shulman, 1999, p. 131). The resting tremor appears in about 70% of cases, and occurs when the distal extremities are relaxed but the proximal and axial muscles are active in maintaining antigravity posture. Tremors often involve the whole hand and wrist, and when severe, the whole limb may shake (Pearce, 1992). The tremor will begin on one side of the body and eventually progress to both sides. A resting tremor can be described as “pill rolling” between the thumb and forefinger (Weiner & Shulman, 1999). The tremor can stop during volitional movement, but as the disease progresses, the tremor is evident at all times. The resting tremor is the most common tremor and affects both upper and lower extremities. Patient’s with this tremor suffer from an impairment in dexterity, which interferes with activities of daily living, such as holding a toothbrush or dressing.

Electromyogram (EMG) evidence shows that during a resting tremor, agonist and antagonist muscles show bursts of activity. Individual motor units fire at high frequency bursts and exhibit an abnormal synchronization of motor units (Shahani & Young, 1977; Young & Shahani, 1979, as cited in Marsden, 1990, p. 59). Researchers hypothesize that a resting tremor occurs due to damage of the nigrostriatal pathway in combination with damage to cerebellar pathways ascending to the thalamus and red nucleus (Marsden, 1990). Due to the decreased amount of dopamine-producing neurons in the substantia nigra, the nigrostriatal pathway does not transport enough dopamine to the striatum.
The depletion of dopamine leads to an increased amount of acetylcholine, which then sends erratic signals to the muscles. In addition, activity in the indirect pathway in the basal ganglia is decreased, which leads to a decreased inhibitory output. The decreased inhibition results in excess motor activity, such as tremors (Mink, 2007).

A second type of tremor is an intention or action tremor, which occurs when a patient voluntarily initiates movement (Weiner & Shulman, 1999). An action tremor is evident during a voluntary movement and is usually most severe at the end of the movement.

Muscular rigidity is also evident in patients diagnosed with Parkinson’s disease and causes resistance during passive movement in agonist and antagonist muscles (Pearce, 1992). Rigidity causes a limited range of motion during flexion and extension of a muscle, and is most evident in the neck, trunk, shoulder, and pelvic girdle, but can affect any part of the body. Due to muscular rigidity, the patient’s elbows may be flexed, the arms are adducted, and the hands are carried in the front of the body. The wrists and metacarpophalangeal joints of the fingers are in permanent flexion while the interphalangeal joints of the fingers are in hyperextension (Pearce, 1992).

For patients with Parkinson’s disease, movements are described as having a “lead pipe rigidity” due to increased muscle tone that leads to “cogwheel-type” movements. (Pearce, 1992, p. 28). The lead-pipe rigidity is more evident in the shoulders, wrists and upper limbs than in the legs. If muscle tone increases, in addition to an existing tremor, the cogwheel movements result (Marsden, 1990). The cogwheel movements are visible during passive movements, such as when a clinician manipulates the upper extremity of the patient. The resistance gives way in small step-like movements, and is described as
though the joint is moving through the teeth of a cog (Swinn, 2005). The source of rigidity is the disruption of dopamine transportation of the direct pathway from the basal ganglia to the brain stem (Miller, 2008). The rigidity results from delays or malfunction of nerve signals sent to the muscles, which causes a change in the muscle tone (Mosley & Romaine, 2004).

A patient diagnosed with Parkinson’s disease may also exhibit slowness of movement, or bradykinesia (Mosley & Romaine, 2004). Bradykinesia is defined as an increase in the time needed to perform a movement. This slowness of the movement is due to a disturbance of dopamine levels (Miller, 2008). Due to the lack of dopamine in the substantia nigra, dopamine is no longer being transported through the cortico-basal loop. This results in the inhibition of the loop that is normally excitatory. A patient may have noticeable difficulty or slowness of hand movements, such as opening and closing the hand (Trail, 2008).

Other deficits of movement include akinesia and hypokinesia. (Berardelli, Rothwell, Thompson, & Hallett, 2001). Akinesia is the inability to initiate movement, which is caused by a slowed muscle response. The slowed responses is caused by the decreased amount of dopamine transported in the cortico-basal ganglia loop, as well as decreased excitement of the thalamus and cortical areas (Miller, 2008). A patient may “freeze” and have a difficult time initiating a movement, such as reaching for an object or beginning to walk. Hypokinesia is the decrease in the execution of spontaneous and automatic movements, as well as a decrease in amplitude or size of motor actions.
A patient may exhibit a reduction of arm swing during walking, or micrographia, which causes handwriting to be small (Jankovic & Lang, 2008). Hypokinesia results from the general loss of dopamine flow within the basal ganglia.

A patient with Parkinson’s disease may also have difficulty in performing simultaneous movements, such as moving both arms together, as well as sequenced motor tasks (Pearce, 1992). The patient will have difficulty reaching for an object and then grasping the object. The difficulty is due to a decreased amount of muscle groups activated, particularly agonist muscles, to complete a task. The decreased activation is the result of the inability of the basal ganglia to send information, particularly dopamine, to cortical areas. The decreased activation results in less coordinated and less smooth movements (Pearce, 1992).

In conclusion, patients with Parkinson’s disease have great difficulty performing well-timed movements due to bradykinesia, as well as problems initiating movements due to akinesia. In addition, during movement, a tremor can worsen, increasing the effort required to perform well-coordinated movements. Because of these deficits, both temporal and spatial aspects of a movement are affected. This results in poorly-timed movements, and smaller movements. Muscular rigidity decreases the range of motion of the upper extremities, prevents accurate movement timing, and inhibits the required distances to perform a complete movement.

**The role of the basal ganglia in the perception of rhythm.** Although patient with Parkinson’s disease may have difficulty performing certain motor tasks, because of the malfunctioning of the basal ganglia, they are still able to perceive rhythm.
A function of the basal ganglia is to assist in time perception and timed motor movements, along with cortical and other subcortical structures. A synchronized motor task such as finger tapping has been used by numerous researchers to investigate well-timed motor tasks and the brain structures involved.

Thaut (2003) used a Magnetoencephalogram (MEG) to measure brain activity related to isochronous finger tapping to a metronome-like beat. Participants included typically-functioning adults. During the isochronous finger-tapping task, tempo changes occurred at a conscious or subconscious level. Results revealed an immediate rhythmic entrainment within 1 to 2 repetitions of the rhythmic stimulus. Changes in tempo, whether conscious or subconscious, caused a higher activation of neurons and an increased firing of neurons to allow for rhythmic entrainment. Thaut (2003) also studied the brain structures activated during isochronous right-finger tapping, tapping to random rhythms, and tapping to rhythms with fluctuated cosine-modulated tempos. A positron emission tomography (PET) scan identified the neural networks involved in the finger tapping. Results revealed that during isochronous right-handed finger tapping, the primary sensorimotor areas of the contralateral hand, bilateral SII (secondary somatosensory cortex), and bilateral opercular premotor areas were activated. Subcortical structures that were activated included the contralateral insula, putamen (basal ganglia structure), and the thalamus. In addition, there was an activation of the cerebellum, specifically the right cerebellar vermis and right anterior hemispheres.

The synchronized motor task of finger-tapping to rhythm activated cortical and subcortical structures, most importantly the basal ganglia, to produce accurate movements. Not only do the basal ganglia assist in performing accurate movements, but
they aid in the identification of durations of auditory stimuli. Tecchio, Salustri, Thaut, Pasqualetti, and Rossini (2000) conducted a study using a series of Magnetoencephalograms (MEG) to find the difference in activation between subcortical and cortical mechanisms during auditory-motor synchronization. Ten healthy adults listened to a sequence of auditory bursts, and the time interval between each burst randomly varied. During the listening task, the MEG recorded the firing in neuronal areas of the subcortical and cortical structures of the brain.

Results of the MEG showed an observable change in the amplitude of the M100 of the brain magnetic field during the auditory stimulation, whether the detection was subconscious or conscious. The authors stated two hypotheses: 1) temporal, auditory input is processed in the neuronal pathway that connects the ear to the auditory cortex or 2) temporal information is analyzed by the auditory cortex and then sent to the basal ganglia for processing. Tecchio et al. (2000) conclude that the perception and discrimination of auditory input is processed by the auditory cortex and sent to the subcortical structures, including the basal ganglia, in order for synchronized movements to occur. The study provides evidence of the perception of rhythm, and that the subcortical structures along with the basal ganglia work together to perform a movement, whether rhythm detection is conscious or subconscious,

Rao, Mayer, and Harrington (1998) also conducted a study using an auditory discrimination task with healthy adults. Seventeen typically-functioning participants were presented with two tones and compared the first tone with the second tone.
The two tones were different in duration. During the discrimination tasks, the researchers used functional magnetic resonance imaging (fMRI) to identify the cortical and subcortical areas that were activated.

Results of the temporal task indicated subcortical activations of the basal ganglia, such as the medial caudate, lateral caudate, and the right putamen, as well as the thalamus. An early and consistent activation of the right putamen and caudate nucleus of the basal ganglia was also discovered. The findings provide further evidence, as shown by the fMRI, that during the temporal discrimination task, the basal ganglia and projections to the thalamus were activated. The researchers add that the basal ganglia, which are damaged in Parkinson’s disease, have been shown to be a critical structure in the timing of well-performed movements and are responsible for an internal timekeeper, supported by striatal dopaminergic transmission.

A similar study by Harrington, Haalan, and Hermanowicz (1998) investigated the basal ganglia and thalamocortical pathways and their role in movement timing and perception in a clinical population. Thirty-four participants diagnosed with Parkinson’s disease (PD), as well as 24 typically-functioning adults performed two motor tasks. The first task was a synchronized tapping task with tones. The second task was the perception of intervals between two tones. The researchers hypothesized that the participants with Parkinson’s disease would have greater variability in timing of motor tasks. In addition, the researchers wanted to find if a correlation existed between the severity of the disease and the timing of movements.
Harrington et al. (1998) found that a motor task, such as finger-tapping to a beat, as well as the perception of time is affected in Parkinson’s disease (PD). Results revealed that the participants with PD tapped at a faster pace and had significantly greater variability in tapping intervals in comparison to the control group. For both groups, the variability of the tapping significantly increased as the duration of the interval increased. Participants with PD were significantly impaired in accurately identifying tone duration in comparison to the control group. Finally, the researchers did find a significantly positive correlation between severity of bradykinesia and paced, finger-tapping variability.

The impaired functioning of the basal ganglia in Parkinson’s disease supports the role of the basal ganglia in time perception and timed motor movements. Harrington et al. (1998) add that the cerebellum is also responsible for time-keeping responsibilities, in conjunction with the basal ganglia. The two brain areas work together to perform well-timed, even movements. The basal ganglia and their projections, such as the supplementary motor area and thalamus, are vital to the reproduction of rhythm and well-timed movements.

In summary, the functions and connections of the basal ganglia when performing well-timed movements depend on the transmission of dopamine. Functional magnetic resonance imaging (fMRI) has identified the activation of cortical areas, as well as subcortical areas like the basal ganglia, during a motor task. Damage to the basal ganglia in Parkinson’s disease can disrupt the initiation and performance of typical motor tasks, such as movement of the arms or locomotion.
The immediate effect of rhythm on upper extremity movement. Although the internal timing mechanism is affected, patients with PD can still entrain movements with rhythm. Rhythmic Auditory Stimulation (RAS) utilizes an external, auditory rhythm to entrain with the internal timekeeper for movement. This Neurologic Music Therapy technique improves gait in patients with neurological damage, such as PD (Thaut, 2005). RAS can improve various parameters of gait, such as velocity, cadence, and stride length, with the addition of a strong, accentuated, auditory rhythm (Miller, Thaut, McIntosh, & Rice, 1996). The use of an external rhythm improves the efficiency of muscle activity due to oscillator-coupling models. Overall, patients with PD can entrain with an external auditory rhythm, which leads to movement benefits.

The effectiveness of RAS to improve gait in patients with a neurological impairment, such as Parkinson’s disease, can also be seen when applied to improvement of movement in the upper extremities. Rhythm improves the timing of the movement, as well as the spatiotemporal aspects of the entire movement pattern (Thaut, Kenyon, Schauer, & McIntosh, 1999). Rhythm provides information for the patient in regard to the total duration of the movement, as well as targets for starting and stopping. This information offers the patient an exact reference point and activates the internal timekeeper to produce an accurate, smooth movement (Thaut, 2005).

The effect of rhythm on typically-functioning adults. Rhythm can enhance temporal and spatial aspects of upper extremities in both participants with a neurological impairment, and in typically-functioning adults. The effect of rhythm on upper extremity movement in typical participants was first explored by Safranek, Koshland, and Raymond (1982). Twenty-four female participants performed a motor task which
included flexion and extension of the elbow by touching a metal peg to three different targets in a sequential pattern. Participants performed this task with or without an auditory rhythm while measurements were recorded via electromyography (EMG). Muscle activity was recorded from the biceps and triceps while performing the motor task. The participants were divided into three groups. One group received an even-rhythm, the second heard an uneven rhythm, and the third group received or no rhythm group, and the movement was performed at their own pace without an external beat.

The study aimed to find the change in variation of the antagonist muscles, as well as to find if a decrease in variation of the EMG activity of the muscles was evident. Results of the study revealed more efficient and desired muscle contractions. An increase in EMG activity occurred for both the even and uneven rhythms, along with an increased co-contraction of the bicep and tricep muscles. With an even rhythm, the biceps became active before the target was hit, as compared to the no rhythm group, in which activation occurred after. In comparison to the uneven rhythm group, the even rhythm group significantly decreased variation in muscle activity.

The use of an even rhythm allowed a more controlled and coordinated movement of flexion and extension of the elbow due to a more efficient recruitment of motor units. The co-contraction of antagonist muscles made the task a new skill, which caused the movement to change from automatic to purposeful. The co-contraction of antagonist muscles also leads to a longer duration of muscle activity for greater joint stability and muscular coordination. The use of a slow, even beat to decrease the inconsistent muscle activity would be helpful to a participant with Parkinson’s disease during a repetitive movement such as flexion and extension of the elbow.
A similar study by Thaut, Schleiffers, and Davis (1991) analyzed the EMG activity of the biceps and triceps with the use of an auditory rhythm. Twenty-four healthy participants used their right arm to contact three target pads in a sequence, while the EMG activity of the bicep and tricep muscles was measured. Participants performed the task for two trials. Trial 1 was performed at the participants’ own internal tempo (i.e., preferred tempo). In Trial 2, participants performed the sequence to an auditory rhythm matched to their internal tempo. They then performed the task at a slower tempo, which was 30% slower than the tempo in Trial 1.

Results of the study revealed a significant difference in the duration of activation of the biceps and triceps. The addition of rhythm resulted in an earlier onset of the bicep muscles, as well as an increased duration of the biceps even after the target was hit, especially in the slower-paced rhythm condition. The earlier onset resulted in co-contraction between the biceps and triceps for both rhythm conditions. Compared to the nonrhythm condition, both rhythm conditions resulted in a significant difference of co-contraction of the biceps and triceps before and after the target was reached.

Decreased variability of the triceps was evident in the participants’ matched tempo with rhythm, indicating that the initiation and completion of the movement resulted from a more regular recruitment of motor units. The results of the study indicate that a decrease in variability of the duration of activation of the triceps, as well as the onset of activation of triceps activity, resulted from a more consistent recruitment of motor neurons.
The study has implications for the effectiveness of rhythmic techniques for patients with neurological impairment to re-teach motor movements and assist in a quicker rehabilitation. An increased co-contraction of antagonist muscles adds stability to the joints to improve upper extremity movements. Due to inconsistent muscle activity in neurological disorders, such as Parkinson’s disease, rhythm provides the organization needed to perform a more focused, well-timed movement. A slow rhythm can increase duration of muscle activity, which in turn increases endurance and strength.

Rhythm not only improves the timing of upper extremity movements, but also improves movements with spatial demands. Thaut, Brown, Benjamin, and Cook (1996) looked at temporal and spatial aspects of movement with and without an external auditory cue. Five typically-functioning participants performed four sequenced movement tasks, which involved either alternating or simultaneous movements of both arms. The sequenced tasks involved movements to five different targets varied in distance. Condition 1 involved the participants first tapping at their desired movement frequency to assess timing of movement. Then, participants completed each task without an auditory cue. In Condition 2, the participants performed the task with an external auditory cue, a 2 Hz metronome beat.

Data were collected for movement time and range of motion for both conditions. Results showed a significant decrease in variability of movement timing with an auditory cue, despite the varying distance between targets. Without an auditory cue, participants were not able to perform the sequence with even timing, and the movement was influenced by the distance of the targets. Thaut et al. (1996) present evidence that an external auditory rhythm can produce evenly-timed movements, despite spatial demands.
The effect of rhythm on patients post-stroke. The previous studies addressed the use of rhythm to improve movement in the upper extremities in populations without neurological impairment. Additional studies have been conducted to investigate the use of a steady beat to improve upper extremity movement in patients post-stroke. Little research has been done, however, with the use of an external timing cue to improve upper extremity movement in patients with Parkinson’s disease. Sensorimotor rehabilitation methods such as Rhythmic Auditory Stimulation, Patterned Sensory Enhancement, and Therapeutic Instrumental Music Playing are applied to patients with both pathologies with positive outcomes (Thaut, 2005). Both pathologies, stroke and Parkinson’s disease, are neurologically based and can benefit from similar rehabilitation methods.

Studies with patients post-stroke have addressed movement of the upper extremities involving simultaneous or alternating movement of the arms, or arm movement involved in playing of a musical instrument. Thaut, Kenyon, Hurt, McIntosh, and Hoemberg (2002) used a metronome to cue movements of the paretic arm in 21, right-handed patients post-stroke. The purpose of the study was to decrease the variability of muscle activation in the arms and to increase the amplitude of the movements. Participants performed a reaching movement, which involved flexion and extension of the elbow, with and without a metronome.

When participants performed the movement with a metronome, they demonstrated an immediate change in movement stability, as well as an immediate change in muscle activation variability. Results revealed a nonsignificant decrease in the mean velocity of arm movements with or without rhythmic cueing.
A decrease in variability of the movement trajectory was significant, as was the increase in range of motion of the elbow in the rhythm condition. The temporal and spatial aspects of the movement were highly correlated with each other in the rhythm condition, but had no significant relationship in the nonrhythm condition.

Thaut et al. (2002) explain that a metronome provides a steady beat, which gives the patient a template or framework in which to perform the complete movement. The template provides information for when to begin the movement, an endpoint for the movement, as well as guidance for the whole trajectory of the movement. The framework helps to restart or improve the oscillator coupling, which means the internal timekeeper for movement is coupling with the external stimulus. Rhythm improves the ability to access a motor plan, especially the execution of the movement due to improved motor recruitment patterns and cortical plasticity of the brain.

A rhythmic stimulus can decrease both spatial and temporal variability. A similar study by Kenyon and Thaut (2003) involved 10 participants post-stroke. A metronome was matched to the participants’ preferred movement frequency while performing an upper extremity motor task of reaching with the paretic arm between two targets. The authors not only found an improvement in temporal variability, but also spatial variability. When comparing self-paced flexion and extension of the elbow to the metronome-driven movement, spatial variability decreased by 40.5% with the addition of a metronome. Variability of movement timing also decreased by 35 % with the addition of a metronome, in comparison to self-paced movements. Kenyon and Thaut (2003) provide further evidence for the immediate effectiveness of rhythm on timing as well as spatial variability.
The effect of rhythm on patients with Parkinson’s disease. The following studies looked at the immediate effects of external cues on upper extremity movement in participants with Parkinson’s disease as well as control groups of adults without neurological impairment. Georgiou et al. (1993) explored the functioning of the basal ganglia in participants with Parkinson’s disease (PD) and their dependence on external cues. Ten PD participants and 10 typically-functioning adults who were right-handed participated in the study. All PD participants were at stage II or III of the Hoehn and Yahr Scale. The Hoehn and Yahr Scale measures the progression of Parkinson’s disease and symptoms such as rigidity, tremors, and deficits of gait, on a scale of I to V (Hoehn & Yahr, 1967).

According to the scale, Stage I indicates the beginning of the disease with impairment on one side of the body with a slight tremor (Manyam, 1994). Stage II begins with involvement on both sides of the body with tremors, rigidity, deficits of gait, as well as changes in speech patterns. At Stage III, impaired righting reflex occurs with an increased impairment of gait and postural stability. Stage IV indicates significant disability in standing and gait, and patients are unable to perform activities of daily living on their own. Stage V is the most advanced stage of the disease, in which the patient uses a wheelchair and needs full-time care.

A majority of the participants exhibited bilateral impairments. Each participant first completed a series of sequential button-pressing tasks with visual cues but not auditory cues. Participants then used an auditory cue and not a visual cue to complete the task.
The auditory cues included: 1) a low level cue (a tone was heard when the button was released), 2) a medium level cue (a tone was heard as the button was pressed), and 3) a metronome set to the average speed of the participants. Finally, the participants performed the sequence without any external cues.

Participants with PD showed significantly slower movement execution than the typically-functioning adults. Participants with PD revealed a significant decrease in the time needed to complete the task with auditory and visual cues than without. The metronome condition produced a significant decrease in time in comparison to no cue, the low auditory cue, and medium auditory cue. No significant difference was found between low or medium levels of auditory feedback. The presence of an external cue, either visual or metronome, significantly decreased movement time. For the typically-functioning adults, however, the low auditory cue significantly increased movement time compared to the other conditions, both auditory and visual.

Down time, defined as the amount of time needed to begin the next response of the sequence, was also measured. PD participants showed a significantly slower initiation time in the absence of cues. They had significantly less down time with the use of a metronome, in comparison to visual cues. In the typical adults, the metronome significantly improved the initiation of movements and had the least amount of down time compared to the visual and other auditory cues.

This study provides further evidence of the usage of an external auditory cue to improve movement time and the initiation of movement. In addition, the study contained two levels of auditory feedback, when the button was pressed or when it was released. The metronome cue demonstrated the most improvement in movement timing of the
motor task in comparison to the two levels of auditory feedback. The performance of both the PD participants and the control group improved with the use of an auditory cue when a visual cue was no longer present. Both external cues, visual and auditory, were effective in improving the execution and movement time of a sequential movement task.

Platz, Brown, and Marsden (1998) also compared the effect of rhythm on the trained and untrained arm with and without an auditory cue in 16 participants with PD and 15 age-matched, typically functioning adults. The participants were assigned to either the rhythmic or non-rhythmic group and performed a motor task with the less affected arm by moving a pen-like apparatus from one target to another. The rhythm-training group used five tones to provide information as to when to start the movement, reach for the target, and return back to resting position.

The study revealed an improvement with practice, in both the cued and uncued groups. The total movement time decreased, but not significantly for either group. The results showed a greater decrease in the movement time during the uncued condition than the cued condition. The accuracy of the movements did not deteriorate during the study. Overall, the participants with PD performed the task at a slower pace than the control participants. The initial movement phase or beginning of the movement was slower in PD, but was faster at the final movement phase or end of the movements.

These findings indicate that PD patients have significant problems with consistent muscle activation and control when performing a task. The speed of the tones may have been too fast for the participants to entrain to and may have added an extra level of complexity. The researchers conclude that the external cue was not effective at improving speed of the movement, which was contrary to their expectations. The authors state that
the cues may have been distracting for the PD participants and the addition of the cue made it more difficult for the participant. By comparison, the PD participants who performed the motor movement without a rhythmic cue showed a greater decrease in speed in both arms. Therefore, the decrease in bradykinetic symptoms may have been due to the practice of the movement, not the external auditory cue.

Sacrey, Clark, and Whishaw (2009) further explored the use of an auditory cue to guide the movements of a reaching task for 15 adults with PD (mild and advanced), 15 age-matched adults, and 11 young adults. A seated reaching task involved reaching for a piece of food, grasping it, and bringing it to the mouth for eating. The participants were given cues of “ready,” and “go,” indicating when to begin the movement. During the reaching task, movement time, motion analysis, and eye tracking were recorded with and without music. The participants performed the task without music and with client-preferred music. The authors noted that the music did not have a steady beat or rhythmic auditory cueing.

Overall, the client-preferred pieces of music produced no significant decrease in movement time in any of the groups. Control groups and the participants with mild PD did not differ in movement timing. Interestingly, the participants with advanced PD benefited the most from the musical pieces. With music, eye-tracking data showed that the participants looked at the target when moving and quickly looked away after the target was reached. The results were not significant. The movement time was not decreased with an external auditory cue, which included a client-preferred piece of music.
The external auditory cue did not contain a steady beat, which is important in patients with Parkinson’s disease due to the inability to initiate and perform well-timed movements. The verbal cues of “ready” and “go” helped the participants to initiate the sequence, but clients with PD needed a continuous external cue.

Patients with PD can utilize an external cue to begin a movement, as well as to guide the movement. The auditory cue can attract the motor system to entrain immediately (Thaut, 2005). Ma, Trombly, Tickle-Degnen, and Wagenaar (2004) found that a single, auditory cue of a bell immediately improved a movement. The researchers wanted to test the effectiveness of an initial auditory cue and its impact on an entire sequence of movement in 16 participants with PD and 16 typically-functioning adults. The sequenced movement involved reaching for a pen, bringing the pen to paper, and writing down a phrase.

The findings indicated that PD participants who performed the motor task with the initial bell performed the sequence faster and more efficiently. Participants with PD with an external timing cue exhibited a higher peak velocity (i.e., initial movement of a sequence) and a decrease in overall movement time. Participants with PD showed a significantly greater improvement with an external auditory cue than did the control group. The single auditory cue impacted the first two steps, including reaching for the pen and bringing the pen to the paper of the motor sequence.

The results provide evidence for the effectiveness of an external auditory cue, which may compensate for the deficits of the basal ganglia. The study also introduces the idea that an auditory cue for every movement may not be needed to enhance movements, and that rhythmic-auditory facilitation is evident from the beginning of the sequenced
movement. However, the final step of the movement sequence, which was writing the phrase, did not improve in movement time, which indicates that patients with Parkinson’s may still need an external auditory cue to produce well-timed movements.

Freeman, Cody, and Schady (1993) provide further evidence of the effectiveness of an external rhythmic stimulus on movement. Nine patients with Parkinson’s disease (PD) and 12 typically-functioning adults completed a finger-tapping task with a rhythmic stimulus. Each participant was asked to tap with a beat, and without a beat. The tapping task was performed with the right and left hands separately at 1, 2, 3, 4, and 5 Hz. Results indicated that the participants with PD demonstrated similar tapping patterns as the typically functioning adults with the use of the rhythmic signal. Both groups were immediately able to entrain with the external rhythm. However, when the auditory signal was removed, the PD participants showed a clear alteration in average tapping frequency, whereas the control group did not. Without rhythm, the tapping rhythm of the PD participants became irregular and increased in frequency.

At a slower tempo with rhythm, some participants with PD tended to tap at a quicker pace. When the tempo was faster, some participants moved unsteadily and had trouble keeping up with the beat. Patients with PD have a disturbance in the internal oscillator or timekeeper, which may prevent accurate tapping frequency. In conclusion, the above studies reveal the dependence of Parkinson’s patients on an external timing cue to execute well-timed movements because the internal timekeeper of the central nervous system, which involves the basal ganglia, is not functioning properly.
Long-term training of upper extremity movement with rhythm. A rehabilitation technique that involves movement of both arms, known as bilateral arm training with the use of rhythmic auditory cuing (BATRAC), can improve movement of the paretic arm in stroke patients. Whitall, McCombe, Waller, Silver, and Macko (2000) explored the use of BATRAC with 14 participants who received training for 20 minutes, 3 times a week for 6 weeks. The upper extremity movements were either simultaneous or alternating and were performed at the patient’s preferred speed with a metronome stimulus. Data were collected at pre-test, post-test, and at a follow-up assessment of motor function performed 8 weeks after the training period. Functional tests and changes in upper extremity strength, as demonstrated by force and grip strength and active or passive range of motion of the arms, were assessed.

Results revealed a significant improvement in scores of the Fugl-Meyer Test and University of Maryland Arm Questionnaire (UMAQ) over the training period (Berglund & Fugl-Meyer, 1986). The Wolf Motor Test showed improvements, but the differences were not significant (Wolf, Lecraw, Barton, & Jann, 1989). Participants made significant improvements in strength and range of motion of the paretic arm. Four out of 28 active and passive range of motion measures of the paretic arm significantly improved from pre-test to post-test. BATRAC training supports the effectiveness of the motor movement of arms with the addition of rhythm to improve upper extremity movements with repetitive practice. The steady beat provides cues as to when the target is reached and promotes repetitive practice, as well as intrinsic feedback for motor learning.
Luft et al. (2004) also researched the effect of BATRAC on both arms as well as the cortical reorganization present in the brain after 6 weeks of cueing sessions. Twenty-one participants post-stroke were involved in the study. Nine participants received BATRAC with the auditory cue of a metronome, while 12 other participants completed Dose-matched therapeutic exercises (DMTE). DMTE consisted of weight-bearing exercises or opening and closing a fist with the paretic hand. Long-term effects were determined two weeks after the training by functional resonance imaging (fMRI) and electromyography (EMG), as well as a series of functional arm tasks, including the Fugl-Meyer Test.

Results revealed that participants who received BATRAC had a significant increase in activation of the cerebellum and the post and precentral gyri at post-test. Participants that received DMTE showed no significant changes in the activation of brain structures. The difference between BATRAC and DMTE in regard to functional outcomes was not significant. However, six of the nine participants in the BATRAC condition showed a significant increase in functional movement scores in comparison to the DMTE group. Luft et al. (2004) determined that there was a greater recruitment of neurons due to the addition of rhythm during bilateral arm training. Consequently, rhythm improves spatiotemporal arm control for both arms and can enhance motor learning. The rhythm provides information for the total duration of the movement, and not just the endpoint, enhancing the overall movement. In addition, the use of both arms allows for a greater amount of cortical reorganization in the damaged area of the brain by recruiting adjacent, unaffected motor areas.
A steady beat can provide a template to perform a movement, thus improving spatiotemporal patterns as well as velocity and range of motion. In addition to moving to a steady beat, playing of a musical instrument can improve motor skills following a stroke, and might also influence movement patterns in patient’s with PD. Therapeutic Instrumental Music Playing (TIMP) is a Neurologic Music Therapy technique in which clients play an instrument to therapeutically enhance meaningful movements, such as those needed for activities of daily living (Thaut, 2005). The instrument provides immediate auditory feedback to inform the patient that the target has been reached so that the patient can perform the movement again. The auditory feedback from the instrument is also highly motivating for the client, so that client will engage in repetitive practice. An external beat or accompaniment by a music therapist may be provided. The musical elements of meter, accentuation, or tempo provide the organization of the movement in time, space, and force dynamic. The organization provides structures to enhance timing and increase strength and endurance of the muscles used for motor activities.

Yoo (2009) worked with three participants post-stroke who received Therapeutic Instrumental Music Playing (TIMP) to improve the timing and variability of upper extremity movements. Functional tasks included the Barthel Index, Fugl-Meyer Test and Modified Ashworth Test (Bohannon & Smith, 1987; Fugl Meyer, Jaasko, Leyman, Ikssin, & Steglin, 1975; Mahoney & Barthel, 1965). All participants exhibited muscle rigidity, a limited range of motion, and poor muscle tone and muscle control of the paretic arm. In addition, one participant had been recently diagnosed with Parkinson’s disease and exhibited tremors on the left side of his body.
Participants received six, 35-minute sessions of TIMP in which they played an electronic drum kit and completed exercises with other instruments such as tambourines or maracas to improve bilateral movements of the elbow, hand, and shoulder. The participants played a sequential pattern on the drum kit to a duple meter of 2/4 or 4/4 while the music therapist played the autoharp and sang preferred songs to facilitate the movements. Musical elements such as meter, accentuation, tempo, harmony, pitch variations and singing provided musical cues for the patient. The therapist first matched the preferred tempo of the client through her playing and then gradually increased the speed, depending on the participant’s abilities.

Overall, the participants showed decreased movement time and variability of movement timing, and increased in velocity between targets using the paretic arm. The decrease in movement and variability of movement timing was not significant, but all three participants showed decreases in movement timing and variability over the 2-week period. The variability of movement timing showed no significant differences from pre, to mid, or posttest. The Fugl-Meyer Test revealed a significant increase in coordination for movements of the wrist and hand. The Modified Ashworth Test also revealed a significant decrease in muscle rigidity in two of the three participants.

The participant recently diagnosed with Parkinson’s disease had more tremors during faster movements and was encouraged to slow down the movement. However, this participant made the most improvement in the force of the movement and also showed improvements in movement timing, but not as great as the other two participants.
Yoo (2009) notes that these results could support a further examination of TIMP with Parkinson’s disease due to the improvements of movement timing. The study also supports the use of complex, sequenced movements, not just simple movements, to address upper extremity deficits in patients with neurological impairments.

In a similar study, Schneider, Schnole, Altenmuller, and Munte (2007) compared the playing of a musical instrument in combination with conventional therapy in comparison to conventional therapy alone in the rehabilitation of stroke patients. Forty participants post-stroke were placed in either the conventional group or the music training plus conventional therapy. Conventional therapy included physical therapy and occupational therapy. Music training sessions and conventional therapy sessions were 30-minutes in duration, and participants attended 15 sessions of intensive training over 3 weeks.

Participants in the music-training group played either a MIDI-piano or an electronic drum set with the paretic arm, the unaffected arm, or both arms together, using exercises of increasing complexity. Three participants performed the task on the drum set and 12 participants received training on the piano, while five participants received training with both. In a pre-test and post-test, finger tapping and hand tapping were recorded using motion analysis. An assessment of arm function using the Action Research Arm Test, Arm Paresis Score, Box and Block Test, and Nine Hole Pegboard Test was also done at pretest and posttest.

At posttest, results revealed that participants in the music training group showed a significant increase in the frequency, velocity and smoothness of finger and hand-tapping compared to pre-test. In addition, improvements in the functional tests were all
significant for participants in the music-training group. Participants who received the
music training plus conventional therapy showed a significantly greater improvement in
upper extremity tasks than did those who received only conventional therapy. Overall, the
participants received a greater benefit from the music training in combination with
conventional therapy than conventional therapy alone.

The findings of Schneider et al. (2007) reveal that intensive training of playing a
musical instrument in combination with conventional therapy allows for the
reorganization of neuronal networks and intensifies the integration of auditory and motor
systems. Playing a musical instrument provides auditory feedback, which gives the
participants cues for the movements and acts as a template in the execution of a sequence
of movements. Just as a rhythm provides a template, the auditory information helps with
the trajectory of movements and gives specific information for a well-timed, functional
movement. In addition, the auditory information enhances proprioceptive feedback for
limb position in participants post-stroke.

Fjare (2000) further investigated the use of TIMP in the rehabilitation of the
paretic arm in two patients post-stroke. Participants included two older adults with a right
hemispheric stroke. The author looked at the changes in finger movement velocity,
duration of notes played, and the onset time of key depressions (delta time) in each
participant. Participants performed seven movement sequences, using hands separately
and simultaneously, on an electronic keyboard. The movement sequences were
performed with and without an external rhythmic stimulus of a metronome, as well as
with the accompaniment of a therapist on the keyboard.
The participants received three, 40-minute sessions per week for 3.5 weeks. A pretest and posttest were also taken using the Fugl-Meyer Test, the Jebsen Hand Test, Barthel Index, and the Modified Ashworth Scale to show a difference in functional tests over the treatment period.

Participant 1 showed a significant decrease of mean delta time of 1.12 seconds, indicating less time between the playing of each finger. This change resulted in increased velocity due to the decreased variability in the force of the paretic hand. The data showed a more controlled movement in both hands. The difference in the functional measures from pretest to posttest for Participant 1 was very small for the Fugl-Meyer Test. The Jebsen Hand Function Test showed decreased timing in a majority of the movement sequences. Participant 1 had a slight increase in muscle tone as indicated by the Modified Ashworth Scale. Participant 2 showed a significant decrease of 5.57 seconds for mean delta time, which increased velocity of the movement pattern. Some of the patterns exhibited a nonsignificant decrease in variability, whereas some patterns showed a nonsignificant increase in variability of mean movement duration. Participant 2 exhibited a 13.7% improvement in function, as shown by the Fugl-Meyer Test, but no changes were found in the Barthel Index and Modified Ashworth Scale.

In conclusion, the study by Fjare (2000) provides further evidence that TIMP that includes keyboard playing is an effective rehabilitation method for stroke patients. The performance of the exercises improved over the duration of the study due to the decreased delta time and decreased variability of finger movement, which led to a more controlled movement of the fingers. The repetitive practice and use of rhythm improved the timing and magnitude of each individual movement.
The previous studies looked at TIMP with patients post-stroke. Although not a neurological disorder, Zelazny (2001) also studied the effect of TIMP on hand rehabilitation in older adults diagnosed with osteoarthritis. Playing the piano as a rehabilitative tool provided motivation, enhanced movements, and worked on pain management for each participant. At pretest, measurements for finger pinch strength for all fingers of both hands and range of motion for each participant were taken. Participants received 30-minute sessions, 4 days a week for a total of 4 weeks. The intervention involved playing folk songs on the piano for twenty minutes. In addition, measurements were taken for finger pinch strength and range of motion at the end of each session.

Results demonstrated variability among the four participants. Participants 1 and 4 increased in strength, as shown by the pinch meter. Participant 2 remained the same and Participant 3 decreased in most of the pinch strength measurements. All participants had full range of motion in the pre-test and posttest. Finger velocity data revealed a significant increase in 3 of the 4 the participants from pretest to posttest due to keyboard playing.

In conclusion, Zelazny (2001) showed that TIMP can be effective for older adults with osteoarthritis. Three of the four participants improved in finger strength and dexterity, which can be helpful for addressing cartilage deterioration. Keyboard playing is an effective intervention for clients with osteoarthritis due to the repetitive use of the fingers to maintain function and reduce pain. Although osteoarthritis is not a neurological disorder, movement of the fingers and hand are affected due to the deterioration of cartilage. TIMP helped improved finger function by improving speed of finger and hand movements. The auditory feedback from the keyboard gave the participants a cue for
velocity. Zelazny (2001) further supports the use of TIMP to improve speed of movements and to maintain functioning to prevent further damage in participants with a progressive disease. Considering that Parkinson’s is also a progressive disease, TIMP can be applied to patients with Parkinson’s disease to address upper extremity deficits.

Evidence has shown that participants diagnosed with Parkinson’s disease can entrain to a steady beat despite impairments of the basal ganglia (Cody, Freeman, & Schady, 1993; Miller, Thaut, McIntosh, & Rice, 1995). The external cue of a steady beat provides important information for the patient and can improve upper extremity movements of the arms and hands. Simple movements of the fingers as well as complex, sequenced movements, such as playing drums or other musical instruments, are greatly improved with the use of an external cue. As stated earlier, little research has been conducted on TIMP with patients diagnosed with Parkinson’s disease. The research that has been conducted has focused on the ability of the participants to entrain to a steady beat with the use of an external cue of a metronome, or an auditory cue, such as a bell or clicking sound.

Bradykinesia, one of the main upper extremity deficits resulting from basal ganglia damage, can prevent a patient with Parkinson’s disease (PD) from performing a movement at an adequate speed. Two similar studies have been conducted to look at the repetitive practice of a motor task to improve arm movements in PD patients with the use of an auditory cue. del Olmo, Arias, Furio, Pozp, and Cudeiro (2006) found that the use of auditory cues from a metronome improved finger-tapping in participants with PD. Nine participants with PD received gait and upper limb training for 1 hour, five days a week for seven weeks. Five age-matched adults also participated, but did not receive the
training. The PD participants performed finger-tapping and repetitive, sequential arm movements with one or both arms, with or without an auditory cue. At pretest, positron emission tomography scans (PET) showed a significantly lower level of glucose in the PD participants compared to the control group. After the training, the PD participants underwent an additional PET scan to reassess the levels of glucose.

With rhythm, PD participants demonstrated a significant decrease in the variability of the interval time between finger-taps from pre to posttest. The PET scan performed after the therapy, showed a significant increase in the levels of glucose to areas of the cerebellum and cortical areas of the temporo-parietal conjunction in PD participants. The increased glucose indicates an alternate pathway to compensate for the damage of the basal ganglia and their connections to the supplementary motor area.

**Summary of Literature Review.** The basal ganglia, along with projections to cortical structures, are responsible for the control of well-timed, coordinated movements. The transmission of dopamine in the nigrostriatal pathway, creates a “brake”, which can prevent movement. When the “brake” is released, activation occurs, which produces smooth, coordinated movements of the upper extremities. Brain imaging studies have shown that the basal ganglia structures, along with cortical structures, are active during a simple finger-tapping task as well as during the perception of time.

Damage to the basal ganglia in Parkinson’s disease (PD) can disrupt basal ganglia functions and their projections to cortical structures. The loss of dopamine-producing neurons in the basal ganglia affects the initiation and performance of upper extremity movement. Bradykinesia causes movement to be slow and labored and akinesia produces “freezing”, both at the initiation of and during movement. The overall execution and
timing of repetitive upper extremity movements are affected. Other upper extremity
deficits, such as tremors and muscular rigidity, also occur due to the deficiency of
dopamine. These deficits cause PD patients to have problems with range of motion,
strength, and timing of the upper extremities when performing activities of daily living.

Despite deficits in time perception and movement performance in patients with
PD a rhythmic auditory stimulus can regulate the internal timing mechanism. Studies
have revealed that despite damage to the basal ganglia, PD patients are still able to
entrain movement with an external auditory cue. The rhythm not only enhances the
timing of the movement, but also acts as a “priming” agent by bypassing the damaged
connections of the basal ganglia to cortical structures (i.e., supplementary motor area)
(Thaut, McIntosh, McIntosh, Hoemberg, 2001). An external auditory cue can influence
the basal ganglia, and thus facilitate accurate and well-timed movements.

The studies discussed in this chapter have illustrated how an external rhythmic
cue affects movement. Rhythm has immediate effects on the timing of upper extremity
movements in both typically-functioning adults and clinical populations. In a clinical
population, such as patients post-stroke, long-term improvement has been examined
through repetitive practice and training. Rhythm has an attractor motor function and
provides a cognitive template, thus helping the patient to perform movements with better
timing. Sequential movements of the upper extremities increase in velocity and are more
consistent in frequency. Overall, the use of an external auditory cue decreases the
variability of muscle activity and produces a more consistent and efficient motor pattern
in patients with neurological disorders, such as stroke and Parkinson’s disease.
The majority of the research supporting Therapeutic Instrumental Music Playing (TIMP) as well as repetitive training with an external auditory stimulus, has been conducted with stroke patients. Similar rehabilitation outcomes, such as improvements in velocity and decreased variability of movement, are desired for both stroke and PD. Studies with PD patients have focused on using an external rhythmic cue to improve timing of the upper extremities. The studies involved a motor task of reaching for an object or moving between two targets to increase velocity or decrease the variability of movements. These studies have shown conflicting results. One possible explanation could be that in some instances the speed of the external cue was not set to the participant’s preferred tempo.

In addition, most of the studies with PD have not looked at the effect of auditory feedback on movement timing in patients with PD. However, Georgiu et al. (1993) compared auditory feedback and an external cue of a metronome during a button-pressing task to improve movement timing. The auditory feedback and external cue of a metronome were presented separately. The results revealed a greater decrease in movement timing with the use of a metronome than with presentation of auditory feedback.

A gap exists in the research literature for PD. Researchers have not yet determined which is most effective in improving movement timing, an external rhythmic cue or an external rhythmic cue in combination with auditory feedback. The findings of this study will provide scientific evidence either supporting or refuting the use of an external rhythm in combination with auditory feedback to improve movement timing in patients with PD.
Research Questions. This study is designed to address the following research questions in regard to upper extremity movement of patients with Parkinson’s disease:

1. What is the main effect of the rhythmic cueing condition on total movement time?

2. What is the main effect of the rhythmic cueing condition on initiation time?

3. What is the main effect of rhythmic cueing condition on delta time?

4. What is the main effect of level of impairment on total movement time?

5. What is the main effect of level of impairment on initiation time?

6. What is the main effect of level of impairment on delta time?

7. What are the interaction effects between level of impairment and rhythmic cueing condition on total movement time, initiation time, and delta time?
Chapter Three

Method

Participants. Fifteen patients diagnosed with Parkinson’s Disease (PD) participated in the study. An informed consent form was filled out by each participant (see Appendix A). Participants were either right-handed or left-handed and were in different stages of PD, including Stages I, II, III, or IV of the Hoehn and Yahr Scale (Hoehn & Yahr, 1967). According to this scale, Stage I includes unilateral symptoms with minimal or no functional impairment. At Stage II, patients exhibit bilateral or midline impairment, with no apparent deficits in balance. Stage III is noted by impairments in righting reflexes as well as an unsteadiness in standing and walking. Within Stage III, patients are still partially independent but may have some problems performing activities.

At Stage IV, the client shows significant impairments in walking and needs assistance with activities of daily living. Stage V is the most severe stage, meaning the patient is either confined to a bed or needs a wheelchair. Patients at Stage V were included in the study because motor symptoms are quite severe, and the patient would have difficulty performing the required motor task.

The participants did not exhibit any cognitive impairments, such as deficits in attention and memory or signs of dementia. The participants were able to follow verbal instructions. In regards to upper extremity functioning, participants were able to perform a simple reaching task with their dominant hand, comparable to reaching for a cup and moving it across a table.
Participants were English speaking and were able to understand verbal cues as well as read in English. Additionally, patients were required to be stabilized on medication for Parkinson’s disease symptoms.

**Materials.** Each participant completed three questionnaires, which took a total of 30-minutes to administer. First, the participant filled out a researcher-generated questionnaire related to demographic information, such as age, sex, and duration of disease. This self-report also obtained information on the frequency of upper extremity problems on a scale of 0 to 3 (see Appendix B). The self-report contained five questions that addressed the frequency of tremors, akinesia, bradykinesia, and dyskinesia. A score of zero indicated that the symptoms had never occurred, and a score of three indicated that the symptoms occurred daily (Freeman, Cody, & Schady, 1993).

The second questionnaire, the Self-Reported Disability Scale (see Appendix C) measured impairments in performing activities of daily living (Biemans, Dekker, & van der Woude, 2001; Brown, MacCarthy, Jahanshahi, & Marsden, 1989). The questionnaire contains 25 questions and uses a scale of 1 to 5 to rate the ability of the participant to perform activities of daily living and instrumental activities of daily living. Examples include the ability to walk around the house or the ability to wash the face and hands. A score of “1” indicates that the patient is able to do the activity alone without difficulty and a score of “5” indicates that the patient is unable to do it at all. The lowest possible score on the Self-Report Disability Scale is a 25 and the highest score is a 125.
Eleven items of the test assess mobility and 14 items assess hand use. The self-report is less commonly used than other self-reports for PD, but internal reliability is high, which means that a consistency has been shown within test items (Biemans et. al, as cited by Sarwar, Trail, & Lai, p. 63, 2008).

Finally, the Schwab and England Activities of Daily Living Scale (see Appendix D) was administered to rate the patient’s ability to perform activities of daily living (Schwab & England, 1967). Participants read ten items and selected one that applied to their level of independence. The scale categorizes the patient’s disability on a scale of 10% to 100%. Ten percent indicates a total dependence on others and 100% indicates complete independence and the ability to do chores around the home without slowness. The scale has revealed a consistent reliability and substantial validity (Gancher, 2002; Ramaker, Marinus, Stiggebout & Van Hilten, as cited in Sarwar, Trail & Lai, p. 63, 2008).

**Equipment.** A Laser Light Plane Multitouch Table Computer Interface, also referred to as an interactive touch table, was used to measure movement timing and provided auditory feedback of upper extremity movement. The table was made by Mark Freeman, Pat O’Keefe, Stephen Molfetta, and Dr. Colby Leider at the University of Miami Music Engineering Department. The dimensions of the table were 48 inches in length, 28 inches in width, and 35 inches in height. The table contained four infrared lasers placed in each corner and pointed toward the center to create a plane of infrared light.
When a participant touched the table, the plane was broken and the light reflected off the participant’s finger downward. A camera below the table caught the reflected light and sent information to a computer, which used a thread timer to measure movement timing in increments of milliseconds.

A software program, Supercollider, measured total upper extremity movement time and delta time, which is the mean time taken to move from target to target. In addition, initiation time was also calculated by measuring the time taken to make contact with the table after a beginning cue. Supercollider was also programmed to produce synthesized music and sounds. Contact with the table produced a synthesized tone. A visual target on the interactive touch table was made using Quartz Composer, an Apple © based graphics development environment, that communicates with Supercollider. The visual display consisted of three targets in a triangular formation (see Figure 3.1).

**Procedure.** A flyer was distributed to healthcare facilities and PD support groups to recruit participants. The flyer described the study and invited adults with PD to participate (see Appendix E). Participants scheduled an individual appointment with the researcher during the on-phase of medication and at a specific time of the day to ensure optimal functioning level. Participants and the researcher met at the Marta and Austin Weeks Music Technology Center in Room 135 at the University of Miami’s Frost School of Music. The room was easily accessible for participants in a wheelchair or using a walker.
Figure 3.1 A representation of the visual on the interactive touch table, containing three targets.
Each participant signed an informed consent form (see Appendix A) and completed the researcher-generated questionnaire to rate specific motor impairments, the Self-Report Disability Scale, and the Schwab and England Activities of Daily Living Scale (Brown et al., 1998; Schwab & England, 1967). Scores on the three questionnaires were used to determine the level of impairment for each participant: mild/moderate, or severe.

Participants were instructed to perform an upper extremity movement sequence using the dominant hand by moving between three visual targets on the interactive touch table. Participants were seated during the task and wore protective goggles as an added precaution because of lasers on the interactive touch table. Direct visual contact with the lasers could have caused irreversible damage to the retina of the eye. The researcher first modeled the movement and the participant had five trials to practice the movement. Participants who were right-handed performed the movement sequence of L-C-R-L, and participants who were left-handed performed the sequence R-C-L-R. The distance between targets R-L was 27.5 inches and the distance between the C- R and C-L targets was 17.5 inches (see Figure 3.1).

After the participant completed five practice trials of the movement sequence, the participant then performed the movement sequence in four counterbalanced conditions. Participants completed 10 repetitions of the sequence in each condition. Between each condition, a five-minute rest period was given to minimize order effect. Using the Supercollider program, the participant began Condition 1 with a verbal cue of “Ready, Go.” In Conditions 2 and 3, participants began each movement sequence after a recorded verbal cue of “1, 2, 3, Go.” Condition 4 contained the same verbal cues as Condition 1,
which were “Ready, Go.” Condition 1 and Condition 4 provided simple verbal cues because the counting of “1, 2, 3” may have influenced the tempo of the participant’s movements. The verbal cues for Condition 2 and Condition 3 were set to the participant’s starting tempo.

Condition 1 was performed at the participant’s preferred tempo without any rhythmic cuing or auditory feedback. In Condition 2, a metronome was used to match the participant’s preferred tempo. The participant then performed the movement sequence to the beat of the metronome (i.e., external rhythmic cue). In Condition 3, the participant performed the movement sequence to a metronome set to their preferred tempo. In addition to the metronome, when each target was contacted on the interactive touch table, the same synthesized tone was produced. Finally, Condition 4 was the same as Condition 1, in which the movement sequence was performed at the participant’s preferred tempo without any rhythmic cuing or auditory feedback. Data were collected individually for each participant.

**Design and Analysis.** The study utilized a repeated-measures design with counterbalanced conditions. Each participant was exposed to all conditions, but in a different order. Due to the repetitive practice, and to discount for performance practice, as well as order effects, a counterbalanced design was utilized to increase internal validity (Fraenkel & Wallen, 2009). All participants performed Condition 1 first, but the order for the following two conditions was randomly assigned. The possible order of conditions was Conditions 1, 2, 3, 4 or Conditions 1, 3, 2, 4.
Two independent variables were examined. The first variable was movement condition. Four levels of this variable existed: 1) the sequence performed at the participant’s preferred tempo, 2) the sequence performed to a metronome set to the preferred tempo (external rhythmic cue), 3) the sequence performed with a metronome and auditory feedback from the interactive touch table, and 4) the sequence performed again at the participant’s preferred tempo. The second independent variable was the degree or level of movement impairment from PD: mild/moderate, or severe. The three dependent variables in the study were: the overall mean timing of the entire sequence (i.e., total movement time), the mean timing of movement between targets (i.e., delta time), and the mean timing to initiate the movement sequence (i.e., initiation time).

Data collected were analyzed using a one-way repeated measures analysis of variance (ANOVA). The ANOVA determined whether a significant difference existed in movement timing between the four conditions, as well as a difference in movement timing across the levels of impairment (Fraenkel & Wallen, 2009). The test was appropriate because ratio data were collected and because two or more conditions were examined with the same participants in each condition (Gravetter & Wallnau, 2008). A post-hoc analysis of pair-wise comparisons was conducted after the ANOVA, as needed.
Chapter Four

Results

This chapter will describe the results obtained from data collection, as well as the statistical analysis conducted on the data. Both descriptive and inferential results from the statistical analysis will be provided according to the five research questions. The analyses were completed using the software Statistical Package for Social Sciences (SPSS) v. 16.0.

To briefly review, each participant performed a movement sequence, similar to a simple reaching task, four times. For Condition 1, participants performed the movement sequence at their preferred tempo with no cue. For Condition 2, participants performed the movement sequence to a metronome that was set to their preferred tempo (i.e., external rhythmic cue). In Condition 3, participants performed the movement sequence to a metronome that was set to their preferred tempo, and also received auditory feedback that was produced when the table was contacted. Finally, in Condition 4 participants again performed the movement sequence at their preferred tempo with no cue.

During each condition, data were collected for total movement time, initiation time, and delta time. Total movement time was the average time the participant took to perform the movement sequence 10 times. Initiation time was the amount of time the participant took to begin the movement sequence after hearing a start cue. Delta time was the time the participant took to move between the individual targets. Movement time was measured in seconds.
Each participant was placed in either a mild/moderate or severe group, based on one of the questionnaires provided for each participant. Participants who answered 1, 2, or 3 for questions on the Self-Reported Disability Scale in Patients with Parkinson’s were placed in the mild/moderate level of impairment group. These participants could perform activities of daily living: (1) without difficulty, (2) with a little effort, or (3) with a lot of effort or a little help. Participants who answered 4 or 5 for all of the questions provided on the Self-Reported Disability Scale in Patients with Parkinson’s were placed in the severe level of impairment group. Participants in this group completed activities of daily living: (4) with a lot of help or, (5) not able to do the task.

Eleven participants were placed in the mild/moderate group and 4 participants were placed in the severe level of impairment group. The data from one of the participants in the severe group were not utilized for analysis due to a malfunction of the computer software on the day of data collection. Additionally, two outliers were removed from analysis due to a change in delta time. Outliers were defined as participants who showed a 50% or greater difference in timing from no cue to one of the cueing conditions for any of the three variables. One participant increased in delta time by 63.5% from Condition 1 to Condition 2. For this same participant, delta time decreased by 81% from Condition 3 to Condition 4. The other participant taken out of the analysis increased in delta time by 50% from Condition 1 to Condition 2.

The final sample included 10 participants in the mild/moderate level of impairment group and two participants in the severe level of impairment group. The age of the final 12 participants ranged from 62 to 74 with a mean age of 69.3 years.
Of the 12 participants included in the final analysis for study, seven were male and five were female. See demographic information in Table 1.

**Research Question # 1: What is the main effect of the rhythmic cueing condition on total movement time in upper extremity movement in patients with PD?**

**Descriptive analysis.** Table 2 provides descriptive statistics for total movement time for all four conditions. Mean total movement time for Condition 2 (external rhythmic cue) was 24.46 seconds ($SD= 8.40$), which showed a .46 second increase from Condition 1 ($M= 24.00, SD= 8.24$) in which no cue was provided. Mean total movement time decreased from Condition 2 (external rhythmic cue) to Condition 4 (no cue; $M= 21.57, SD= 6.74$) by 2.83 seconds. A decrease of .34 seconds in mean total movement time was also noted between Condition 2 (external rhythmic cue) and Condition 3 ($M= 24.12, SD= 8.06$), in which both an external rhythmic cue and auditory feedback were provided.

Mean total movement time for Condition 3 (external rhythmic cue with auditory feedback) was 24.13 seconds ($SD= 8.06$), which showed a .13 second increase from Condition 1 ($M= 24.00, SD= 8.24$) in which no cue was provided. Mean total movement time also decreased from Condition 3 (external rhythmic cue with auditory feedback) to Condition 4 (no cue; $M= 21.57, SD= 6.74$) by 2.44 seconds. Inferential data for Research Questions # 1, 2, and 3 will follow the additional descriptive analysis.
### Table 1

**Demographics of Participants**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Sex</th>
<th>Dominant Hand</th>
<th>Side more affected</th>
<th>Main UE Deficits</th>
<th>Level of Disability</th>
<th>Order of Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>62</td>
<td>M</td>
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<tr>
<td>B</td>
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<td>M</td>
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<td>right</td>
<td>Rigidity</td>
<td>mild/moderate</td>
<td>1,2,3,1</td>
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<tr>
<td>C</td>
<td>68</td>
<td>M</td>
<td>right</td>
<td>both</td>
<td>Tremor, Akinesia</td>
<td>mild/moderate</td>
<td>1,2,3,1</td>
</tr>
<tr>
<td>D</td>
<td>73</td>
<td>F</td>
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<td>left</td>
<td>Tremor, Bradykinesia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
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<tr>
<td>F</td>
<td>74</td>
<td>M</td>
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<td>right</td>
<td>Tremor, Bradykinesia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
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<td>right</td>
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<td></td>
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<tr>
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<td>Bradykinesia</td>
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<tr>
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<td>Tremor, Bradykinesia</td>
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<td>M</td>
<td>right</td>
<td>left</td>
<td>Tremor</td>
<td>mild/moderate</td>
<td>1,2,3,1</td>
</tr>
</tbody>
</table>

N/A = Information not available
Research Question # 2: What is the main effect of the rhythmic cueing condition on initiation time for upper extremity movement in patients with PD?

Descriptive analysis. Table 2 provides descriptive statistics for initiation time across all four conditions. Mean initiation time for Condition 2 (external rhythmic cue) was .59 seconds ($SD= .52$), which showed a .90 second decrease in initiation time from Condition 1 ($M= 1.49, SD= 3.39$) in which no cue was provided. Initiation time increased by .04 seconds from Condition 2 (external rhythmic cue) to Condition 4 (no cue; $M= .63, SD= .53$). A .13 second increase in initiation time was also evident between Condition 2 (external rhythmic cue) and Condition 3 ($M= .72, SD= .44$), in which an external rhythmic cue in combination with auditory feedback was provided.

Mean initiation time for Condition 3 (external rhythmic cue with auditory feedback) was .72 seconds ($SD= .44$), which showed a .77 second decrease from Condition 1 ($M= 1.49, SD= 3.39$) in which no cue was provided. Initiation time also decreased from Condition 3 (external rhythmic cue with auditory feedback) to Condition 4 (no cue; $M= .63, SD= .53$) by .09 seconds.

Research Questions # 3: What is the main effect of rhythmic cueing condition on delta time for upper extremity movement in patients with PD?

Descriptive analysis. Table 2 contains descriptive statistics for delta time across all four conditions. Mean delta time for Condition 2 (external rhythmic cue) was 1.92 seconds ($SD= .56$), which represented a .01 second decrease from Condition 1 (no cue; $M= 1.93, SD= .52$). Mean delta time also decreased from Condition 2 (external rhythmic cue) to Condition 4 (no cue; $M= 1.79, SD= .43$) by .13 seconds.
Table 2

Means and Standard Deviations of Total Movement Time, Initiation Time, and Delta Time for All Participants in Each Condition

<table>
<thead>
<tr>
<th></th>
<th>Condition 1 No Cue</th>
<th>Condition 2 External Rhythmic Cue</th>
<th>Condition 3 External Rhythmic Cue and Auditory Feedback</th>
<th>Condition 4 No Cue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Total Movement Time</td>
<td>24.00</td>
<td>8.24</td>
<td>24.46</td>
<td>8.40</td>
</tr>
<tr>
<td>Initiation Time</td>
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<td>3.39</td>
<td>.59</td>
<td>.52</td>
</tr>
<tr>
<td>Delta Time</td>
<td>1.93</td>
<td>.52</td>
<td>1.92</td>
<td>.56</td>
</tr>
</tbody>
</table>
A decrease of .02 seconds was also evident between Condition 2 (external rhythmic cue) and Condition 3 ($M=1.90$, $SD=.54$) in which both an external rhythmic cue and auditory feedback were provided. Mean delta time for Condition 3 (external rhythmic cue with auditory feedback) was 1.90 seconds ($SD=.54$), which represented a .03 second decrease from Condition 1 (no cue; $M=1.93$, $SD=.52$). Mean delta time also decreased from Condition 3 (external rhythmic cue with auditory feedback) to Condition 4 (no cue; $M=1.79$, $SD=.43$) by .11 seconds.

**Additional descriptive analysis.** An additional analysis was conducted to look at each individual participant and identify specific trends that might be evident in the descriptive data. Table 3 presents each participant’s average scores for total movement time, initiation time, and delta time across all conditions. For total movement time, 11 of the 12 participants showed a decrease from Condition 1 to Condition 4. From Condition 1 to Condition 2, 6 out of 12 participants decreased total movement time with an external rhythmic cue. The remaining participants increased total movement time with an external rhythmic cue. From Condition 1 to Condition 3 (i.e., an external rhythmic cue with auditory feedback), six participants decreased in total movement time and six participants increased in total movement time.

Four of the 12 participants decreased in initiation time from Condition 1 to Condition 4. In Condition 2 (i.e., addition of an external rhythmic cue), 5 of the 12 participants decreased initiation time from Condition 1, and two stayed the same. From Condition 1 to Condition 3 (i.e., external rhythmic cue in combination with auditory feedback), three participants decreased in initiation time and two participants had the same initiation time, and seven participants increased in initiation time.
Table 3

*All Participants When Exposed to All Conditions and the Results for Total Movement Time, Initiation Time, and Delta Time*

<table>
<thead>
<tr>
<th>Participant</th>
<th>Condition 1</th>
<th>Condition 2</th>
<th>Condition 3</th>
<th>Condition 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Cue</td>
<td>External Rhythmic Cue</td>
<td>External Rhythmic Cue and Auditory Feedback</td>
<td>No Cue</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Movement Time</td>
<td>13.80</td>
<td>20.69</td>
<td>12.16</td>
<td>12.02</td>
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<tr>
<td>Initiation Time</td>
<td>.001</td>
<td>.001</td>
<td>.33</td>
<td>1.02</td>
</tr>
<tr>
<td>Delta Time</td>
<td>1.38</td>
<td>1.42</td>
<td>1.18</td>
<td>1.10</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Movement Time</td>
<td>29.17</td>
<td>18.69</td>
<td>25.60</td>
<td>19.89</td>
</tr>
<tr>
<td>Initiation Time</td>
<td>1.21</td>
<td>1.07</td>
<td>1.21</td>
<td>.20</td>
</tr>
<tr>
<td>Delta Time</td>
<td>1.67</td>
<td>1.58</td>
<td>1.63</td>
<td>1.58</td>
</tr>
<tr>
<td>C</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Movements Time</td>
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<td>17.90</td>
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<td>.99</td>
<td>.90</td>
<td>.78</td>
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<tr>
<td>Delta Time</td>
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<td>1.55</td>
<td>1.53</td>
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<td>D</td>
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<td>.001</td>
<td>.001</td>
<td>.003</td>
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<tr>
<td>Delta Time</td>
<td>1.84</td>
<td>1.79</td>
<td>2.08</td>
<td>1.92</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Movement Time</td>
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<td>42.06</td>
<td>42.17</td>
<td>32.47</td>
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<tr>
<td>Initiation Time</td>
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<td>.78</td>
<td>.26</td>
<td>.001</td>
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<tr>
<td>Delta Time</td>
<td>3.05</td>
<td>3.03</td>
<td>3.25</td>
<td>2.53</td>
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<td>F</td>
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<td></td>
</tr>
<tr>
<td>Total Movement Time</td>
<td>31.96</td>
<td>32.06</td>
<td>31.10</td>
<td>30.46</td>
</tr>
<tr>
<td>Initiation Time</td>
<td>.22</td>
<td>.09</td>
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<td>.001</td>
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<tr>
<td>Delta Time</td>
<td>2.56</td>
<td>2.53</td>
<td>2.41</td>
<td>2.45</td>
</tr>
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</table>
Table 3. (continued)

<table>
<thead>
<tr>
<th>Participant</th>
<th>Condition 1</th>
<th>Condition 2</th>
<th>Condition 3</th>
<th>Condition 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Cue</td>
<td>External Rhythmic Cue</td>
<td>External Rhythmic Cue and Auditory Feedback</td>
<td>No Cue</td>
</tr>
<tr>
<td>G</td>
<td>21.38</td>
<td>18.02</td>
<td>20.19</td>
<td>19.05</td>
</tr>
<tr>
<td></td>
<td>.001</td>
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<td>.57</td>
<td>.99</td>
</tr>
<tr>
<td></td>
<td>1.95</td>
<td>1.62</td>
<td>1.73</td>
<td>1.65</td>
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<tr>
<td>H</td>
<td>21.32</td>
<td>21.14</td>
<td>30.47</td>
<td>19.97</td>
</tr>
<tr>
<td></td>
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<td>.45</td>
<td>.75</td>
<td>.82</td>
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<td></td>
<td>1.73</td>
<td>1.86</td>
<td>1.87</td>
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<tr>
<td>I</td>
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<td>16.28</td>
<td>16.94</td>
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<td>.78</td>
<td>.33</td>
</tr>
<tr>
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<td>1.50</td>
<td>1.43</td>
<td>1.48</td>
<td>1.45</td>
</tr>
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<td>J</td>
<td>18.23</td>
<td>27.56</td>
<td>20.51</td>
<td>17.16</td>
</tr>
<tr>
<td></td>
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<td>1.49</td>
<td>1.52</td>
<td>1.01</td>
</tr>
<tr>
<td></td>
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<tr>
<td>K</td>
<td>34.53</td>
<td>37.25</td>
<td>28.23</td>
<td>32.58</td>
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<td></td>
<td>.45</td>
<td>.001</td>
<td>1.07</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td>2.60</td>
<td>2.88</td>
<td>2.21</td>
<td>2.30</td>
</tr>
<tr>
<td>L</td>
<td>21.20</td>
<td>20.94</td>
<td>19.72</td>
<td>19.89</td>
</tr>
<tr>
<td></td>
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<td>.74</td>
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<td></td>
<td>1.77</td>
<td>1.74</td>
<td>1.71</td>
<td>1.69</td>
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</table>
For delta time, 9 of the 12 participants decreased from Condition 1 to Condition 4. Compared with Condition 1, 7 of the 12 participants decreased delta time with the addition of an external rhythmic cue (i.e., Condition 2). From Condition 1 to Condition 3 (i.e., an external rhythmic cue in combination with auditory feedback), eight participants decreased in delta time, and four participants increased in delta time.

**Inferential Analysis for Research Questions 1, 2, and 3.** A one-way repeated measures analysis of variance (ANOVA) was utilized to investigate the effect of an external rhythmic cue and an external rhythmic cue in combination with auditory feedback on the dependent variables. Unfortunately, an analysis to address the order effects of the various conditions could not be conducted due to the uneven distribution.

For total movement time, normality was assumed, which means a normal distribution of means was evident. Mauchly’s test indicated that the assumption of sphericity was met $x^2(5) = 4.2, p > .05$, which means that the variances of differences were not significantly different from one another (Field, 2009; Hill & Lewicki, 2005). The analysis did not reveal a main effect of condition on total movement time, $F(3, 33) = 2.16, p = .11$. Please see Table 4.

**Table 4**

*Summary of ANOVA Results for Effect of Condition on Total Movement Time*

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
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<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factor</td>
<td>63.57</td>
<td>3</td>
<td>21.19</td>
<td>2.16</td>
<td>.11</td>
</tr>
<tr>
<td>Error</td>
<td>324.26</td>
<td>33</td>
<td>12.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2800.87</td>
<td>47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For average initiation time, normality was assumed, which means a normal
distribution of means was evident. Mauchly’s test indicated that the assumption of
sphericity had been violated, $x^2(5) = 64.06$, $p < .05$, and Greenhouse-Geisser estimates
were used to account for the lack of sphericity ($\varepsilon = .36$) (Field, 2009; Hill & Lewicki,
2005). The analysis did not reveal a main effect of condition on initiation time, $F(1.07$,
$11.73) = .77$, $p = .41$. Please see Table 5.

Table 5

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
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<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factor</td>
<td>6.59</td>
<td>1.07</td>
<td>6.18</td>
<td>.77</td>
<td>.41</td>
</tr>
<tr>
<td>Error</td>
<td>94.47</td>
<td>11.73</td>
<td>8.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>140.96</td>
<td>23.80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For average delta time, normality was assumed, which means a normal
distribution of means was evident. Mauchly’s test indicated that the assumption of
sphericity was met $x^2(5) = 4.94$, $p > .05$, which means that the variances of differences
were not significantly different from one another (Field, 2009; Hill & Lewicki, 2005).
The analysis indicated that a main effect was not found for cueing condition on average
delta time, $F(3, 33) = 2.50$, $p = .08$. Please see Table 6.
Table 6

Summary of ANOVA Results for Effect of Condition on Delta Time

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
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<td>11</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Factor</td>
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<td>3</td>
<td>.05</td>
<td>2.50</td>
<td>.08</td>
</tr>
<tr>
<td>Error</td>
<td>.66</td>
<td>33</td>
<td>.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11.85</td>
<td>47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on the additional analysis of the individual participants, a post-hoc test was conducted. Although the ANOVA did not show a significant effect of condition, individual participants did show changes in movement timing. For total movement time, 11 of the 12 participants decreased from Condition 1 to Condition 4. Four of the 12 participants decreased in initiation time from Condition 1 to Condition 4 and for delta time, 9 of the 12 participants decreased from Condition 1 to Condition 4. Therefore, a paired samples t-test was conducted for total movement time, initiation time, and delta time. These pair-wise comparisons examined differences between each of the four conditions. An important point to note is that each time the separate test was performed, the chance of a Type 1 error increased. A Type 1 error occurs when the researcher concludes that a significant difference was found, when in actuality a difference was not evident (Gravetter & Wallnau, 2008). Significance was set at a .05 level.

Although the ANOVA did not reach significance for the dependent variables, the pair-wise comparisons did show differences for total movement time and delta time. The paired samples t-test revealed a significant difference for total movement time between Condition 1 and Condition 4, $t(11) = 2.69, p = .02$, and from Condition 2 to Condition 4, $t(11) = 2.304, p = .04$. 
Condition 3 to Condition 4 approached significance, $t(11)= 2.09, \quad p = .06$. A significant difference was not found when comparing Condition 1 to Condition 2, $t(11)= -.318, p = .76$, Condition 1 to Condition 3, $t(11)= -.107, p = .92$, or Condition 2 to Condition 3, $t(11)= .20, p = .85$.

For initiation time, the paired samples $t$-test did not reveal a significant difference between Condition 1 and Condition 4, $t(11)= .84, p = .42$. A significant difference in initiation time was not found when comparing Condition 1 to Condition 2, $t(11)= .97, p = .35$, Condition 1 to Condition 3, $t(11)= .83, p = .42$. Similarly, a significant difference was not found when comparing Condition 2 and Condition 3, $t(11)= -1.23, p = .25$, Condition 2 to Condition 4, $t(11)= -.21, p = .84$, and Condition 3 to Condition 4, $t(11)= .63, p = .54$.

For delta time, the paired samples $t$-test indicated a significant difference between Condition 1 and Condition 4, $t(11)= 2.79, p = .02$. Changes in delta time from Condition 2 to Condition 4 approached significance, $t(11)= 2.07, p = .06$. A significant difference was not found when comparing Condition 1 to 2, $t(11)= .18, p = .86$, Condition 1 to 3, $t(11)= .48, p = .64$, Condition 2 to Condition 3, $t(11)= .266, p = .79$, and Condition 3 to Condition 4 $t(11)= 1.84, p = .09$.

**Level of Impairment**

Research Questions 4, 5, 6, and 7 will be explored descriptively only. A main effect, as well as interaction effect could not be analyzed because the severe level of impairment group contained only two participants. Therefore, an inferential analysis was not conducted because the researcher did not have enough power to run an analysis of variance (ANOVA) due to a small sample size. The research questions were as follows:
Research Questions # 4: What is the main effect of level of impairment on total movement time in upper extremity movement in patients with PD?
Research Question # 5: What is the main effect of level of impairment on initiation time in upper extremity movement in patients with PD
Research Question # 6: What is the main effect of level of impairment on delta time in upper extremity movement in patients with PD?
Research Question # 7: What are the interaction effects between level of impairment and rhythmic cueing condition on total movement time, initiation time, and delta time?

Of the 12 participants involved in the analysis, ten participants were placed into the mild/moderate group and two participants were placed into the severe level of impairment group. The descriptive results, shown in Table 7 and Table 8, include the results for total movement time, initiation time, and delta time by level of impairment for all cuing conditions. See Figures 4.1, 4.2, and 4.3 for a visual representation of the means for total movement time, delta time, and initiation time for all cuing conditions for mild/moderate and severe groups, and both groups combined (total).

Mild/moderate level of impairment. In Condition 2 (i.e., external rhythmic cue), participants in the mild/moderate group moved at a mean of 24.03 seconds ($SD = 8.85$) for total movement time, which represented a 0.55 second increase from Condition 1 (no cue; $M = 23.48$, $SD = 8.65$). In Condition 3 (i.e., external rhythmic cue with auditory feedback), participants moved at a mean of 22.80 seconds ($SD = 8.22$), which represented a .68 second decrease from Condition 1 (no cue). From Condition 1 to Condition 4 ($M= 20.84$, $SD= 6.77$), mean total movement time decreased by 2.64 seconds. Mean total
movement time decreased between Condition 2 (external rhythmic cue) and Condition 3 by 1.23 seconds, in which an external auditory cue in combination with auditory feedback was provided. A decrease of 3.59 seconds was found between Condition 2 (external rhythmic cue) and Condition 4 (no cue). A decrease of 1.96 seconds was also found from Condition 3 (external rhythmic cue with auditory feedback) to Condition 4 (no cue).

For Condition 2 (external rhythmic cue), participants in the mild/moderate group initiated movement at a mean of .65 seconds (SD= .54), which represented a .96 second decrease from Condition 1, in which no cue was provided (M= 1.61, SD= 3.71). For Condition 3 (external rhythmic cue with auditory feedback), participants in the mild/moderate group initiated movement at a mean of .76 seconds (SD= .47), which represented a .85 second decrease from Condition 1, in which no cue was provided. From Condition 1 to Condition 4 (no cue; M= .68, SD= .55), mean initiation time decreased by .93 seconds. Mean initiation time increased from Condition 2 (external rhythmic cue) to Condition 4 (no cue) by .03 seconds. An increase of .11 seconds was also evident from Condition 2 (external rhythmic cue) to Condition 3, in which both an external rhythmic cue and auditory feedback were provided. A decrease was evident from Condition 3 (external rhythmic cue with auditory feedback) to Condition 4 (no cue) of .08 seconds.

Mean delta time for Condition 2 (external rhythmic cue) for participants in the mild/moderate group was 1.87 seconds (SD= .59), which represented a .02 decrease from Condition 1, in which no cue was provided (M= 1.89, SD= .53). Mean delta time for Condition 3 (external rhythmic cue with auditory feedback) was 1.86 seconds (SD= .57), which represented a .03 decrease from Condition 1, in which no cue was provided.
<table>
<thead>
<tr>
<th>Condition</th>
<th>No Cue</th>
<th>Rhythmic Cue</th>
<th>No Rhytihmic Cue and Auditory Feedback</th>
<th>No Cue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Time</td>
<td>23.48</td>
<td>24.03</td>
<td>22.80</td>
<td>20.84</td>
</tr>
<tr>
<td>Initiation</td>
<td>8.65</td>
<td>8.85</td>
<td>8.22</td>
<td>8.03</td>
</tr>
<tr>
<td>Delta Time</td>
<td>1.61</td>
<td>3.71</td>
<td>1.62</td>
<td>1.89</td>
</tr>
</tbody>
</table>

Table 7: Means and Standard Deviations of Total Movement Time, Initiation Time, and Delta Time for Mild/Moderate Level of Impairment in Each Condition.
A decrease of .16 seconds was evident from Condition 1 to Condition 4 (M=1.73, SD=.42), in which no cue was provided. Delta time also decreased from Condition 2 (external rhythmic cue) to Condition 4 by .14 seconds. Mean delta time decreased by .01 seconds from Condition 2 (external rhythmic cue) to Condition 3 (external rhythmic cue and auditory feedback). Delta time also decreased from Condition 3 (external rhythmic cue with auditory feedback) to Condition 4 (no cue) by .13 seconds.

**Severe level of impairment.** For Condition 2 (external rhythmic cue), participants in the severe group moved at a mean of 26.60 seconds (SD= 7.72) for total movement time, which represented a 0.04 second decrease from Condition 1 in which no cue was provided (M= 26.64, SD= 7.53). For Condition 3 (external rhythmic cue with auditory feedback), participants moved at a mean of 30.79 seconds (SD= .45) for total movement time, which represented a 4.15 second increase from Condition 1, in which no cue was provided (M= 26.64, SD= 7.53). A decrease of 1.42 seconds was evident from Condition 1 to Condition 4 (M=25.22, SD= 7.42), in which no cue was provided. Mean total movement time also decreased by 1.38 seconds from Condition 2 (external rhythmic cue) to Condition 4 (no cue). An increase of 4.19 seconds was evident between Condition 2 (external rhythmic cue) and Condition 3, in which both an external rhythmic cue and auditory feedback were provided. Mean total movement time decreased by 5.57 seconds from Condition 3 (external rhythmic cue with auditory feedback) to Condition 4 (no cue).
Table 8

*Means and Standard Deviations of Total Movement Time, Initiation Time, and Delta Time for Severe Level of Impairment in Each Condition*

<table>
<thead>
<tr>
<th>Condition 1</th>
<th>Condition 2</th>
<th>Condition 3</th>
<th>Condition 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Cue</td>
<td>External Rhythmic Cue</td>
<td>No Cue</td>
</tr>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Total Movement Time</td>
<td>26.64 7.53</td>
<td>26.60 7.72</td>
<td>30.79 .45</td>
</tr>
<tr>
<td>Initiation Time</td>
<td>.90 .97</td>
<td>.27 .26</td>
<td>.57 .26</td>
</tr>
</tbody>
</table>
Participants in the severe group initiated movement at a mean of .27 seconds in Condition 2 (external rhythmic cue; SD=.26), which represented a .63 second decrease from Condition 1, in which no cue was provided ($M=.90$, $SD=.97$). Participants initiated movement at a mean of .57 seconds in Condition 3 (external rhythmic cue with auditory feedback; SD=.26), which represented a .33 second decrease from Condition 1 in which no cue was provided ($M=.90$, $SD=.97$). A decrease of .49 seconds was evident from Condition 1 to Condition 4 ($M=.41$, $SD=.58$), in which no cue was provided. Mean initiation time increased by .14 seconds from Condition 2 to Condition 4 (no cue). An increase of .30 seconds was also noted from Condition 2 and to Condition 3. Mean initiation time decreased by .16 seconds from Condition 3 to Condition 4 (no cue).

For Condition 2 (external rhythmic cue), participants in the severe group moved at a mean delta time of 2.19 seconds ($SD=.47$), which represented a .05 second increase from Condition 1 (no cue; $M=2.14$, $SD=.58$). For Condition 3 (external rhythmic cue with auditory feedback), participants moved at a mean of 2.14 seconds as shown by mean delta time, which stayed the same as Condition 1 (no cue; $M=2.14$, $SD=.58$). A decrease of .04 seconds was evident from Condition 1 to Condition 4 ($M=2.10$, $SD=.49$) in which no cue was provided. Mean delta time also decreased from Condition 2 (external rhythmic cue) to Condition 4 by .09 seconds. A decrease of .05 seconds was also noted between Condition 2 and Condition 3, in which both an external rhythmic cue and auditory feedback were provided. Mean delta time also decreased from Condition 3 (external rhythmic cue with auditory feedback) to Condition 4 (no cue) by .04 seconds.
Figure 4.1. Average total movement time in seconds by level of severity across all conditions.

Figure 4.2. Average initiation time in seconds by level of severity across all conditions.
Figure 4.3. Average delta time in seconds by level of severity across all conditions.
Chapter Five

Discussion

This chapter will interpret the results of the study and review each research question, followed by a discussion of the theoretical and clinical implications. In addition, limitations involved in the study and recommendations for future research studies will be identified.

The purpose of the study was to investigate the effect of rhythm on the timing of upper extremity movements in patients with Parkinson’s disease. The study compared the use of an external rhythmic cue and an external rhythmic cue in combination with auditory feedback. Data were analyzed to determine which condition had the most impact on the timing of upper extremity movements. In addition, participants were placed into either a mild/moderate group or severe level of impairment group. Inferential analyses could not be performed to identify interaction effect and main effect of level of impairment. For those questions, only a descriptive analysis was completed. Fifteen participants performed a movement sequence similar to a reaching task four times, and met with the researcher one time. However, only 12 participants were included in the analysis.

Review of the Research Questions

The effect of rhythmic cueing condition on total movement time, initiation time, and delta time. The results of the study did not reveal significant differences for total movement time, initiation time, or delta time in response to either auditory rhythmic condition. From Condition 1 (no cue) to Condition 2 (external rhythmic cue), total movement time increased, whereas initiation time and delta time decreased. From
Condition 1 (no cue) to Condition 3 (external rhythmic cue with auditory feedback), total movement increased, and initiation time and delta time both decreased. Both auditory cues had a similar effect on the dependent variables, which further supports that a difference was not evident between an external rhythmic cue with or without auditory feedback.

The additional descriptive analysis helped to identify the specific ways in which participants had responded to the various conditions. The analysis led to post-hoc, pairwise comparisons between all conditions. These comparisons revealed significant decreases in total movement time from Condition 1 to Condition 4, and from Condition 2 to Condition 4. Decreases in total movement time from Condition 3 to Condition 4 also approached significance. For initiation time, no significant differences were found between any conditions. However, when comparing responses from Condition 1 to Condition 2, initiation time decreased by 60.4%, and from Condition 1 to Condition 3, initiation time decreased by 51.7%. One reason why these decreases in initiation time did not reach statistical significance could have been due to the relatively large standard deviation for Condition 1 (SD= 3.39), which indicates a wide range in responses to the rhythmic cueing conditions. For delta time, a significant decrease was found between Condition 1 and Condition 4. Decreases in delta time from Condition 2 to Condition 4 also approached significance.

An important point to note is that the overall means for total movement time, initiation time, and delta time decreased from Condition 1 to Condition 4. Additionally, the decreases for total movement time and delta time from Condition 1 to Condition 4 yielded statistically significant differences. The results suggest that participants improved
the timing of their upper extremity movements with practice. By repeatedly practicing the
sequence, overall total movement time decreased, and participants initiated the movement
sequence more quickly. In addition, the decrease in delta time indicates that participants
were able to move from target to target at a faster pace. The practice effect allowed for all
three variables to have a positive change from Condition 1 to Condition 4.

Therefore, the findings provide evidence that one auditory cue was not more
beneficial than the other for improving the timing of upper extremity movements for all
participants. However, mean scores for total movement time, initiation time, and delta
time decreased overall. The results indicate that in both auditory conditions, participants
showed a decrease in initiation time and delta time, and an increase for total movement
time. Although results did not reach significance, an immediate effect of rhythm was
evident for initiation time and delta time, but was not observable for total movement
time.

The results of the current study are similar to those of Platz, Brown, and Marsden
(1998), who found that participants with PD, while performing an upper extremity motor
task of moving between two targets, significantly improved the speed of their movements
with practice. Overall, the timing of their movements significantly decreased both with
and without cueing. In addition, the uncued movements showed a greater decrease in
total movement time, in comparison to the cued condition. However, in the study by Platz
et al. (1998), the participants were involved in repetitive training that involved more
trials.
After a baseline was established, the procedure consisted of 100 trials with one arm, then 15 additional trials of each arm, and a final assessment after a one-hour break. In the current study, each participant performed the movement sequence only 10 times in each of the four conditions.

In contrast, the findings of the present study differ from those of Georgiou et al. (1993), who found an immediate effect of rhythm on the timing of upper extremity movements during a button-pressing task in patients with PD. A metronome set to the participant’s baseline tempo resulted in a significant decrease in timing in comparison to the other conditions, which were: 1) no cue, 2) a tone heard when the button was pressed, and 3) a tone heard when the button was released. The metronome condition produced the greatest decrease in movement timing, in comparison to no cue and auditory cues, which is different from the findings of the current study.

**Level of impairment.** When analyzing the two groups descriptively, both mild/moderate and severe level of impairment groups decreased in total movement time from Condition 1 to Condition 4. However, participants in the mild/moderate group increased in total movement time with the addition of an external rhythmic cue. Total movement time also increased with the addition of an external rhythmic cue in combination with feedback for participants in the severe group.

Participants in both the mild/moderate and severe groups decreased in initiation time from Condition 1 to Condition 4, as well as from Condition 1 to each auditory condition (i.e., Conditions 2 and 3). Another important point to note is that although the severe level of impairment group contained only two participants, participants F and H showed dramatic changes from Condition 1 to Condition 2 in initiation time.
Participant F decreased in initiation time by 59.09% and Participant H decreased in initiation time by 71.69%. The demographic information in Table 1 indicates that the participant H did not have problems with akinesia. Participant F only had occasional akinesia (several times a week) in comparison to participants in the mild/moderate group who exhibited akinesia daily.

For delta time, both the mild/moderate group (8.5% decrease) and severe group (1.9% decrease) decreased from Condition 1 to Condition 4; however, the mild/moderate group showed a 6.6% greater decrease than the severe group. Overall, participants in the mild/moderate group showed a more consistently positive response to auditory cues, as evidenced by the decrease from Condition 1 to 3 for total movement time and the decrease from Condition 1 to 2, and Condition 1 to 3 for delta time. Participants in the severe group did not show a consistently positive response to the cueing conditions; however, final conclusions are difficult to formulate due to the small size of this group (i.e., n = 2).

The results are consistent with previous research which found that participants in the later stages of PD perform movements at a slower rate (Sacrey, Clark, & Whishaw, 2009). The descriptive analysis in the present study indicates overall slower timing for total movement time and delta time for the participants in the severe group than the participants in the mild/moderate group.
The findings are also similar to a previous study, which found that participants in the early stages of the disease were able to decrease the amount of time needed to initiate an upper extremity movement sequence with the aid of auditory cues (Georgiou et al., 1993). In the current study, both mild/moderate and severe level of impairment groups decreased the amount of time needed to initiate a movement sequence with either auditory cue.

By contrast, some of the findings of the present study are not consistent with those of Sacrey et al. (2009). Those researchers found that in a reaching task (i.e., reaching for a piece of food and bringing it to the mouth), participants with advanced PD benefited the most from the use of an auditory cue, as compared to participants with mild PD. The study consisted of five practice trials of the reaching task. Participants then performed the reaching task 10 times without music, and 10 times with client-preferred music. Most importantly, the music did not contain rhythmic cueing, which differs from the current study.

**Limitations of the Study**

Limitations of the study included small sample size and an uneven number of participants in the level of impairment groups. The researcher originally collected data for 15 participants, but due to a malfunction of the interactive touch table and the presence of outliers, three participants had to be removed from the data analysis. A larger sample size would have increased the statistical power needed to identify an effect of the two auditory cues on total movement time, initiation time, or delta time. In addition, a larger sample size could have resulted in the outcome that one auditory cueing condition
was more beneficial than the other in improving total movement time, initiation time, or delta time.

Regarding level of impairment groups, the mild/moderate group was much larger than the severe group. The reasons for this difference were that potential participants had difficulty with transportation or were unable to travel to campus to utilize the interactive touch table. In addition, more patients in the earlier stages of the disease attended the weekly support group meetings where recruitment took place. If the members of the group did not attend the meetings due to difficulty with transportation, the researcher could not recruit them for the study.

If the level of impairment groups had been equal in size, the researcher would have had the statistical power needed to conduct an inferential analysis to explore the interaction effect or main effect of level of impairment. This analysis of an interaction effect could have identified differences between the mild/moderate and severe level of impairment groups when exposed to the four conditions. An analysis of a main effect could have indicated whether or not a difference existed between the mild/moderate and severe level of impairment groups on total movement time, initiation time, or delta time.

An additional limitation of the study was that only one of the participants knew what stage of the Hoehn & Yahr (1967) they were in at the time of the study. This information would have assisted in grouping the participants by level of severity, instead of using the self-report questionnaires. Using the Hoehn and Yahr would have improved the reliability of determining level of impairment group. Instead of using a self-report, obtaining Hoehn & Yahr scores, as reported by each participant’s neurologist, would have been a more objective way of identifying the level of impairment.
Theoretical Implications

The study indicates that an immediate entrainment effect was not evident for all of the participants, as well as for all of the dependent variables. Overall, a metronome, or a metronome plus auditory feedback did not consistently improve movement timing of the upper extremities. The study also suggests that results are still inconclusive as to which auditory cueing condition is more beneficial for improving the timing of upper extremity movements.

The findings do, however, provide evidence of a practice effect that occurred within conditions, as well from the first to the last condition. These results indicate that through repetitive practice of an upper extremity movement, total movement time, initiation time, and delta time can decrease. Additionally, the results of the practice effect reveal that although patients with PD have damage to the basal ganglia, motor learning still occurred.

Clinical Implications

The results of the study provide implications for the use of an auditory cue to improve timing of upper extremity movements in patients with PD. Considering that the study did not find one auditory cue to be more effective than the other, either technique in isolation may be helpful for improving the timing of upper extremity movements. Music therapists, as well as physical therapists or occupational therapists, can choose either technique, an external rhythmic cue or an external rhythmic cue with auditory feedback, to provide cues for rehabilitation.
Previous research has found that patients with PD respond better to blocked practice, in which the patient is exposed repeatedly to one rehabilitation technique, instead of alternating between different techniques (Lin, Sullivan, Wu, & Kantak, 2007). In the current study, the participants switched from one technique to another, which can be difficult for patients with Parkinson’s disease during motor learning.

**Recommendations for Future Research.**

To further explore the effects of rhythm on upper extremity movement in patients with Parkinson’s disease, future research should be conducted with a larger sample size, and with an even number of participants placed in each level of impairment group. Future research could also look at order effect, to analyze how the order of exposure to each cueing condition affects the dependent variables. Additionally, a future study could analyze how upper extremity deficits, such as tremors, akinesia, or bradykinesia can affect the participant’s response to the rhythmic cueing conditions.

A similar study could explore the effect of one type of auditory cue at a time, instead of examining both auditory cues (i.e., external rhythmic cue with or without feedback). In addition, considering that a practice effect was found from Condition 1 to Condition 4, long-term practice could be useful for improving overall timing of upper extremity movements. Long-term training can include either an external rhythmic cue or an external rhythmic cue with feedback at least 3 times per week, for a duration of 3 to 4 weeks (Luft et al., 2004; Yoo, 2009).
Similar to studies conducted with patients post-stroke, a control group could perform the same movements as the experimental group, but without cueing (Schneider et al., 2007). A comparison between the two groups could determine whether the rhythmic cueing or the repetitive practice is responsible for improving the timing of the upper extremity movements.

**Summary and Conclusions**

The purpose of the study was to analyze the immediate effect of an external rhythmic cue with or without auditory feedback on the timing of upper extremity movements in patients with PD. Participants were involved in a single, one-hour session in which they performed a reaching movement task under four conditions. Each participant was placed into a mild/moderate group or severe level of impairment group for analyses purposes.

The findings did not indicate a consistently immediate effect of rhythm on the timing of upper extremity movement in patients with PD. No main effect was found either for an external rhythmic cue or for an external rhythmic cue with auditory feedback on total movement time, initiation time, or delta time. An interaction effect and main effect of level of impairment on the dependent variables were not analyzed due to the small sample size.

As a result, the two auditory cues did not appear to have a differential effect on total movement time, initiation time, and delta time. Initiation time and delta time decreased in both cueing conditions, whereas total movement time increased. Although an immediate effect of rhythm was found for initiation time and delta time, it did not reach statistical significance.
When evaluating each participant individually, a majority of the participants decreased in total movement time and delta time from Condition 1 to Condition 4. However, the improvements in total movement time, initiation time, and delta time were not consistent across the cueing conditions. The significant decreases in total movement time and delta time from Condition 1 to Condition 4 suggest that a practice effect was evident for the participants. A significant decrease in timing was also found for total movement time and delta time within the conditions (i.e., from Condition 2 to Condition 4), which further supports evidence of a practice effect. Further research is needed to examine the different effects of the two auditory cues and the stages of the disease on the timing of upper extremity movements in patients with Parkinson’s disease.
References


Appendix A

University of Miami
CONSENT TO PARTICIPATE IN A RESEARCH STUDY
The Immediate Effect of Rhythm on the Timing of Upper Extremity Movements in Patients with Parkinson’s Disease

The following information describes the research study in which you are being asked to participate. Please read the information carefully. At the end, you will be asked to sign if you agree to participate.

PURPOSE OF STUDY:
You are being asked to participate in a research study, entitled “The Immediate Effect of Rhythm on the Timing of Upper Extremity Movements in Patients with Parkinson’s Disease.” The purpose of this study is to find the immediate effect of rhythm on arm movements in patients with Parkinson’s disease.

PROCEDURES:
You will be asked to fill out three short questionnaires in regard to your Parkinson’s symptoms.

Then, you will be asked to perform a movement sequence involving touching three targets on a table with the hand you are most comfortable using. The table consists of three targets in a triangular formation and the table can produce a tone when touched. You will be asked to wear goggles during the sequence. The researcher will demonstrate how the movement sequence is performed and then you will perform five practice sequences.

When you are ready to begin, you will be asked to perform the research movement sequence in 4 different categories, each 10 times: 1) at your own pace, 2) with a steady beat, 3) a steady beat plus a tone heard when target is touched, and 4) at your own pace.

The length of time you are expected to participate in the study is one hour and you will meet with the researcher one time.

RISKS AND/OR DISCOMFORTS:
Direct eye contact with the lasers on the table can result in damage to the eye. You will wear protective eye goggles as a precaution due to the lasers.

BENEFITS:
No benefits can be promised to you from your participation in this study.

ALTERNATIVES:
You have the alternative not to participate in this study. During the study, you can decide to stop participation at any time.
The Immediate Effect of Rhythm on the Timing of Upper Extremity Movements in Patients with Parkinson’s Disease

CONFIDENTIALITY:
The researcher will consider all information throughout the study confidential. By signing this consent, you authorize the Investigators(s) to assess your performance as may be necessary for purposes of this study. Each participant will be given a code to secure confidentiality. Records will be stored on a secure and locked computer and the principal investigator and student investigator will have access to individual data.

COSTS:
There are no costs associated with your participation in this study

COMPENSATION:
There is no compensation as a result of participating in this study.

RIGHT TO DECLINE OR WITHDRAW:
Your participation in this study is voluntary. You are free to refuse to participate in the study or withdraw your consent at any time during the study. The investigator reserves the right to remove you without your consent at such time that they feel it is in the best interest for you.

CONTACT INFORMATION:
Shannon de l’Etoile, Ph. D., MT-BC (305-284-3943) will gladly answer any questions you may have concerning the purpose, procedures, and outcome of this project. If you have any questions concerning the research study, please contact Erin Keenan, Master’s Degree Candidate (732-241-5834). If you have questions about your rights as a research subject you may contact the Human Subjects Research Office at the University of Miami, at (305) 243-3195.

PARTICIPANT AGREEMENT:
I have read the information in this consent form and agree to participate in this study. I have had the chance to ask any questions I have about this study, and they have been answered for me. I am entitled to a copy of this form after it has been read and signed.

________________________________________  __________________________
Signature of Participant                      Date

________________________________________  __________________________
Signature of person obtaining consent          Date
Appendix B

Parkinson’s Disease Questionnaire

Participant Code: _______________

Age: ______

Sex: __________

Duration of Parkinson’s disease: __________

Hoehn & Yahr Stage (if known): __________

Type of medication: ________________

How long have you been on medication for Parkinson’s? : _______________

Time last taken: ________________

What hand do you write with?: ________________

Upper Extremity Problems:
0= Never
1=Several times per month
2=Several times per week
3=daily

Tremors: _______ At rest: _______ During movement: _______

Freezing: _______

Slowness of movement: _______

Difficulty starting movements: _______

Unwanted movements: _______

Any additional information:
________________________________________________________________________
________________________________________________________________________
Please read the instructions below:
For each item circle the number which describes how easy or difficult it is for you to perform the activity. If you are more able at some times than others, indicate how you are in general at time of the day you would normally perform these activities. If you use a walker or walking stick or any special aids, please answer according to how well you would manage without the aid.

1. Able to do alone without difficulty.
2. Able to do alone with a little effort.
3. Able to do alone with a lot of effort or a little help.
4. Able to do alone with a lot of help.
5. Unable to do at all.

1. Get out of bed 1 2 3 4 5
2. Get up from arm chair 1 2 3 4 5
3. Walk around the house 1 2 3 4 5
4. Walk outside, for example, to local shops 1 2 3 4 5
5. Travel by public transport 1 2 3 4 5
6. Walk up stairs 1 2 3 4 5
7. Walk down stairs 1 2 3 4 5
8. Wash face and hands 1 2 3 4 5
9. Get into a bath 1 2 3 4 5
10. Get out of a bath 1 2 3 4 5
11. Get dressed 1 2 3 4 5
12. Get undressed 1 2 3 4 5
13. Brush your teeth 1 2 3 4 5
1. Able to do alone without difficulty.
2. Able to do alone with a little effort.
3. Able to do alone with a lot of effort or a little help.
4. Able to do alone with a lot of help.
5. Unable to do at all.

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<td>14. Open tins/ cans</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>15. Pour milk from a bottle or can</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>16. Make a cup of coffee or tea</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>17. Hold a cup or saucer</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>18. Wash and dry clothes</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>19. Cut food with a knife and fork</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>20. Pick up an object from the floor</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>21. Insert and remove an electric plug</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>22. Dial a telephone</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>23. Hold and read a newspaper</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>24. Write a letter</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>25. Turn over in bed</td>
<td>1</td>
<td>2</td>
<td>3</td>
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Appendix D
Schwab and England Activities of Daily Living

Please check one that applies to activities of daily living, such as dressing, eating, and chores of the home.

_______ 100%. Completely independent. Able to do all chores without slowness, difficulty or impairment. Essentially normal. Unaware of any difficulty.

_______ 90 %. Completely independent. Able to do chores with some degree of slowness, difficulty and impairment. Might take twice as long. Beginning to be aware of difficulty.

_______ 80 %. Completely independent in most chores. Taking twice as long. Conscious of difficulty and slowness.

_______ 70%. Completely independent. Most difficulty with some chores. Three to four times as long as some. Must spend a large part of day with chores.

_______ 60 %. Some dependency. Can do most chores but exceedingly slowly and with much effort. Errors; some chores seem impossible.

_______ 50 %. More dependent. Difficulty with everything.

_______ 40 %. Very dependent. Can assist with all chores but few alone.

_______ 30 %. With effort now and then does a few things along or begin alone. Much help needed.

_______ 20 %. Not able to do chores alone. Can help with some chores.

_______ 10 %. Completely dependent on others to do chores around the home.
Appendix E

University of Miami

The Immediate Effect of Rhythm on the Timing of Upper Extremity Movements in Patients with Parkinson’s Disease

Volunteers Wanted for a Research Study

You are invited to participate in a research study. The study is designed to examine the immediate effect of rhythm on the timing of arm movements in participants with Parkinson’s disease.

In order to participate in the study, participants must be diagnosed with Parkinson’s disease and be able to perform a simple reaching movement with the dominant hand. Participants can not exhibit any signs of dementia. Participants must be taking medication related to Parkinson disease symptoms. Participants need to meet with the researcher only one time, for a one-hour appointment on the University of Miami campus in Coral Gables.

No compensation will be provided, however, the results may be used to develop techniques for Parkinson’s disease patients.

Research will be conducted at the University of Miami’s Frost School of Music. To learn more about this research, please contact Erin M. Keenan, student investigator, 732-241-5834.

This research is conducted under the direction of:

Shannon K. de l’Etoile, Ph. D., MT-BC
Program Director, Music Therapy
University of Miami
Frost School of Music
P. O Box 248165
Coral Gables, FL 33124
(305) 284-3943