The Effect of Auditory Stimulus Complexity on Rhythmic Motor Entrainment in Elderly Persons with Cognitive Impairment

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THE EFFECT OF AUDITORY STIMULUS COMPLEXITY ON RHYTHMIC MOTOR ENTRAINMENT IN ELDERLY PERSONS WITH COGNITIVE IMPAIRMENT

By

Emily Anne Dugas Lambert

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THE EFFECT OF AUDITORY STIMULUS COMPLEXITY ON RHYTHMIC MOTOR ENTRAINMENT IN ELDERLY PERSONS WITH COGNITIVE IMPAIRMENT

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This study investigated the effects of stimulus complexity and cognitive impairments on rhythmic motor entrainment behaviors in the elderly. Participants \( n = 24 \) between the ages of 70 and 90 provided demographic information, completed the St. Louis University Mental Status Examination, and finger-tapped on an iPad© to three different auditory stimulus conditions with varying levels of complexity: Simple Rhythm, Music and Rhythm, and Simple Music. Two repeated measures ANOVA analyses compared synchronization error mean (SE-mean) and variance (SE-variance) values between each of the conditions and between the two cognitive groups (Elderly no-CI and Elderly w-CI). These analyses showed a significant difference in SE-variance between the two cognitive groups and significant differences in SE-mean values between the Music and Rhythm condition and the other two stimulus conditions for all older adults. Additional correlation and regression analyses showed significant relationships between cognitive abilities and entrainment accuracy indicating that lower cognitive functioning and less education result in less accurate entrainment abilities. This study provides basic data to support further research on the appropriateness of using of certain music therapy
protocols with older adults with cognitive impairments. Through discussion and future recommendations, the study concludes that future research should confirm the effect of cognitive decline on entrainment accuracy, investigate ways to improve entrainment accuracy for older adults with mild cognitive impairments, and further investigate the relationship between entrainment accuracy and cognitive abilities such as attention and memory.
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Chapter 1

Introduction

Statement of the Problem

Alzheimer’s disease (AD), a type of neurocognitive disorder (i.e. dementia), is a terminal condition that is increasing in prevalence in the United States and across the globe (Ballard et al., 2011). AD currently affects over 5 million Americans, with projections of over 16 million Americans having AD by 2050 as the baby boomer generation ages (Alzheimer’s Association, 2013a). Globally, AD affects over 24 million individuals. Caring for those with AD is costly, and the cost is escalating (Ballard et al., 2011). Direct care costs exceed $200 billion annually in the United States, with an estimated additional $200 billion in care provided by friends and family (Alzheimer’s Association, 2013a). With no current cure or treatment that halts the disease available, the prognosis for AD is discouraging. Treating or managing symptoms is the only course of action for helping those with AD (Alzheimer’s Association, 2012).

AD begins with minor cognitive impairments, such as difficulties with memory and learning (American Psychiatric Association [APA], 2013). As the disease progresses, cognitive functioning declines and individuals with AD often experience significant changes in personalities and behaviors. Beginning with minor lapses in memory, early cognitive symptoms also include difficulties acquiring a correct name or word, trouble planning, and performing other executive function tasks (Alzheimer’s Association, 2012). These cognitive deficits increase as the disease progresses, eventually affecting the formation of new memories, retrieving personal memories, mathematical and spatial abilities, and mood regulation. Individuals with these
symptoms begin to require assistance with finances, planning, and some activities of daily living.

As AD advances, individuals with the disease become more reliant on others for day-to-day living (Alzheimer’s Association, 2012). Navigation, remembering personal details such as one’s address, and choosing appropriate food and clothing become increasingly difficult. Fine and complex motor skill abilities fade, and minor disturbances in balance and walking may appear. In the most severe stages of AD, individuals lose the ability to control bladder or bowels, dress or feed themselves, remember family and friends, maintain orientation to place and time, and eventually, move, speak, or swallow (Tschanz et al., 2011). As individuals lose independence and ability to complete activities of daily living, the cost of caring for them significantly increases as they move to higher levels of nursing care and require more time with skilled caregivers (Alzheimer’s Association, 2013b). The loss of independence can also contribute to depression in those with AD (Chi, Yu, Tan, & Tan, 2014). For these reasons, maintaining skills that assist in independence is essential for comprehensive care of those with AD.

The profession of music therapy often addresses skill maintenance in those with AD. The American Music Therapy Association (2013) reported that 12% of music therapists work with elderly clients and clients with dementia, projecting that music therapists serve approximately 23,000 individuals in this population. A literature review on music therapy and dementia research from 1985 to 1996 noted that music therapy for those with dementia and AD can immediately enhance social, emotional, and cognitive (memory) abilities and provide a non-pharmacological method of managing behaviors
(Brotons, Koger, & Pickett-Cooper, 1997). Additionally, the ability to participate in music therapy interventions persists late into the course of AD (Brotons et al., 1997; Takahashi & Matsushita, 2006). Maintaining cognitive skills is one long-term benefit from participating in music therapy sessions (Takahashi & Matsushita, 2006).

Music therapy also addresses physical abilities in those with AD, although the literature supporting this practice is sparse. One significant measure of independence and physical ability in those with AD is the ability to stand and walk. The neurologic music therapy technique Rhythmic Auditory Stimulation (RAS) can improve gait parameters and walking abilities in those with Parkinson’s disease, traumatic brain injury, stroke, and cerebral palsy (Thaut & Abiru, 2010). However, two studies that focused on the use of RAS to improve gait parameters in those with AD did not find significant improvements using the technique (Clair & O’Konski, 2006; Nishikawa, 2009).

One study with 28 individuals in late-stage dementia utilized RAS as part of restorative ambulation therapy (Clair & O’Konski, 2006). The study compared metronome only, metronome embedded in music, and no auditory stimulus conditions and measured cadence, velocity, and stride length during the sessions over the course of five weeks. Although participants’ average stride length was greatest during the music condition, results only approached, but did not reach, statistical significance. No other measures or conditions were significant, and the researchers did not report effect sizes. Though the study did not specifically measure entrainment accuracy, subjective observations by the researchers suggest the participants entrained to the auditory stimuli while not demonstrating any improvements in gait.
A second study compared the use of RAS to no auditory cueing on gait parameters in 10 older adults diagnosed with AD over the course of one week (Nishikawa, 2009). Participants took part in daily sessions, including one pre-test session, three treatment sessions, and one post-test session. Like the previous study, no significant effects emerged from use of the RAS technique on velocity, cadence, and stride length. Additionally, participants’ total walking distance did not change significantly between the two conditions, implying no increase in endurance.

In combination, these two studies suggest that RAS may not improve gait parameters in those with AD. Future research should to investigate the use of RAS to help individuals with AD maintain their ability to walk as the disease progresses in comparison to traditional restorative therapy methods or no therapy. However, the basic research supporting the RAS technique for neurologically healthy individuals has not been replicated for individuals with AD. Therefore, prior to conducting any additional clinical research on the use of RAS with AD, studies should investigate how persons with AD respond to auditory rhythmic stimuli and how rhythmic auditory stimuli may influence their behaviors.

A major component of the research outlining the mechanisms of RAS is the ability of individuals to entrain simple movements, such as finger tapping, to an auditory rhythmic stimulus. In healthy individuals, entraining simple movements occurs regularly, even when changes in the stimulus time interval are below the threshold of perception, and entrainment usually begins within three or four appearances of the stimulus (Thaut, 2005; Thaut, Kenyon, Schauer, & McIntosh, 1999; Thaut, Tian, & Azimi-Sadjadi, 1998). Minimal literature exists on the ability of those with AD to
synchronize movement to a beat. One study by Duchek, Balota, and Ferraro (1994) investigated the ability of individuals with Mild Cognitive Impairment (MCI) or AD to entrain to a rhythmic stimulus in comparison to healthy controls. The researchers found that individuals with AD can finger-tap in synchrony with an auditory rhythmic stimulus but demonstrate significantly greater variability in the time difference between the auditory stimulus and their finger tap. Clair, Bernstein, and Johnson (1995) reported those with AD entrain their rhythmic playing of instruments to a model or group, but the task was observed visually and not investigated with the use of timing data. Based on the small amount of literature available, adults with AD appear to synchronize motor movements to auditory stimuli but with questionable accuracy.

Another important component that impacts synchronization to auditory stimuli is the complexity of the auditory stimulus. Finger tapping at a moderate tempo to music as compared to a simple metronome beat results in lower variability and better synchronization in healthy young adults (Thaut, Rathbun, & Miller, 1997). Older adults also entrain better to the music condition at moderate tempos but display significantly more variability in their timing. The additional information provided by the music, such as rhythmic subdivisions and melody, in comparison to the metronome may facilitate better entrainment by clarifying the beat or providing anticipatory information.

For persons with AD, however, the additional information contained within the music may overwhelm their computational abilities. Individuals with AD take longer to process and respond to more complex auditory stimuli (Shucard, Abara, McCabe, Benedict, & Shucard, 2004). Therefore, stimulus complexity may play a role in determining the abilities of those with AD to entrain to an auditory rhythmic stimulus.
Overall, the existing literature does not offer a strong consensus on the ability of those at any stage of cognitive impairment or AD to entrain simple motor movements to a rhythmic auditory stimulus. Additionally, the current body of research does not expound upon how the complexity of the auditory stimulus may affect the ability of those with cognitive impairments to entrain.

**Definition of Terms**

**Alzheimer’s disease.** Alzheimer’s disease is a diagnosis for a specific type of neurocognitive disorder (i.e. dementia) with a distinct pattern of neurological changes and progression of symptoms, including initial memory and cognitive deficits that lead to social, emotional, and physical declines (Alzheimer’s Association, 2013b). Participants with early AD will be included in this study.

**Entrainment.** For the purposes of this study, entrainment is a specific type of synchronization, defined as the direct sensorimotor coupling of a rhythmic movement to a rhythmic auditory stimulus (Thaut, 2005).

**Mild Cognitive Impairment (MCI).** Mild Cognitive Impairment is a diagnosis for individuals with noticeable impairment in one or more cognitive domains such as memory, executive function, attention, language, or visuospatial skills. The impairment represents a decline from previous functioning and does not align with typical declines due to aging. Additionally, the cognitive impairment does not affect social, occupational, or self-care functional abilities and is not severe enough for a diagnosis of dementia (NIA & AA, 2010). Participants with MCI will also be included in this study.

**Rhythmic auditory stimulus.** For the purposes of this study, a rhythmic auditory stimulus is an auditory stimulus with a regular rhythmic, or periodic, foundation (Thaut,
The stimulus complexity may vary from simple tones to full pieces of music with a distinct periodicity (beat).

**Synchronization.** Synchronization is the result of two or more things happening at the same time and/or the act of making two or more things happen at the same time and speed (Synchronization, 2015; Synchronize, 2015). For the purposes of this study, synchronization refers to matching either single or multiple motor movement(s) to any external stimuli. Many authors of literature related to the current study use the terms synchronization and entrainment synonymously and interchangeably when referring to the matching of specified motor movements to an auditory stimulus over time.

**Need for the Study**

**Theoretical relevance.** This study will contribute information to the research literature about the durability of entrainment mechanisms during the process of aging and onset of cognitive impairments. By investigating simple rhythmic motor entrainment to auditory stimuli through a neurological approach, this study will help clarify the specific mechanisms required for entrainment and the effects of aging and dementia on these mechanisms. In addition, this study will add to knowledge in the field of music therapy by detailing how the aging process and cognitive impairments may alter simple motor entrainment behaviors at differing levels of auditory stimulus complexity.

**Practical relevance.** At the present time, the research on music therapy techniques for improving motor functioning does not show significant benefits for those with AD, specifically with the use of Rhythmic Auditory Stimulation for improvements in gait. The present study, with its focus on the ability of those with cognitive impairments to entrain movements to rhythmic auditory stimuli, will provide basic
knowledge on whether or not entrainment is possible for this population and their quality of entrainment accuracy at different stimulus complexity levels.

Findings from the present study may also guide future research on the use of music therapy techniques that utilize rhythm for those with MCI or AD and the possible development of new techniques to address motor deficits in AD. If this study determines basic motor synchronization to auditory stimuli occurs in those with AD, researchers in music therapy can adjust research methodologies and therapeutic protocols to create a way to use music as a means of improving or maintaining physical skills through the entrainment of functional movements. Individuals with AD would benefit from these successful protocols by maintaining a higher level of independence later into the course of the disease, reducing their need for assistance and more skilled caregivers. Additionally, the results from this study on stimulus complexity may inform the overall practice of music therapy with adults with dementia and inform the profession on the best practices for this population.

**Purpose of the Study**

The purpose of this study was to examine motor entrainment to rhythmic auditory stimuli in elderly individuals with cognitive impairment (i.e., MCI and early AD) and elderly individuals without cognitive impairment. Furthermore, this study also investigated the effect of auditory stimulus complexity on motor entrainment in older adults with cognitive impairment.
Chapter 2

Related Literature

This chapter will review research literature relevant to the mechanisms required to synchronize a physical movement to a rhythmic stimulus. The chapter will also provide an overview of Alzheimer’s disease, including diagnosing the disease, the symptomatic progression of the disease, neurological changes over the course of the disease, and resulting changes in cognitive and psychomotor functioning. The first section of the chapter will address the mechanisms of timing, auditory processing, and motor functioning in relation to rhythmic entrainment as well as the effects of the typical aging process on these mechanisms. The first section will also address previous research about music therapy techniques that use rhythmic entrainment with specific populations.

The remaining section of the chapter describes the degenerative process that occurs during Alzheimer’s disease (AD), including neurological and behavioral changes that may affect the mechanisms required for rhythmic entrainment. Lastly, the literature review will examine previous research on music therapy rhythmic entrainment techniques with AD and provide a rationale for investigating the ability of those with Mild Cognitive Impairment (MCI) or early AD to entrain to auditory rhythm.

Rhythmic Entrainment Mechanisms and the Effects of Age

Timing. Timing, or the ability to perceive and produce different intervals of time, is a well-researched phenomenon. Yet, little consensus exists in the literature on how humans perceive or produce time intervals based on internal timing mechanisms. Explanations and experimental results pertaining to the mechanisms of timing vary
greatly depending upon the speed and length of the timing elements, the complexity of the task, and whether an individual is producing or perceiving time intervals.

Many conflicting ideas exist on how the brain and body regulate time perception and production, but one popular timing model suggests that a central timing mechanism (internal clock) within the brain regulates the perception and production of timing intervals (Ragot, Ferrandez, & Pouthas, 2002). Though research surrounding this model includes contradictory interpretations, theories, and experimental results, the researchers specify well-documented outcomes on how external factors can influence the central timing mechanism. Increases in body temperature or arousal levels will speed up the internal clock, while decreases in these measures will slow down the internal clock (Baudouin, Vanneste, & Isingrini, 2004; Wearden, Philpott, & Win, 1999). Auditory stimuli with fixed time intervals can also prime and influence the internal clock. The internal clock speeds up in response to auditory stimuli at a faster tempo, whereas a slower tempo can slow the internal clock (Wearden et al., 1999). Despite these observed behaviors, no unified theory emerges from the research on exactly how the internal clock functions with respect to the neurological systems of the body and the brain.

Typical young adults appear to use the same internal clock mechanism(s) for both perceiving and producing time intervals, but a simple clock model consisting of an internal pacemaker and interval counting cannot account entirely for both behaviors (Ivry & Hazeltine, 1995; Wearden, 2004). Processing speed (Baudouin et al., 2004), executive function and hierarchical processes (Krampe, Mayr, & Kliegl, 2005), and attentional factors (Krampe, Engbert, & Kliegl, 2001) influence the perception and production of time. Low-level, or simple, timing tasks (i.e., simple finger tapping) do not seem to
engage higher levels of thought or hierarchical processing in typical adults and typically conform to a simple clock model (Krampe et al., 2005). However, more complex tasks, such as two-handed tapping or tapping difficult rhythms, engage executive functioning and generally conflict with a simple clock model.

**Age-related changes.** First reported by LeBlanc (1969), the aging process may slow perception of time, including an underestimation of some interval durations. The aging process also slows motor production, including a decrease of spontaneous (preferred) motor tempos with age (Baudouin et al., 2004) and reduced speed while performing fastest possible motor tempos (Turgeon, Wing, & Taylor, 2011). Some researchers ascribe these declines in speed to decreases in body temperature or arousal that accompany natural aging, while others suggest a decrease in mental processing speed resulting directly from the slowing of an internal clock mediates these timing changes (Baudouin et al., 2004).

The aging process appears to affect perception and production tasks in different ways. Although fastest possible tapping rates and preferred tapping rates do slow with age, age does not affect discrimination between perceived brief time intervals (i.e., less than 100 ms) (Rammsayer, Lima, & Vogel, 1993). Additional research indicates accuracy in simple tapping exercises, including error detection and correction, does not decrease with age. Age may affect more complex timing tasks, as an increased demand on executive control functions through complex tasks causes decreases in accuracy in older adults (Krampe et al., 2005; Turgeon et al., 2011). Additionally, older adults demonstrate greater variability and increases in timing errors compared to younger adults as the timing interval lengthens (Ivry & Hazeltine, 1995; Wing & Kristofferson, 1973).
Overall, declining motor tempos and decreases in executive control functions accompany the aging process, thus affecting timing mechanisms, but healthy older adults maintain simple timing abilities at moderate tempos.

**Auditory processing.** Human processing of an auditory signal involves many different pathways, processing strategies, and areas of the brain. Auditory perception includes locating the sound source, segregating the auditory stream based on the type(s) of information, assigning attentional resources, and attaching the sound information to other types of information such as visual or tactile input (Ward, 2010). Attention, processing speed, processing efficiency, and memory all influence an individual’s processing of auditory information much like how increased demands on executive functioning and attention influence timing (Anderson, Parbery-Clark, White-Schwoch, & Kraus, 2012; Shinn-Cunningham & Best, 2008).

**Age-related changes.** The greatest change in auditory processing that accompanies aging is hearing loss, representing the third most common health problem in older adults (Walling & Dickson, 2012). The degree of hearing loss can range from slight to profound based on the number of decibels lost in relation to normative hearing levels (American Speech-Language-Hearing Association, 2013). Many adults whose hearing has deteriorated slowly do not recognize they suffer from hearing loss, especially when the loss is mild or moderate. Compounding the difficulties of hearing loss recognition and/or acceptance is the difficulty often encountered during selection of hearing aids and adherence to their use due to discomfort or dissatisfaction (Pacala & Yueh, 2012). Cognitive decline affecting attention and executive function and hearing loss are the greatest changes affecting auditory processing in older adults.
**Motor functioning.** Voluntary muscle movements are fundamental to human existence and require precise coordination between many human systems. Both finger tapping and walking require sensory input and motor output for successful completion (Martin, 2012; Ward 2010). Typically, sensory input travels from mechanoreceptors and proprioceptors through the spinal cord into the thalamus and terminates in areas of the cerebral cortex. Descending motor instructions originate in several areas such as the primary motor cortex, supplemental motor area, and superior colliculus, and then descend through the spinal cord to innervate muscles. There, an individual motor neuron innervates one or more muscle fibers to create a motor unit.

Typically, information from cortical areas directly controls motor units, but auditory stimuli can influence muscle movements at the segmental level of the spinal cord, bypassing the higher-level structures and creating faster and stronger motor unit responses (Pal’tsev & El’ner, 1967; Rossignol & Jones, 1976). In addition to input from the cortex, central pattern generators in the brain stem and spinal cord control many aspects of gait, such as muscle timing and activation levels (Thaut, 2005). Auditory stimuli, specifically rhythm, can influence the output of these central pattern generators. Overall, motor behaviors such as finger tapping or walking involve many structures of the central nervous system and these structures are subject to influence from external auditory stimuli.

**Age-related changes.** Aging affects the motor output system on several levels. In the central nervous system, the total number of spinal cord neurons and motor units dedicated to lower extremity movement decreases with age (Roos, Rice, & Vandervoort, 1997). Additionally, the number of slow-twitch motor units needed for sustained
movements increases in comparison to the number of fast-twitch motor units used for quick movements. Despite the loss in number of motor units, neither the synchronization accuracy between motor units nor the amplitude of motor unit signals are significantly different between younger and older adults, implying no loss in the functioning of available motor units due to aging (Kamen & Roy, 1999).

Research also suggests that the excitability threshold for muscle activation may progressively increase with age resulting in reduced firing rates that cause declines in force, sustaining power, and dexterity (Roos et al., 1997). These reduced firing rates correspond to the slowing of fastest possible finger tapping rates with age (Rammsayer et al., 1993). Older adults also display longer reaction times during visually cued button pressing compared to younger adults (Mattay et al., 2002). At the musculoskeletal level, aging correlates with decreases in the number of muscle fibers and decreased muscle size, also contributing to declines in muscle force and sustainability (Roos et al., 1997). Additionally, decreases in white matter brain volume that occurs in very old adults (i.e., mid-to-late 80s) correlates with slower movement during walking (Camicioli, Moore, Sexton, Howieson, & Kaye, 1999). Many of these changes may explain why older adults have slower spontaneous motor tempos and fastest possible tapping speeds while, possibly, simultaneously contradicting the absence of increased timing variability (Ragot et al., 2002).

Synchronization to auditory stimuli. The human motor system is sensitive to auditory stimulation, especially when the auditory stimulation is rhythmic. Auditory rhythmic stimulation can create quicker and stronger motor unit responses in the quadriceps and gastrocnemius muscles (Pal’tsev & El’ner, 1967; Rossignol & Jones,
Auditory rhythmic stimulation can also promote neural impulses that entrain movements to the auditory input signal through coupling, and this entrainment of movements occurs with stimuli that vary at a level below the threshold of perception (Thaut et al., 1999). Synchronization of movements in the lower limbs to rhythmic stimuli during walking partially happens through the influence of auditory input on central pattern generators in the brain stem and spinal cord (Thaut, 2005). Rhythmic stimuli also influence movement of the upper limbs by possibly increasing the accuracy of the internal timing mechanism, resulting in decreased variability in timing and kinematic movement parameters in arm movements (Luft et al., 2004; Thaut, 2005).

A comparison of arm movements in response to visual, auditory, and tactile stimuli showed auditory cueing led to the greatest timing accuracy of the three sensory modalities (Thaut, Brown, Benjamin, & Cook, 1996). This increased accuracy to auditory cues implies an auditory processing advantage for movements cued by external timing stimuli. Within the auditory domain, entrainment to an evenly-timed rhythmic stimulus usually occurs after approximately three instances of the auditory stimulus and occurs through matching the interval between two adjacent auditory stimuli (Thaut et al., 1999). Individuals adjust to timing changes in the auditory stimulus below the perception threshold (Thaut, Tian, et al., 1998), implying basic entrainment can occur without active cognitive processing (i.e., occurs subconsciously).

The perception and production of simple rhythmic intervals is most accurate when the tempo of the auditory stimuli is closest to the individual’s spontaneous motor tempo (Turgeon & Wing, 2012). Spontaneous motor tempo (SMT), also referred to as preferred tempo, measures an individual’s selected comfortable or natural tempo, most often
assessed through finger-tapping. Some studies suggest the SMT reflects the internal clock or other intrinsic biological functions, though no consensus exists in the research (Turgeon & Wing, 2012). Arousal level, advanced age, and certain mood disorders can impact an individual’s SMT (Baudouin et al., 2004).

**Executive function and attention.** Synchronization of movement to auditory stimuli may be automatic in low-level timing tasks, such as finger tapping to a simple beat. Motor movements that require more executive functioning or hierarchical processing, such as tapping complex rhythms, bi-manual tasks, and in some cases, walking, are not automatic or simple (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005; Krampe et al., 2005; Turgeon et al., 2011). Tasks requiring increased demand of cognitive resources result in greater variability of motor synchronization, regardless of age (Krampe et al., 2005).

**Age-related changes.** For simple repetitive tasks, such as finger tapping, synchronization to an external auditory rhythmic stimulus and error detection within an auditory stimulus remain intact until very old age, if the central nervous system is healthy (Krampe et al., 2001; Turgeon et al., 2011; Vanneste, Pouthas, & Wearden, 2001). Only when older adults must generate movement timing internally, without matching movements to external references, do they demonstrate significantly greater variability than younger adults (Turgeon & Wing, 2012).

When motor tasks and timing require the use of executive function, decision-making, and attentional resources, significant differences arise between younger and older adults. Increased attentional workloads required for the completion of polyrhythmic tasks negatively impact motor timing accuracy and tempo in older adults.
(Krampe et al., 2001). Age affects the speed of executive function tasks, such as selection, maintenance, and updating, so rhythmic tasks involving alternation or task switching also produce poorer performances by older adults (Krampe et al., 2005).

Complexity of the auditory stimulus also impacts motor synchronization tasks in conjunction with age (Thaut et al., 1997). At moderate tempos (1 Hz to 3 Hz), young adults exhibit lower variability and better synchronization in finger tapping to a music condition compared to a metronome condition, probably as a result of the extra information, such as rhythmic subdivisions and melody, contained in the music stimulus versus the metronome stimulus. At less moderate tempos (0.5 Hz and 5 Hz), young adults perform better with the metronome condition than the music condition. Older adults mirror the results of the younger adults in their synchronization abilities when comparing the two tempo levels; however, older adults perform with significantly more variability in their tapping at the moderate tempos. Therefore, older adults have, overall, similar performance patterns compared to young adults on synchronization taps, but demonstrate more variability within their synchronization errors.

Lastly, a great deal of research considers walking to be an automatic and ballistic process; however, some research indicates attention and other cognitive skills significantly affect walking, especially in older adults (Abbud, Li, & DeMont, 2009). Adding a secondary task to walking, such as providing verbal responses to an auditory cue, negatively impacts the muscle activity of healthy older adults when the task occurs during the one-leg stance portion of the stride. These results indicate portions of gait require more attention than others, suggesting it may not be a purely automated task. Additionally, declines in cognitive skills and executive function correlate significantly
with deficits in walking (Hausdorff et al., 2005). This correlation may be the result of decreased sensory feedback and motor control that, in turn, require cognitive intervention for successful walking.

**Clinical applications.** Rhythm is an essential part of music, and movement to rhythm is often utilized in the practice of music therapy. One of the most common uses of simple rhythmic stimuli in music therapy occurs in a neurologic music therapy technique called Rhythmic Auditory Stimulation (RAS) (Thaut, 2005). RAS draws on the ability of auditory stimuli to influence movement, usually for gait training. RAS uses rhythmic auditory stimuli to entrain walking to a beat for immediate improvements of gait parameters. The use of RAS also helps stabilize and improve gait over long-term therapy (several months) with benefits that persist for many weeks after the completion of RAS treatment (McIntosh, Rice, Hurt, & Thaut, 1998). RAS successfully aids in gait rehabilitation for patients with Parkinson’s disease, stroke, and certain types of traumatic brain injury. RAS may also assist in gait development for children with cerebral palsy (Thaut & Abiru, 2010).

Other rehabilitative music therapy techniques that rely on synchronization or movement to rhythm include Patterned Sensory Enhancement and Therapeutic Instrumental Music Performance for the learning or relearning of functional movements (Thaut, 2005). Melodic Intonation Therapy and Rhythmic Speech Cuing also rely on rhythm for speech and vocal rehabilitation. The most common diagnoses for treatment with these techniques are Parkinson’s disease, stroke, traumatic brain injury, speech and language disorders, and aging. Regardless of diagnosis or population, rehabilitation protocols using entrainment require sufficient intensity and frequency of their application
to produce lasting effects. The ability to synchronize simple motor movements (i.e. finger-tapping) to an external stimulus with accuracy over a short period of time merely indicates the presence of a fundamental skill necessary for more in-depth treatment modalities.

**Summary of Rhythmic Entrainment Mechanisms and the Effects of Age**

In summation, questions remain about exactly how the internal human clock functions. Research, however, does provide evidence that factors external to timing such as temperature, arousal, auditory stimuli, and cognitive function can influence an individual’s perception and production of timing intervals. As a direct result of differing executive function and attentional demands, task complexity also affects timing and motor synchronization to auditory stimuli. Increases in both executive function and attentional demands influence auditory processing and, to an extent, motor tasks such as walking. As simple motor and synchronization tasks, such as finger tapping, require fewer demands on cognitive systems, these types of tasks are less susceptible to maladaptive influences.

Entrainment of simple motor movements to an auditory stimulus happens quickly, usually within three stimulus presentations. Individuals continue to entrain to a varying stimulus, even when the variations are below the noticeable threshold. No significant differences exist between older and younger adults in synchronization abilities, except when tempos are extremely fast or the tasks become complex. Major changes from younger to older adults include the slowing of preferred and fastest possible motor tempos and changes in how cognitive functioning affects synchronization. The aging process also reduces the number of motor units, quick movement muscle fibers, and
muscle firing rate, but these do not transfer into deficits of simple motor synchronization tasks at moderate tempos. Overall, older adults perform similarly to younger adults on a simple auditory synchronization task. Though older adults are more susceptible to interference from task complexity, previous research does not delineate a clear level of task complexity where older adults begin to perform more poorly than their younger counterparts.

Lastly, rhythm is an essential part of the construct of music. Many music therapy techniques rely on the element of rhythm and movement to rhythm for rehabilitation of gait, other functional movements, and speech and language. Older adult populations benefitting from these techniques are those with Parkinson’s disease, stroke, and traumatic brain injuries, all of which can lead to motor and speech/language deficits.

**The Effects of Alzheimer’s Disease on Rhythmic Entrainment Mechanisms**

**Alzheimer’s disease.** Alzheimer’s disease (AD) is an etiological subtype of both major and minor neurocognitive disorders, also known as dementia (APA, 2013). AD is a progressive and terminal disease beginning with a decline of cognitive abilities, including memory and learning, and progressing through a continuing loss of abilities and significant changes in behaviors. Early symptoms include deficits in cognitive and executive function processes (Alzheimer’s Association, 2012). As the disease progresses, these deficits increase, while additional changes in physical, social, and emotional functioning develop, such as personality changes and mood swings. Individuals with AD require progressively more help with activities of daily living, eventually becoming unable to engage with their environment, control their movements, communicate, or even swallow.
**Diagnosis.** According to the Alzheimer’s Association (2012), common early symptoms of AD include: memory loss, declines in executive functioning such as planning and problem solving, poor judgment, difficulty completing familiar tasks, confusion of time or place, misplacing things, withdrawal, and changes in mood and personality. Prior to a diagnosis of early AD, many individuals with some of these symptoms receive a diagnosis of Mild Cognitive Impairment (MCI) (APA, 2013). MCI does not always lead to AD, but individuals with MCI commonly develop some type of dementia.

Only a post-mortem autopsy or Magnetic Resonance Imaging (MRI) can provide an official diagnosis of AD, but individuals usually receive a diagnosis of dementia, probable/possible AD type while still alive (APA, 2013). Individuals receive this probable diagnosis based on interviews with the individual and their families, along with different cognitive and physical tests (Ballard et al., 2011). A comparison of results from a person’s neuropsychological tests to the tests’ normative data determines both the diagnosis of dementia and the severity of the dementia (APA, 2013). Physical diagnostic markers include atrophy of cortical matter (as seen via MRI or computed tomography), neurofibrillary tangles caused by the tau protein, and build-up of beta-amyloid plaques in the brain (Ballard et al., 2011; APA, 2013). Some research suggests measurements of tau and beta-amyloid in cerebrospinal fluid may differentiate AD from other types of dementia (Ballard et al. 2011).

One the many neuropsychological tests that doctors may use for identifying individuals with MCI or dementia is the St. Louis University Mental Status Examination (SLUMS). This 11-item examination assesses many cognitive skills, including: attention,
short- and long-term memory, numeric calculation, spatial reasoning, and executive function (Tariq, Tumosa, Chibnall, Perry, & Morely, 2006). The SLUMS accounts for the examinee’s level of education during score interpretation by establishing two different score ranges based on a minimum of a high school education. For both scoring systems, results from the test indicate normal functioning, a mild neurocognitive disorder (i.e., MCI), or dementia (Cummings-Vaughn et al., 2014; Tariq et al., 2006).

Two of the most common tools for screening for MCI and dementia are the Mini-Mental State Examination (MMSE) and the Montreal Cognitive Assessment (MoCA) (Cummings-Vaughn et al., 2014). The SLUMS has similar validity to the MoCA for detecting and differentiating between MCI and dementia as shown in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Examination</th>
<th>MCI</th>
<th>Dementia</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLUMS</td>
<td>.74</td>
<td>[.65, .84]</td>
</tr>
<tr>
<td>MoCA</td>
<td>.77</td>
<td>[.68, .86]</td>
</tr>
</tbody>
</table>

Note. AUC = area under curve. CI = confidence interval. Data from “Veterans Affairs Saint Louis University Mental Status Examination compared with the Montreal Cognitive Assessment and the Short Test of Mental Status,” by L. A. Cummings-Vaughn, N. N. Chavakula, T. K. Malmstrom, N. Tumosa, J. E. Morely, & D. M. Cruz-Oliver, 2014, Journal of the American Geriatrics Society, 62, p. 1341-1346.

Additionally, the SLUMS is more sensitive than the MMSE at detecting differences between MCI and dementia, as shown in Table 2 (Tariq et al., 2006).

However, in comparison to both the MMSE and the MoCA, the SLUMS is much quicker to administer (Cummings-Vaughn et al., 2014; Tariq et al., 2006).
Table 2

*Expected Performance of SLUMS and MMSE for Detecting MCI and Dementia*

<table>
<thead>
<tr>
<th>Examination</th>
<th>MCI</th>
<th>Dementia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AUC</td>
<td>95% CI</td>
</tr>
<tr>
<td>SLUMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; HSE</td>
<td>.93</td>
<td>[.89, .96]</td>
</tr>
<tr>
<td>≥ HSE</td>
<td>.94</td>
<td>[.91, .96]</td>
</tr>
<tr>
<td>MMSE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; HSE</td>
<td>.67</td>
<td>[.58, .76]</td>
</tr>
<tr>
<td>≥ HSE</td>
<td>.64</td>
<td>[.59, .70]</td>
</tr>
</tbody>
</table>


*Stages of Alzheimer’s disease.* The Alzheimer’s Association uses the seven-stage Global Deterioration Scale (GDS) originally created in 1982 (Reisberg, Ferris, De Leon, & Crook) to separate and describe the different stages of AD (Alzheimer’s Association, 2012). The scale represents a continuum of functioning from typical functioning (Stage 1) to very severe cognitive decline (Stage 7). Individuals with little or no changes in functioning comprise Stages 1 and 2 of the GDS. A typically functioning individual would receive a Stage 1 label on the GDS. Stage 2 of the GDS includes occasional memory problems that may either be an indication of early cognitive impairment or a typical part of aging. Although individuals in Stage 2 may be demonstrating early signs of dementia, individuals in Stages 1 and 2 do not usually receive diagnoses of MCI or early AD.
Stages 3 and 4 of the GDS represent a significant change in functioning and usually a diagnosis of MCI or AD (Alzheimer’s Association, 2012). Individuals in Stage 3 demonstrate a mild cognitive decline that may be noticeable by family, friends, or co-workers. The cognitive decline usually appears as deficits in short term memory recollection, difficulties with executive function skills such as planning and organizing, difficulties concentrating, and losing or misplacing important objects or names. Stage 3 individuals may receive a diagnosis of MCI or early AD, while a diagnosis of mild or early AD usually accompanies Stage 4 of the GDS. Individuals in Stage 4 exhibit greater losses in short term memory, difficulties in basic math, difficulties managing finances and events, loss of lifetime memories, and mood changes. Individuals in stages 3 or 4 also begin to display difficulties with fine and/or complex motor skills (Kluger et al., 1997; Kluger et al., 2008).

Individuals in Stages 5 through 7 of the GDS have moderate to severe AD (Alzheimer’s Association, 2012). In addition to experiencing increased difficulties with a greater variety of cognitive tasks, individuals in these later stages of AD experience significant changes in personalities and behaviors, major disturbances in typical sleep patterns, and considerable decreases in physical functioning. Some physical declines include losing the ability to balance, walk, sit up, smile, control bodily functions, and swallow.

Neuropsychological examinations, such as the SLUMS, are one of the most common ways to determine a patient’s AD stage. Scoring on the SLUMS directly corresponds to stages of the GDS, as shown in Table 3. Scored out of 30 points, score
interpretations on the SLUMS depend on whether or not the examinee has a high school education (Cummings-Vaughn et al., 2014; Tariq et al., 2006).

Table 3

**Corresponding Values: Diagnoses, SLUMS Scores, and GDS Stages**

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>SLUMS Score ≥ HSE</th>
<th>SLUMS Score &lt; HSE</th>
<th>Corresponding GDS Stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>27-30</td>
<td>25-30</td>
<td>1, 2</td>
</tr>
<tr>
<td>Mild Neurocognitive Disorder/MCI</td>
<td>21-26</td>
<td>20-24</td>
<td>3, 4</td>
</tr>
<tr>
<td>Dementia</td>
<td>0-20</td>
<td>0-19</td>
<td>5, 6, 7</td>
</tr>
</tbody>
</table>


**Neurological changes in Alzheimer’s disease.** Understanding what happens in the brain of an individual with AD is an ongoing and evolving process, but current research indicates two main neurological changes in proteins are responsible for the progression of AD (Alzheimer’s Association, 2012). First, beta-amyloid protein collects and forms plaques between nerve cells throughout the brain in significantly greater numbers than those without the disease. Secondly, tau protein builds neurofibrillary tangles that collect within the nerve cells. In addition to the accumulation of these two proteins, the brains of individuals with AD demonstrate cortical atrophy, decreased ventricular volume, and thinning of the entorhinal cortex (Peña-Casanova, Sánchez-Benavides, de Sola, Manero-Borrás, & Casals-Coll, 2012).

Beta-amyloid plaques and tau tangles both disrupt normal brain functioning but through different means (Alzheimer’s Association, 2012; Ballard et al, 2011). While
beta-amyloid plaques develop between neurons in the brain, preventing proper intercellular communication, the formation of tau neurofibrillary tangles disrupts the function of the individual neurons they inhabit. After forming, tau tangles can migrate to other areas of the brain, spreading their destructive effects. Beta-amyloid plaques increase damage to the brain by triggering an inflammatory response that results in the destruction of healthy cells in the brain. In comparison to beta-amyloid, the concentration of tau tangles in the brain is more closely related to the severity of the symptoms and progression of AD.

The accumulation of neurofibrillary tangles and plaques in the brain usually follows a particular pattern that corresponds to the progression of symptoms (Peña-Casanova et al., 2012). Neurofibrillary tangles first appear in the trans-entorhinal areas and the entorhinal cortex, affecting the limbic system, including the amygdala and the hippocampus and their communication pathways (Braak & Braak, 1996; Ward, 2010). These areas correspond to the initial memory problems, minor cognitive impairments, and minor mood changes displayed during the early stages of AD.

The protein accruals then spread outward to the cerebral cortex, specifically along axonal projections and functional pathways from the entorhinal area (Reid & Evans, 2013). During this proliferation, the cortex begins to atrophy, as visible during neuroimaging. First affecting cortical association areas, the proteins eventually disrupt cortical functioning in major areas such as executive function, sensory perception, language, and motor centers (Braak & Braak, 1996). This loss of functioning results in the symptoms exhibited during the later stages of AD, including loss of cognition, emotional regulation, language, and motor control (Alzheimer’s Association, 2012).
The loss of cerebral functioning in any individual typically invokes the brain’s neuroplasticity to reorganize and compensate for the lost or damaged areas. Research suggests the brain systematically reorganizes functional areas in the brain during AD as the protein accumulations spread (Mattay et al., 2002; Reid & Evans, 2013). In addition to reorganizing areas, the brain recruits greater cortical areas and/or alternate networks to perform certain tasks in comparison to healthy individuals (Stern et al., 2000). Both cortical reorganization and additional recruitment suggest major changes in how individuals with AD complete many tasks, including those in the language and motor domains. These increased demands by AD on the brain’s compensatory abilities most likely overloads the plasticity mechanisms. Because AD is a progressive disease, even cortical plasticity cannot prevent the advancing loss of functioning and progression of symptoms.

**Neurological mechanisms of timing and Alzheimer’s disease.** Despite inconsistent literature on human timing mechanisms and how they typically function in the brain, a body of evidence implicates both the cerebellum and the basal ganglia as important structures in timekeeping functions. Overall, the cerebellum acts to regulate precise timing in both perception and production tasks (Ivry, 1996). The basal ganglia play an important role in the act of perceiving time intervals and controlling paced movements (Harrington, Haaland, & Hermanowicz, 1998; Rao, Mayer, & Harrington, 2001). Specifically, the basal ganglia appear to encode time intervals and produce the timing (clock), but not motor, component of timed movements.

The basal ganglia and cerebellum work in conjunction, using the thalamus and some additional cortical areas, to perceive timing information accurately and produce
reactions or motions related to timing (Rao et al., 2001). Activation in the cerebellum begins later in the process than activation in the basal ganglia during interval comparison and self-paced finger tapping tasks. This later activation implies that the cerebellum helps interpret or modify the timing of the basal ganglia as well as plays a significant role in making decisions and comparisons. Both the basal ganglia and the cerebellum are integral to accurate perception and production of timing.

While both the cerebellum and the basal ganglia are crucial for timing, changes in the cerebellum resulting from AD are significantly greater than changes in the basal ganglia (Braak, Braak, Bohl, & Lang, 1989). Though the presence of Lewy bodies (a different type of protein accrual) in dementia, as found in Parkinson’s disease and dementia with Lewy bodies, triggers significant lowering of dopamine levels in the basal ganglia, dopamine levels in the basal ganglia are not affected significantly in AD (Langlais et al., 1993). The cerebellar cortex also does not amass the same amount of neurofibrillary tangles or plaques as the cerebral cortex during the course of AD (Braak et al., 1989). However, the cerebellum shows significant atrophy during the progression of the disease, resulting from neuronal loss and an excess of glial cells in the molecular layer (Sjöbeck & Englund, 2001).

*Changes in timing resulting from Alzheimer’s disease.* Because AD does not affect the basal ganglia as much as it does the cerebellum, deficits in timing due to AD may be more likely to be a result of the atrophy of the cerebellum (Langlais et al., 1993). Individuals with significant atrophy of the cerebellum, as might be found in a person with AD, demonstrate significantly diminished abilities to detect changes in timing interval lengths when the difference is 50 ms (Molinari et al., 2005). A reduced ability to
perceive variable interval lengths indicates a deficit in the tracking and comparison of events on a timeline. Specifically, individuals with AD struggle with perceiving changing tempos in an external auditory stimulus, but only with no motor response, such as finger tapping, paired to the auditory stimulus.

**Neurological mechanisms of auditory processing and Alzheimer’s disease.**
Auditory information from the ear is segregated and sent through various neurological pathways for processing and analyzing before recombining in the primary auditory cortex and secondary auditory areas (Lipscomb & Hodges, 1996). The two main pathways for sound processing are for localizing (where) or identifying (what) sounds (Ward, 2010). These pathways travel through the brainstem and thalamus before ending in the primary auditory cortex, located in the temporal lobe of both cerebral hemispheres (Lipscomb & Hodges, 1996; Ward, 2010). The primary and associated auditory areas in the cortex process the incoming information, synthesize meaning, and send information to other areas of the brain, as necessary, including instructions to assist in movement, speech, and body orientation (Martin, 2012). A small portion of incoming auditory information directly interacts with the brain stem and spinal cord, bypassing higher processing, as will be discussed in the neurological mechanisms of synchronization to auditory stimuli.

AD presents two major challenges to the auditory system: delayed processing of incoming stimuli, and development of neurofibrillary tangles in associated auditory areas (Lewis, Campbell, Terry, & Morrison, 1987; Swartz, Walton, Crummer, Hantz, & Frisina, 1992). Overall, individuals with AD display slower stimulus processing as measured by changes in the electrical activity of the brain (Swartz et al., 1992). This delay also occurs with auditory stimuli. In addition to a significant delay in the
processing of incoming auditory stimuli, AD creates a distinct pattern of neurofibrillary tangles in the primary and associated auditory areas (Lewis et al., 1987). The primary auditory cortex has very few neurofibrillary tangles, while the auditory association cortex contains more than ten times the number of neurofibrillary tangles in comparison. This accumulation pattern implies little disturbance of the primary auditory cortex, at least from neurofibrillary tangles, and significant disturbance of the association areas. This distribution of neurofibrillary tangles suggests little interruption of basic auditory processing in AD while implying significant deficits in behaviors driven by auditory information.

*Changes in auditory processing resulting from Alzheimer’s disease.* AD results in a significant delay in the processing of auditory stimuli, as indicated by P3 latency (Swartz et al., 1992), a measurement of stimuli processing within the brain to determine the true speed of neurological processing independent of observable outward reactions or responses. Individuals with AD have significantly greater P3 latency to both nonmusical and musical auditory stimuli compared to healthy controls. This difference is greater for simple musical and nonmusical events than for complex events. Significant delays in processing incoming auditory stimuli affect both comprehension of and reaction to those stimuli.

The large number of neurofibrillary tangles in the auditory association cortex greatly affects the functioning of the association areas. The auditory association cortex includes both the secondary auditory cortex and the higher-order auditory cortex, and it helps guide movements to sounds and comprehend speech, including rhythm and intonation (Martin, 2012). Therefore, the greater concentration of neurofibrillary tangles
in the auditory association areas implies greater deficits in sound-guided movement and speech functions, though little research has quantified these differences.

**Neurological mechanisms of motor functioning and Alzheimer’s disease.**

Voluntary motor functioning involves five different areas of the central nervous system: the cerebral cortex, the cerebellum, the brainstem, the spinal cord, and muscle innervation (Martin, 2012; Ward, 2010). The cerebral cortex is the main controller of movement. In the cortex, different areas control different aspects of the movement process. Overall, the primary motor cortex, located immediately anterior to the cortex’s central sulcus, controls voluntary movement of the muscles on the contralateral side of the body. The supplemental motor area, immediately anterior to the primary motor cortex, helps control pre-learned actions or patterns, including movement sequences that have a definite motor organization and timing arrangement, as well as movements generated internally. The lateral pre-motor cortex, inferior to the supplemental motor area, controls movements in response to external cues. Both the supplemental motor area and the lateral premotor cortex assist in the planning of action.

The remaining four areas of the central nervous system involved in movement contribute considerably less to the planning and initiation of movement compared to the cortex, but these areas significantly contribute to the movement process during the execution of the cortex’s commands (Ward, 2010). The cerebellum modifies the actions and controls the accuracy of movements, while the basal ganglia help chain movements and control the intensity of movements. The spinal cord, located between the brain stem and the individual motor units, transmits information between the two areas while generating commands for simple reflex movements (Martin, 2012). In addition to
receiving input from the cortex, basal ganglia, cerebellum, and brain stem, the spinal cord contains segmental interneurons that receive information directly from sensory receptors. These segmental interneurons automate reflexive movements and can modify movements, and they respond to auditory information that bypasses the cortex. Finally, the movement signal path terminates at the individual motor units that cause the muscles to contract.

The neurological hallmarks of AD, plaques and tangles, accumulate in the primary motor cortex, though usually later in the disease. Beta-amyloid plaques collect in the primary motor cortex at the same level as other cortical regions throughout the disease (Suvá et al., 1999). However, the primary motor cortex has fewer neurofibrillary tangles than the entorhinal cortex and the associated cortical areas throughout the disease. Examination of post-mortem brains also show that individuals with more severe or later stage AD have more tangles in the primary motor cortex than during the middle stages of the disease, indicating that AD affects the primary motor cortex progressively. This accumulation pattern of neurofibrillary tangles suggests that the primary motor cortex is one of the last areas to be affected by AD, a neurological progression that is consistent with the course of symptoms.

In addition to the buildup of proteins in the brain, studies on motor functioning (specifically, studies on locomotion) in individuals with AD illuminate the compensatory behaviors of a brain with AD. Both abnormal activation of supplemental cortical areas and cortical reorganization in AD are very common, and they are evident during both cognitive and motor tasks (Scherder et al., 2007). Locomotion typically utilizes the primary motor cortex, supplementary motor area, brain stem, and central pattern
generators in the spine. Individuals with early AD show increased activity in and around their motor cortex during the act of walking compared to those without AD (Sheridan & Hausdorff, 2007). This atypical increase in cortical activation may affect locomotion by overloading the cerebellum and causing irregular gait behaviors such as balance difficulties and stride asymmetry. Additionally, motor behaviors requiring sensory feedback and modification utilize the hippocampus, an area previously discussed as being one of the first areas to be affected by AD. Lastly, the atrophying cerebellum plays a role in modifying the motor commands with respect to timing as well as the comparison of motor plans and executions (Sjöbeck & Englund, 2001).

Changes in motor functioning resulting from Alzheimer’s disease. Individuals with MCI and early AD perform significantly more poorly on complex motor function tests with tasks that require rapid, alternating, or asymmetric hand movements or the coordination of two or more body regions (Kluger et al., 1997; Kluger et al., 2008). These individuals with MCI also perform significantly more poorly on fine motor function tests, while those with early AD also perform significantly more poorly on gross motor function tests compared to typical older adults. AD causes the loss of complex and fine motor skills prior to affecting gross motor skills, and these deficits are accurate indicators of MCI or early AD, regardless of education or cognition level. In addition to losing complex and fine motor skills, general slowing of motor tasks is indicative of AD (Almkvist & Bäckman, 1993; Goldman, Baty, Buckles, Sahrmann, & Morris, 1999; Müller, Weisbrod, & Klingberg, 1991). Individuals with MCI and early AD show significant slowing in reaction times, a component of the movement process that affects most motor activities. Individuals with AD also demonstrate slower psychomotor speeds
in a variety of movements, such as fastest possible finger tapping, quick arm movements, and motor response reaction times, when compared to their age matched peers (Almkvist & Bäckman, 1993; Ott, Ellias, & Lannon, 1995).

Previous literature on AD and specific motor tasks is somewhat contradictory. Individuals with MCI and early AD often show signs of gait disturbances. These gait disturbances include the slowing of gait velocity (Goldman et al., 1999), coordination impairments, loss of static balance (Scherder et al., 2007), bradykinesia (Aggarwal, Wilson, Beck, Bienias, & Bennett, 2006), and difficulties with advanced gait tasks, such as sit-to-stand movements and turning (Eggermont et al., 2010). Yet, in the task of simple rapid finger tapping, some studies indicate psychomotor slowing in those with AD compared to controls (Müller, Weisbrod, et al., 1991; Ott et al., 1995) while other studies do not show a difference in psychomotor speeds between individuals with early AD and individuals without (Almkvist & Bäckman, 1993; Goldman et al. 1999). Therefore, AD may or may not affect simple motor task speeds, such as speed of finger tapping.

**Neurological mechanisms of synchronization to auditory stimuli and Alzheimer’s disease.** The act of synchronizing motor movements to an auditory stimulus requires the use of the neurological mechanisms discussed in the previous sections on timing, auditory processing, and motor functioning. Research focused specifically on neurological activity during finger tapping to a beat solidifies these observations and provides additional information that clarifies the responsible brain network. Several studies show that finger tapping to auditory stimuli engages the posterior superior temporal gyrus, contralateral primary motor cortex, contralateral thalamus, ipsilateral cerebellum, anterior cingulate, contralateral insula, and basal ganglia.
in the brain (Chen, Zatorre, & Penhune, 2006; Lewis, Wing, Pope, Praamstra, & Miall, 2004; Thaut, 2003). Production of timed motor responses also requires the lateral region and the vermis of the cerebellum (Penhune, Zatorre, & Evans, 1998). This network is extremely large but remains consistent across research.

Additional areas identified, though not consistently, in the finger-tapping network include the supplemental motor area, dorsolateral prefrontal cortex, and different areas of the basal ganglia. The internalization of the tempo or beat at the beginning of the stimulus is possibly stored in the supplemental motor area, which may be utilized to continue the rhythm internally (Jäncke, Loose, Lutz, Specht, & Shah, 2000). The supplemental motor area, along with the basal ganglia, is also active during beat perception tasks (Grahn, 2009). Lastly, the dorsolateral prefrontal cortex may be responsible for maintaining attention to changing auditory stimuli and timing information (Chen, Penhune, & Zatorre, 2008).

The brain stem and the spinal cord also play a role in controlling motor movements, and both the brain stem and the spinal cord are susceptible to rhythmic auditory input (Martin, 2012; Scartelli, 1991; Thaut, 2005). Located in the center of the brain stem, the reticular formation is one of the main relays in the auditory pathway (Scartelli, 1991). Rhythmic input to reticular formation, when coupled with naturally rhythmic movements, causes greater neurological activation along the signal path for the movements. Similarly, in the spinal cord, rhythmic auditory stimuli influence movements by affecting segmental interneurons in the gray matter of the cord (Martin, 2012). The auditory stimuli modulate outputs of the central pattern generators to help regulate innate biological rhythmic movements such as walking, breathing, and sucking.
(Barlow, Finan, & Park, 2004; Thaut, 2005). However, central pattern generators may not govern non-essential movements such as finger tapping, and the relationship between central pattern generators and finger-tapping is not clear. Overall, the neurological components required for finger tapping to a stimulus are numerous and well distributed throughout the central nervous system.

Almost every area identified in the network for motor synchronization to auditory stimuli succumbs to AD at some point during the course of the disease. AD begins with the gathering of neurofibrillary tangles in the entorhinal cortex, affecting the thalamus and anterior cingulate areas of the network. The progression to the associated cortical areas then affects the posterior superior temporal gyrus, insula, supplemental motor area, and dorsolateral prefrontal cortex. The disease reaches the primary motor cortex last, preserving the most basic motor movements after losing the ability to plan and coordinate those movements. During the advancement of the neurofibrillary tangles throughout the brain, the cerebellum, along with the cortex and ventricles, significantly atrophies, affecting the precision of movements and accuracy of timing. Only the basal ganglia seem to escape significant deterioration in AD.

Changes in synchronization to auditory stimuli resulting from Alzheimer’s disease. AD appears to negate the auditory processing advantage for transferring external timing stimuli into movements. In healthy adults, auditory cueing produced more accurate motor responses versus tactile and visual cuing (Thaut et al., 1996). The auditory cueing advantage also exists in reaction times compared to visual cueing (Müller, Richter, Weisbrod, & Klingberg, 1991). Healthy participants reacted 20 to 25 ms faster to auditory stimuli than to visual stimuli. However, participants with AD did
not demonstrate any difference in reaction times between auditory cueing and visual cueing. In addition, individuals with AD relied more on expectations than pure reactions, as their reaction times were longer when the interval between cues was unexpectedly shorter.

Individuals with AD maintain some rhythmic and synchronization capabilities in matching or imitating exercises but experience difficulty maintaining rhythmic continuity in a solo exercise (Duchek et al., 1994). When comparing adults with AD and typically functioning adults, adults with AD can adequately finger tap along with an auditory rhythmic stimulus, but demonstrate significantly greater variability in their response delay. Individuals with AD have little success continuing the rhythmic tapping after the elimination of the auditory cues, while the typically functioning adults easily completed the continuation task.

In a music therapy setting, older adults with AD entrain their drum playing to other members of the group without instruction (Clair et al., 1995). This ability to entrain did not improve over an extended course of sessions, implying the basic ability still exists in those with AD, but does not improve with experience. However, over the same course of sessions, individuals with AD successfully imitated more complex rhythms over time, indicating that practice and learning of higher cognitive rhythm functions persists into the more severe stages of AD. This rhythmic ability endures in individuals with AD even after significant cognitive impairments (Lipe, 1995).

**Executive function and attention.** In completing tasks, often dual tasks, that require divided attention or additional executive function abilities, individuals with AD struggle to complete the tasks. During walking, a secondary task (such as counting
backwards while walking) significantly reduces gait velocity and stride symmetry while significantly increasing stride variability in those with AD compared to controls (Maquet et al., 2008; Sheridan, Solomont, Kowall, & Hausdorff, 2003). These results support the concept that even basic motor functions rely on attention or executive functioning ability and may be subject to deterioration during the course of AD.

**Clinical applications.** Auditory rhythm and entrainment are essential to sensorimotor rehabilitation techniques in the field of music therapy (Thaut, 2005). Maintaining sensorimotor skills in individuals with AD helps contribute to performing activities of daily living independently, such as ambulation, dressing, and feeding. Retaining independence is fundamental to reducing the cost of care and possibly depression for those with AD (Alzheimer’s Association, 2013b). Research indicates adults with AD can still successfully participate in traditional music therapy sessions that use rhythm and entrainment, though rhythmic and entrainment interventions do not elicit as much participation or maintain attention as movement or singing interventions for those with AD. Research also indicates that persons with AD can continue to learn new rhythmic patterns well into the course of the disease and that rhythmic imitation abilities persist well past severe cognitive declines (Clair et al., 1995; Hanson, Gfeller, Woodworth, Swanson, & Garand, 1996; Lipe, 1995).

Despite rhythmic and general entrainment abilities persisting well into AD, researchers have not yet shown that the specific rehabilitation technique of Rhythmic Auditory Stimulation (RAS) is effective at improving standard gait parameters in adults with dementia (Clair and O’Konski, 2006; Nishikawa, 2009). The technique of RAS works well for many populations with neurological deficits, such as Parkinson’s disease,
traumatic brain injury, stroke, and cerebral palsy (Thaut & Abiru, 2010). However, despite subjective observations of gait entrainment to auditory stimuli for those with AD, individuals with AD showed no significant improvements in velocity, cadence, or stride length after short and long-term gait training with RAS (Clair and O’Konski, 2006; Nishikawa, 2009). No current studies address the use of RAS for the maintenance of gait in those with AD, a true reflection of needs of individuals with AD. In addition to a lack of research on other music therapy rehabilitation techniques, such as Therapeutic Instrumental Music Performance and Patterned Sensory Enhancement for those with AD, there is a significant absence of research on the fundamental components of rhythmic motor entrainment to an auditory rhythmic stimulus.

**Summary of the Effects of Alzheimer’s Disease on Rhythmic Entrainment**

**Mechanisms**

In summary, AD is a progressive neurocognitive disorder that results from the accumulation of neurofibrillary tangles and beta-amyloid plaques as well as cortical and cerebellar atrophy. This disease begins with a decline in cognitive abilities. As the disease progresses, cognitive abilities further decline and deterioration in functioning spreads to the motor, emotional, and social domains. Individuals who reach the end-stage of the disease are reliant on others for care and have minimal to no interaction with their environment. The Global Deterioration Scale outlines seven stages of AD, ending in death, as AD is a terminal disease. Presently, no cure or significant treatment exists for AD that prevents the progression of the disease.

Timing, auditory processing, motor functioning, and motor synchronization to auditory stimuli all use a variety of components within the central nervous system. The
most common areas are the auditory and motor cortices of the brain, cerebellum, basal ganglia, thalamus, brain stem, and spinal cord. The cerebral cortex atrophies and amasses tangles and plaques in AD, affecting all systems reviewed in this chapter. The cerebellum also atrophies during the course of AD, affecting timing, motor movements, and motor synchronization. As a major relay center with a direct connection to the entorhinal cortex, the neuropathology of AD also damages the thalamus. Damage to the thalamus causes deficits in sensory processing and difficulties pairing actions to sensory input. Research on the basal ganglia, brain stem, and spinal cord does not show a significant impact of AD on these regions.

AD negatively affects behavioral outcomes related to the synchronization of simple motor movements to rhythmic auditory stimuli. Individuals with AD demonstrate difficulty tracking and comparing temporal events, indicating an interference with the internal timing mechanism. Possibly as a result of a damaged internal timing mechanism, individuals with AD also display deficits in keeping steady rhythms without an external cue or model. Slower sensory processing, specifically auditory processing, is indicative of AD, as well. The disease also causes slower reaction times, difficulty with fine motor skills and complex motor tasks, and disturbances in gait (even in the early stages). AD also impairs cognition and executive function. Increased executive function demands affect behavioral outcomes of those with AD more than their healthy counterparts, feasibly due to the reduction in cortical availability and overloading of the plasticity mechanisms in the brain.

Overall, individuals with AD demonstrate greater variability in their motor entrainment behaviors than typically functioning older adults. The degenerative
progression of AD affects many, but not all, of the central nervous system structures used to synchronize motor movements to auditory stimuli. When combined, deficits caused by AD in timing, auditory processing, motor functioning, and cognition may explain why the precise technique of Rhythmic Auditory Stimulation does not help improve the gait of those with AD while the general use of rhythmic activities in music therapy can be beneficial for those with AD.

**Research Questions**

The following research questions were addressed in this study:

1. What is the entrainment accuracy of finger tapping to a simple rhythmic auditory stimulus in elderly individuals with cognitive impairments?
2. What are the differences in entrainment accuracy to a simple rhythmic auditory stimulus between elderly individuals with and without cognitive impairments?
3. What is the entrainment accuracy of finger tapping to simple music *without* beat accentuation in elderly individuals with cognitive impairments?
4. What are the differences in entrainment accuracy to simple music *without* beat accentuation in elderly individuals with and without cognitive impairments?
5. What is the entrainment accuracy of finger tapping to simple music *with* beat accentuation in elderly individuals with cognitive impairments?
6. What are the differences in entrainment accuracy to simple music *with* beat accentuation in elderly individuals with and without cognitive impairments?
7. What are the differences in accuracy amongst entrainment to a simple rhythmic auditory stimulus, simple music *without* beat accentuation, and simple music *with* beat accentuation in elderly individuals with cognitive impairments?
Chapter 3

Method

Participants

The researcher recruited 25 participants from Miami-Dade County in south Florida. The researcher recruited participants through community advertising by means of informational fliers (see Appendix A), attendance at support group meetings and community groups, and speaking with potential participants and/or their caregivers. In working with community agencies such as support groups, community centers, and adult learning centers, the student researcher offered to provide written information, a brief presentation, or a guest presentation session on music therapy and its use with Alzheimer’s disease, caregivers, and/or the well elderly. Some, but not all, community agencies accepted the researcher as a guest speaker. The researcher recruited both elderly individuals with cognitive impairment and elderly individuals without cognitive impairment.

Inclusion/Exclusion criteria. Individuals from all ethnicities and genders between the ages of 70 and 90 were eligible to participate. The average age of participants from studies included in the related literature is 77 years, with an average age range of 64 to 88. Because research indicates early onset AD, with symptoms appearing before 65, has a different course and timing of symptoms (Llado & Sanchez-Valle, 2011; Panegyres & Chen, 2013), the minimum age for this study was set at 70 to exclude participants with early AD who displayed symptoms prior to age 65. In addition to age restrictions, participants had to be proficient in reading and understanding English. Recruiting materials and recruiting visits by the researcher advertised that participants
had to be free of hearing problems not appropriately corrected by an assistive device and free of symptoms of Parkinson’s disease. During the informed consent process, the researcher confirmed that participants had no major disability affecting their dominant hand.

**Design and Variables**

The overall design of the present study was a 2 x 3 repeated measures quasi-experimental design (Gamst, Meyers, & Guarino, 2008; Privitera, 2012). The first independent variable in the study was the participant’s cognitive functioning level. There were two groups for the cognitive functioning level variable: elderly adults without cognitive impairment (Elderly no-CI) and elderly adults with Mild Cognitive Impairment or early Alzheimer’s disease (Elderly w-CI). The second independent variable in the study, the repeated measure, was the auditory stimulus condition. The stimulus condition had three levels. The first level, labeled simple rhythm (SR) condition, consisted of only a metronomic beat. The second level, labeled simple music (SM), consisted of only music. The third level, labeled music and rhythm (MR), consisted of the music from the SM condition with the metronomic beat from the SR condition overlaid to emphasize the pulse of the music. The dependent variable in the study was the synchronization error (SE), or time between the presented beat and the corresponding finger tap, as measured in each of three stimulus conditions: SR, SM, and MR.

**Cognitive functioning level.** A continuum exists between typical functioning and a diagnosis of any type of neurocognitive disorder, including dementia. Clinicians usually determine a patient’s formal placement on this continuum through the administration of neuropsychological exams and/or through extensive gathering of
information from the patient and their caregiver(s). A valid and reliable exam, the St. Louis University Mental Status Examination (SLUMS), is an 11-item examination that assesses a variety of cognitive skills to determine an individual’s cognitive functioning level (See Appendix B). The SLUMS accounts for the examinee’s level of education during score interpretation, and results from the test indicate if the examinee has normal cognitive functioning, a mild neurocognitive disorder (i.e., MCI), or dementia (Cummings-Vaughn et al., 2014; Tariq et al., 2006), as shown in Table 4.

Table 4

Corresponding Values: Diagnoses, SLUMS Scores, and Cognitive Functioning Level

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>SLUMS Score ≥ HSE</th>
<th>SLUMS Score &lt; HSE</th>
<th>Cognitive Functioning Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>27-30</td>
<td>25-30</td>
<td>Elderly no-CI</td>
</tr>
<tr>
<td>Mild Neurocognitive Disorder/MCI</td>
<td>21-26</td>
<td>20-24</td>
<td>Elderly with-CI</td>
</tr>
<tr>
<td>Dementia</td>
<td>0-20</td>
<td>0-19</td>
<td>Excluded</td>
</tr>
</tbody>
</table>

*Note.* HSE = high school education. Elderly no-CI = elderly adults without cognitive impairment. Elderly w-CI = elderly adults with Mild Cognitive Impairment or early Alzheimer’s disease.

In this study, the researcher administered the SLUMS to all participants to obtain a cognitive functioning score, which the researcher then used to determine each participant’s cognitive functioning level. Although the administration of the SLUMS by the researcher cannot confirm a diagnosis of MCI or early AD, the SLUMS provides valid results that are highly correlated with other commonly used neuropsychological and functional measures that determine functional status (Cummings-Vaughn et al., 2014; Tariq et al., 2006). The researcher assigned each participant to a cognitive functioning level group based on the SLUMS score, as seen in Table 4.
Measures

The researcher gathered demographic measures for the study using a researcher-designed background information form that included demographic information about the participants. Though the demographic information did not constitute the primary dependent variables in the study, the researcher analyzed the demographic measures and their correlations with the dependent variable in post-hoc analyses. The researcher recorded the participant’s spontaneous motor tempo, neither an independent or dependent variable, but necessary for conducting the rhythmic entrainment procedure. The final measures in the study were the synchronization error (SE) values (the dependent variable) for each stimulus condition and the values calculated from the SE values, such as the mean and variance for the SE values in each condition.

Demographics. In addition to completing the SLUMS, participants completed a researcher designed background information form (See Appendix C) prior to the auditory entrainment exercises. This information form asked participants to self-report basic information such as gender, age, and hand-dominance. The information form also addressed the participant’s musical experiences, including whether or not they received any formal music training and for how many years, what instruments the participant played or currently plays, and if the participants currently performed solo music or in an ensemble. The form also had participants indicate their highest level of completed education and any past or present occupations. Lastly, the participants elected to answer if they had received a prior formal diagnosis of MCI or early AD.

Spontaneous motor tempo. Spontaneous motor tempo (SMT), also referred to as preferred tempo, is the participant’s selected comfortable or natural finger-tapping
rate. For the purposes of this study, SMT was the average time interval (in milliseconds) between finger taps. Because synchronization to simple rhythmic intervals is most accurate when the tempo of the stimuli is closest to the individual’s SMT (Turgeon & Wing, 2012), this research protocol established the participant’s SMT and created the rhythmic stimulus conditions for entrainment at the same tempo to ameliorate any effects of personal differences in SMT.

**Synchronization error.** Synchronization error (SE) is the error, or time difference (in milliseconds), between the presentation of the auditory stimulus and the motor response (i.e. finger tap) (Thaut, Tian, et al., 1998). Each individually presented auditory stimulus and its corresponding motor response created a SE value. A negative SE value indicated a motor response occurring prior to the stimulus, or an anticipatory tap. A positive SE value indicated a mean motor response after the event.

The synchronization error mean (SE-mean) is the calculated mean from all of the SE values in one stimulus condition for one participant. The SE-mean calculation is: SE-mean = Σ (SE) / N, where N = the number of measured SE values in the performance. Therefore, each participant had three SE-mean values after completing all of the auditory entrainment exercises. SE-mean values allowed for the comparison of overall timing accuracy between stimulus conditions and participant groups.

In addition to absolute SE values for each individual motor response and SE-mean values for each stimulus condition, each stimulus condition had a value for the participant’s synchronization error variance (SE-variance). The SE-variance calculation is the same as the calculation used for population variance (Privitera, 2012):
SE-variance = $\left[ \Sigma (SE^2) \right] / N$, where $N =$ the number of measured stimulus/motor response pairs in the performance. Thus, SE-variance indicated the average squared difference in SE (in ms) from the mean SE for one stimulus condition. SE-variance allowed for the comparison of timing consistency between stimulus conditions and participant groups in absolute timing (ms) terms.

**Materials**

*Equipment.* The researcher used an iPad Mini© running a software application designed specifically for this experiment by a research assistant in the Music Engineering Technology program at the University of Miami Frost School of Music. The software application collected the SMT data, produced the auditory entrainment stimuli, and collected finger tap response data.

*Construction of the stimulus conditions.* The stimulus conditions for all participants were of equal loudness, had the same pitch center regardless of different tempos, and had the same number of beats (48). For each participant, the tempo for all three stimulus conditions was the same and based on their SMT. Each stimulus condition lasted between 20 and 45 seconds, approximately, depending on the participant’s SMT.

*Simple Rhythm (SR).* The SR condition consisted of only a metronomic beat and was 48 beats in length. The metronome sound was a percussive clicking sound, sampled from a commercially available metronome, and was approximately 100 ms in length. The rhythmic (i.e. metronome) sound profile was the same for both the SR condition and the MR condition where the metronome sounds along with the music. The SR condition had the lowest level of stimulus complexity of the three conditions.
**Simple Music (SM).** The SM condition consisted of 12 measures (48 beats) of researcher-composed music in a 4/4 time signature composed in the style of American folk music (See Appendix D). The style of American folk music should be familiar to most participants, as it is the second most recommended genre of music for the elderly (behind popular music) in a survey of professional music therapists (VanWeelden & Cevasco, 2007). Despite using a familiar genre to avoid significant novelty that may be distracting to the participants, the researcher composed the original music to avoid any effects of emotions, preferences, or memories associated with pre-existing musical selections (Thaut et al., 1997). The SM condition represented an intermediate level of stimulus complexity in this study, as it contained more melodic and rhythmic information than the SR condition, but it lacks the addition of the metronome found in the MR condition.

The music of the SM condition features a simple melody with a range of one octave while avoiding more complicated rhythmic features that may interfere with the perception of beat. The chordal structure consists of I, IV, V<sup>7</sup>, and II<sup>7</sup> (V<sup>7</sup>/V) chords. The use of IV and II<sup>7</sup> chords provide strong harmonic leading into the V<sup>7</sup>, or dominant, chord, whose function is to strengthen perception of the tonic (I) key (Aldwell, Schachter, & Cadwallader, 2011). Using IV or II chords in addition to the I and V<sup>7</sup> also helps establish the main tonal center, as well, by presenting the rest of the available scale tones. The regular use of IV and II chords in the Western music tradition dates back to the mid-18<sup>th</sup> century, and the use of these four chords should be familiar to most participants with experience with tonal Western music of the last two or three centuries. The researcher
sequenced the music in MIDI using a synthesized keyboard patch for inclusion in the application.

**Music and Rhythm (MR).** The MR condition consisted of the music from the SM condition with the SR beat overlaid. This condition was also 48 beats in length. Because the MR condition contains the melodic and rhythmic information from the SM condition in addition to the sampled metronome sound of the SR condition, the MR condition had the highest level of stimulus complexity of the auditory stimulus conditions.

**Procedure**

The researcher gave potential participants information about the study and inclusion/exclusion criteria. If potential participants qualified and chose to enroll in the study, they first completed the informed consent (See Appendix E), followed by the researcher designed demographic information form (See Appendix C). The researcher then administered the SLUMS (See Appendix B), according to instructions provided by the Veterans Administration Medical Center (2009). After completing the paperwork tasks and the cognitive exam, the researcher led the participant through the spontaneous motor tempo and auditory entrainment exercises.

For the finger-tapping exercises, participants received instruction from the researcher to rest the heel of their hand comfortably on the table immediately adjacent to the iPad Mini© and then tap with their dominant index finger anywhere on the screen where it was comfortable. The participants generally completed all of the tasks within 20 minutes during one session. All sessions were individual and took place in participants’
places of residence, classrooms in the University of Miami Frost School of Music, and community meeting locations.

**Spontaneous motor tempo.** To obtain SMT, the researcher asked each participant to tap on the touch screen with his or her dominant hand’s index finger at a comfortable and consistent tempo for approximately 15 seconds. The researcher verbally instructed the participant when it was time to begin and verbally instructed them to continue tapping until the researcher said to stop. The software application calculated and stored the SMT value for each participant.

**Auditory rhythmic entrainment.** The application modified each stimulus condition and presented it to the participant at the same tempo as their SMT. The application presented the three stimulus conditions in a randomized order to account for any practice effect that may have occurred. However, the application did not record the order of presentation for the stimulus conditions for a later analysis on the order of effects. The application maintained the same pitch center for all participants, despite differences in tempo (based on the participant’s SMT).

Prior to any stimulus presentation, the researcher instructed the participants to tap the touch pad to the beat after the auditory stimulus began. The researcher stated participants should find the main beat in the music as if they were walking/marching to the beat or clapping along. The research specifically instructed participants not to copy or imitate the specific rhythms but, rather, to find the main beat or pulse of the music. Then, the researcher instructed the participants to continue tapping until they no longer heard the stimulus. Immediately prior to the beginning of each stimulus presentation, the researcher verbally prompted the participant to begin the task. The researcher paused for
a few seconds after the completion of each stimulus condition before giving verbal
instructions and beginning the next stimulus condition.

**Data Collection and Analysis**

For the auditory rhythmic entrainment exercises, the application began saving tap
data at the ninth beat. Typically functioning adults require approximately three beats to
entrain to a stimulus (Thaut, Tian, et al., 1998). The additional, non-collected beats
accounted for any processing delays or false starts in individuals with cognitive
impairment as well as allowed data collection to start at the beginning of a measure
during the conditions with music. Many participants, even in the group without cognitive
impairment, did not begin tapping until the sixth or eighth beat in the SM condition. This
delay is most likely due to the absence of the clear metronome sound found in the other
conditions, as well as the time it takes to identify a main pulse within music.

The application collected data for the next 24 beats/taps. Prior research collected
30 to 40 taps for data analysis (Krampe et al., 2005; Ivry & Hazeltine, 1995; Thaut,
Miller, & Schauer, 1998; Wing Kristofferson, 1973). The specifications for the
application originally stipulated data collection for 32 finger taps, but due to an oversight
during the development of the application and the need for the researcher to analyze
individual finger-tap/stimulus points to confirm accurate pairing, the application only
collected 24 finger-tap/stimulus pairs. The participants continued tapping for 16
additional, non-recorded beats to complete the musical phrase. This arrangement
provided a buffer of 8 or 16 taps on either side of data collection.

For each condition, the application recorded each individual tap time and the
individual stimulus onset times. The researcher kept these raw data for reference but did
not include them in this study’s reported results. From these information points, the researcher calculated the SE-mean and the SE-variance for each stimulus condition for each participant.

The researcher analyzed the reported data using two mixed-design ANOVAs on SPSS Statistics Version 21. The mixed-design ANOVAs compared the data between the two person conditions and between the three stimulus conditions within each participant, as well as analyzed any interaction effects between the person conditions, and stimulus conditions. In addition to the ANOVA, the researcher conducted correlation analyses between several demographic variables, SLUMS scores, and SE values and developed two simple regression models.
Chapter 4

Results

Descriptive Results

This chapter describes the statistical analyses of the collected data. First, the chapter outlines the demographic, SMT, and synchronization error data in descriptive form. Next, in the inferential section, the chapter reviews one-way ANOVAs related to the SMT data as well as summarizes the outcomes of two mixed-design ANOVAs that address synchronization error data. Lastly, the chapter lists significant correlations found between study variables and offers two regression models to predict synchronization error data based on selected independent variables.

For this study, 25 participants completed all study tasks. Study tasks included filling out a demographic information form, completing the SLUMS examination, and performing the auditory rhythmic entrainment exercises. After completing data collection, the researcher excluded data from one participant, a male in the Elderly no-CI group, from the final analyses. This participant’s SE-mean value was approximately 3 SD higher than both the overall mean SE-mean and the Elderly no-CI group mean SE-mean. The remaining 24 participants form the basis of the following analyses.

Demographics. Participants ranged from 71 to 89 years old, with an average age of 78.6 (SD = 5.0) years, as shown in Table 5. This age distribution is comparable to the average age of participants (77 years) in the related literature. There were 16 female participants, representing 67% of all participants. Women in the US represent approximately 58% of the population between the ages of 70 and 90 (Werner, 2011).
Therefore, the percentage of women participating in this study is greater than the percentage of women in the general population.

The levels of education completed by participants ranged from some high school to doctoral degrees. The researcher recruited heavily from the Osher Lifelong Learning Institute on the University of Miami campus, which may explain the large amount of college and graduate degrees among the participants. The researcher categorized the participants’ highest level of education into 5 categories: some high school, high school diploma/GED, some college/trade school, bachelor’s degree, and graduate degree. Eleven participants held a graduate degree, five participants held an undergraduate degree, seven participants had some post-secondary education, and one participant completed the tenth grade.

A second education variable, years of education, represents the number of years of schooling relative to completing high school. Therefore, the participant who completed tenth grade had 2 years of education while the participants with doctorates had nine years. The average years of education for all participants was 4.27 ($SD = 2.84$) years.

The number of years of formal musical training completed by participants ranged from zero to eleven years, with a mean of 2.75 years. A majority of participants reported their formal training occurred during adolescence, but a few participants reported they were currently receiving instruction. Only three of the 24 participants still actively performed in public, and an additional three participants still engaged in playing musical instruments privately. Participants still actively playing instruments reported played the piano, guitar, saxophone, and miniature accordion.
Cognitive functioning level. The average SLUMS score for all participants was 26.5 ($SD = 2.6$). Of the 24 participants, 15 placed into the Elderly no-CI group (i.e. SLUMS diagnosis: Normal) based on their SLUMS score. SLUMS scores for the Elderly no-CI group ranged from 27 to 30, with a mean score of 28.1 ($SD = 1.0$). A SLUMS diagnosis of Normal results from scores between 27 and 30.

The remaining nine participants scored in the Elderly w-CI group, thus receiving a SLUMS diagnosis of Mild Neurocognitive Disorder. Participant scores ranged from 20 to 26, with an average of 23.4. SLUMS scores for Mild Neurocognitive Disorder fall between 21 and 26. The w-CI group contained two participants with scores of 20. For participants with a high school education, a score of 20 falls at the top of the Dementia category. However, both participants that earned a score of 20 were living in a skilled nursing facility and answered one day earlier or later than the current day for question #1 on the SLUMS (See Appendix B). Neither participant had a calendar on the wall of their room, and neither had their TV set to the morning news when the researcher approached. Therefore, knowing the current day may have been very difficult, especially living in a skilled nursing facility. The researcher decided to include the data for both participants.

Of the 15 participants in the Elderly no-CI group, ten were female and five were male. The average age of participants in the Elderly no-CI group was 78.6. The Elderly w-CI group included six females and three males with a mean age of 78.2. The Elderly no-CI group had 2.7 years of formal musical training, on average, while Elderly w-CI participants had a mean of 2.9 years. One-way ANOVAs confirmed no statistically significant differences between the two groups with respect to distribution of gender, age, current music performance, or years of formal musical training. Conversely, the highest
levels of education between the two groups was significantly different ($F_{(1,22)} = 5.18, p < .05, \eta^2 = .19$), with the Elderly no-CI group having significantly more education than the Elderly w-CI group.

Table 5

**Participant Demographic Information by Cognitive Functioning Level**

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Elderly no-CI</th>
<th>Elderly w-CI</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n = 15$</td>
<td>$n = 9$</td>
<td>$n = 24$</td>
</tr>
<tr>
<td>Age</td>
<td>78.6 (5.6)</td>
<td>78.2 (4.0)</td>
<td>78.6 (5.0)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>5</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>F</td>
<td>10</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Education Level</td>
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<td></td>
</tr>
<tr>
<td>&lt; HS</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>HS</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&gt; HS</td>
<td>2</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Bachelor’s</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Graduate</td>
<td>8</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Years Musical Training</td>
<td>2.7 (3.2)</td>
<td>2.9 (4.3)</td>
<td>2.8 (3.6)</td>
</tr>
<tr>
<td>SLUMS Score</td>
<td>28.1 (1.0)</td>
<td>23.4 (2.4)</td>
<td>26 (2.6)</td>
</tr>
</tbody>
</table>

*Note.* Education Levels: < HS = Some high school, HS/GED = High school diploma, > HS = Some college or trade school, Bachelor’s = Bachelor’s degree, Graduate = Graduate degree. Years Musical Training represents reported years of formal music training.

**Spontaneous motor tempo.** All participant SMT values ranged from 423 to 925 ms, or 65 to 142 beats per minute (bpm). The mean SMT was 642 ms ($SD = 149$), or 99 bpm ($SD = 23$). Mean SMT values from the related literature for typical participants between 70 and 90 years old ranged from approximately 650 to 750 ms, or 80 to 90 bpm. The participants in this study had faster mean SMTs than those reported in the related literature by a minimum of almost 10 bpm.
For the SMT collection, the researcher instructed participants to try and keep the speed of their finger-taps as even and regular as possible. However, individuals typically do not keep a perfectly equal beat during un-cued finger taps. Therefore, SMT has a measure of variance, much like synchronization error. The overall mean SMT variance was $13,488 (SD = 26,036)$ with a range of SMT variance values from 1,600 to 102,400.

**SMT and cognitive function level.** As shown in Table 6, SMT for participants in the Elderly no-CI group ranged from 454 to 925 ms with a mean SMT of 643 ms ($SD = 159$), or 99 bpm ($SD = 24$). Participants in the Elderly w-CI group had a mean SMT of 642 ms ($SD = 139$) or 98 bpm ($SD = 23$), and SMT values ranged from 423 to 870 ms. The difference in mean SMT between groups was less than 1 ms. The mean SMT variance in the Elderly no-CI group was $10,447 (SD = 22,273)$, while the mean SMT variance in the Elderly w-CI group was $18,556 (SD = 32,164)$.

Table 6

<table>
<thead>
<tr>
<th>Spontaneous Motor Tempo by Cognitive Functioning Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spontaneous Motor Tempo</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Mean SMT (in ms)</td>
</tr>
<tr>
<td>Mean SMT (in bpm)</td>
</tr>
<tr>
<td>SMT Variance</td>
</tr>
</tbody>
</table>

*Note.* SMT variance based on measurements completed in ms.

**Synchronization error.** The overall mean synchronization error (SE-mean) for all participants and all conditions was 160 ms ($SD = 72$). Previous research suggests that a typical individual will tap prior to the sound, and thus create a negative SE-mean value, even though the person perceives the actions as simultaneous (Molinari et al., 2005; Thaut et al., 1998). This anticipatory tap may be the result of the time needed for
mechanoreceptors in the skin to send information to the brain. In this study, however, the combination of the iPad© and the software application introduced a timing delay. Measuring this exact delay is not possible, but the delay was consistent across all participants and conditions. Therefore, comparisons within the study are accurate but direct comparisons to other studies would not be reliable. The overall mean synchronization error variance for all participants and all conditions was 11,992 (SD = 24,178). Again, directly comparing these values to other studies is not necessarily appropriate.

**Stimulus conditions.** For all participants, the SE-means for the Simple Rhythm (SR) condition ranged from 54 to 384 ms. As shown in Table 7, the average SE-mean for all participants in the SR condition was 180 ms (SD = 76). For the Music and Rhythm (MR) stimulus condition, the mean SE-mean was 138 ms (SD = 75). Participants’ SE-means for the MR condition ranged from 28 to 300 ms. Lastly, the mean SE-mean for Simple Music (SM) condition fell between the mean SE-means for the SR and MR conditions. The SE-means ranged from 3 to 344 ms, with a mean of 162 ms (SD = 85) for all participants.

The mean SE-variance for the SR condition was 7,828 (SD = 18,180). For the MR condition, the mean SE-variance was more than double that of the SR condition at 17,263 (SD = 43,697). Again falling between the SR and MR conditions’ means, the SM condition’s mean SE-variance was 10,883 (SD = 19,881).

**Cognitive functioning levels.** For the Elderly no-CI group, the overall mean SE-mean was 140 ms (SD = 51). The mean SE-means for the SR, MR, and SM conditions were 161 (SD = 54), 122 (SD = 55), and 137 (SD = 59) ms, respectively. Overall, and
for all three individual stimulus conditions, the mean SE-mean for the Elderly w-CI group was larger than for the Elderly no-CI group. The overall mean SE-mean for the Elderly w-CI group was 193.7 ms ($SD = 91.3$). For the SR condition, the mean SE-mean was 210.9 ms ($SD = 98.2$). The mean SE-mean of the MR condition was 165.9 ms ($SD = 98.0$), and the mean SE-mean of the SM condition was 204.2 ms ($SD = 107.3$).

Table 7

*Synchronization Error Values by Cognitive Functioning Level*

<table>
<thead>
<tr>
<th>Stimulus Condition</th>
<th>Elderly no-CI</th>
<th>Elderly w-CI</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M (SD)$</td>
<td>$M (SD)$</td>
<td>$M (SD)$</td>
</tr>
<tr>
<td>Simple Rhythm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE-Mean</td>
<td>161 (64)</td>
<td>211 (98)</td>
<td>180 (76)</td>
</tr>
<tr>
<td>SE-Variance</td>
<td>2,234 (2,966)</td>
<td>17,001 (27,988)</td>
<td>7,828 (18,180)</td>
</tr>
<tr>
<td>Music and Rhythm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE-Mean</td>
<td>122 (55)</td>
<td>166 (98)</td>
<td>138 (75)</td>
</tr>
<tr>
<td>SE-Variance</td>
<td>1,388 (1,008)</td>
<td>43,720 (65,022)</td>
<td>17,263 (43,697)</td>
</tr>
<tr>
<td>Simple Music</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE-Mean</td>
<td>137 (59)</td>
<td>204 (107)</td>
<td>162 (85)</td>
</tr>
<tr>
<td>SE-Variance</td>
<td>4,622 (8,287)</td>
<td>21,320 (28,637)</td>
<td>10,883 (19,881)</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE-Mean</td>
<td>140 (51)</td>
<td>194 (91)</td>
<td>160 (72)</td>
</tr>
<tr>
<td>SE-Variance</td>
<td>2,778 (3,105)</td>
<td>27,437 (35,205)</td>
<td>11,992 (24,178)</td>
</tr>
</tbody>
</table>

*Note.* Values reported in ms.

The Elderly w-CI mean SE-variances were also larger than the Elderly no-CI mean SE-variances for each stimulus condition, as well as the overall mean SE-variances. For the Elderly no-CI group, the overall mean SE-variance was 2,778 ($SD = 3,105$), while the overall mean SE-variance for the Elderly w-CI group was 27,437 ($SD = 35,205$). Similarly, for the SR condition, the mean SE-variance for Elderly no-CI was 2,234 ($SD = 2,966$), and the mean SE-variance for Elderly w-CI was 17,001 ($SD = 27$,
An even greater difference existed in the MR condition, where the mean SE-variances for the two groups were 1,388 (SD = 1,008) and 43,720 (SD = 65,022). Like the SE-means, the Elderly w-CI group’s mean SE-variance for the SM condition (21,320 (SD = 28,637)) fell between the SR and MR conditions. Again, this was larger than the mean SE-variance for the Elderly no-CI group (M = 4,622 (SD = 8,287)).

**Inferential Results**

**Spontaneous motor tempo.** A univariate ANOVA revealed no significant difference between the Elderly no-CI and Elderly w-CI groups for mean SMT values (F(1,22) = 0.00, p = .992, η² = .00). Another univariate ANOVA confirmed no significant difference in SMT variance between the groups with different cognitive functioning levels (F(1,22) = .54, p = .472, η² = .02).

**Synchronization error.** Two mixed-design 2 x 3 ANOVAs compared, individually, the SE-mean repeated measures and the SE-variance repeated measures by cognitive functioning levels.

**SE-mean.** The first mixed-design ANOVA for the SE-mean showed a significant main effect of stimulus condition but no significant effect based on cognitive functioning level and no significant interaction effect. As shown in Table 8, there was a statistically significant mean difference for the SE-mean values depending on the stimulus condition (F(2,48) = 6.49, p = .003, η² = .23). Post-hoc pairwise comparisons, using a Sidak adjustment, indicated a statistically significant difference in SE-mean values (Mdiff = 42.10, SE = 11.84, p = .005) between the SR (M = 185.84, SD = 75.79) and MR (M = 143.74, SD = 76.13) conditions. An additional statistically significant (Mdiff = -26.67, SE = 9.16, p = .024) difference emerged between the MR (M = 143.74, SD = 76.13) and SM
(\(M = 170.41, SD = 82.50\)) stimulus conditions. The analysis revealed no statistically significant mean differences for SE-mean values between groups based on cognitive functioning level.

Table 8

**SE-mean Mixed Design Repeated Measures ANOVA Summary**

<table>
<thead>
<tr>
<th>Source</th>
<th>SS (x 10^9)</th>
<th>df</th>
<th>MS (x 10^9)</th>
<th>F</th>
<th>p</th>
<th>(\eta^2_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFL</td>
<td>49,207.50</td>
<td>1</td>
<td>49,207.50</td>
<td>3.50</td>
<td>.075</td>
<td>.14</td>
</tr>
<tr>
<td>Error_CFL</td>
<td>309,102.67</td>
<td>22</td>
<td>14,050.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>20,412.82</td>
<td>2</td>
<td>10,206.41</td>
<td>6.49</td>
<td>.003**</td>
<td>.23</td>
</tr>
<tr>
<td>CFL * SC</td>
<td>1,660.32</td>
<td>2</td>
<td>830.16</td>
<td>.53</td>
<td>.594</td>
<td>.023</td>
</tr>
</tbody>
</table>

*Note.* CFL = Cognitive Function Level (Elderly w-CI or Elderly no-CI); SC = Stimulus Condition (SR, MR, SM).

**p < .01**

Table 9

**SE-variance Mixed Design Repeated Measures ANOVA Summary**

<table>
<thead>
<tr>
<th>Source</th>
<th>SS (x 10^9)</th>
<th>df</th>
<th>MS (x 10^9)</th>
<th>F</th>
<th>p</th>
<th>(\eta^2_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFL</td>
<td>10.19</td>
<td>1</td>
<td>10.19</td>
<td>7.43</td>
<td>.012*</td>
<td>.25</td>
</tr>
<tr>
<td>Error_CFL</td>
<td>30.15</td>
<td>22</td>
<td>1.37</td>
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</tr>
<tr>
<td>SC\textsuperscript{a}</td>
<td>2.02</td>
<td>2</td>
<td>1.01</td>
<td>2.52</td>
<td>.119</td>
<td>.10</td>
</tr>
<tr>
<td>CFL * SC\textsuperscript{a}</td>
<td>2.67</td>
<td>1.21</td>
<td>2.22</td>
<td>3.34</td>
<td>.072</td>
<td>.13</td>
</tr>
<tr>
<td>Error_SC\textsuperscript{a}</td>
<td>17.60</td>
<td>26.52</td>
<td>0.66</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* CFL = Cognitive Function Level (Elderly w-CI or Elderly no-CI); SC = Stimulus Condition (SR, MR, SM).

\textsuperscript{a} Mauchley’s test of sphericity was significant (\(X^2_\text{(2)} = 30.64, p < .001\)), therefore values are based on the Huynh-Feldt adjustment.

\textsuperscript{*} p < .05

**SE-variance.** The mixed-design ANOVA for SE-variance showed a significant between-subjects effect of cognitive functioning level. No significant effect based on stimulus conditions and no significant interaction effect emerged.
Table 10

Correlation Coefficients Between Select Demographics, SLUMS Scores, SMT Values, and SE Values for Stimulus Conditions

<table>
<thead>
<tr>
<th></th>
<th>SLUMS Score</th>
<th>SMT (ms)</th>
<th>SMT Var</th>
<th>SR Mean</th>
<th>SR Var</th>
<th>MR Mean</th>
<th>MR Var</th>
<th>SM Mean</th>
<th>SM Var</th>
<th>Overall Mean</th>
<th>Overall Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years Edu</td>
<td>.534**</td>
<td>.084</td>
<td>-.114</td>
<td>-.504**</td>
<td>-.380</td>
<td>-.552**</td>
<td>-.626**</td>
<td>-.738***</td>
<td>-.376</td>
<td>-.660***</td>
<td>-.576***</td>
</tr>
<tr>
<td>SLUMS Score</td>
<td>-.133</td>
<td>-.092</td>
<td>-.577**</td>
<td>-.582**</td>
<td>-.546**</td>
<td>-.537**</td>
<td>-.473**</td>
<td>-.647**</td>
<td>-.579***</td>
<td>-.647**</td>
<td></td>
</tr>
<tr>
<td>SMT (ms)</td>
<td>.593**</td>
<td>.049</td>
<td>.226</td>
<td>.231</td>
<td>.418**</td>
<td>.264</td>
<td>.218</td>
<td>.201</td>
<td>.368</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMT Var</td>
<td>-.145</td>
<td>.282</td>
<td>.148</td>
<td>.628**</td>
<td>.207</td>
<td>.053</td>
<td>.082</td>
<td>.464**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR Mean</td>
<td>.540**</td>
<td>.735***</td>
<td>.300</td>
<td>.669**</td>
<td>.643**</td>
<td>.873***</td>
<td>.492**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR Var</td>
<td>.487**</td>
<td>.706***</td>
<td>.365</td>
<td>.837***</td>
<td>.502**</td>
<td>.905***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MR Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.563**</td>
<td>.856***</td>
<td>.583**</td>
<td>.943***</td>
</tr>
<tr>
<td>MR Var</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.616**</td>
<td>.518**</td>
<td>.544**</td>
<td>.921***</td>
</tr>
<tr>
<td>SM Mean</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.446**</td>
<td>.585**</td>
</tr>
<tr>
<td>SM Var</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.604**</td>
<td>.796***</td>
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<tr>
<td>Overall Mean</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.619**</td>
<td></td>
</tr>
</tbody>
</table>

Note. Years Edu = Years of Education; Var = Variance.

*p < .05  **p < .01  ***p < .001
As shown in Table 9, the mean difference for SE-variance values depending on cognitive functioning level was statistically significant ($F_{(1,22)} = 7.43, p = .012, \eta^2_p = .25$). The mean difference between Elderly no-CI ($M = 2,779, SD = 27,037$) and Elderly w-CI ($M = 27,347, SD = 34,900$) was 24,569 ($SE = 9,012, p = .012$).

Correlational Analyses

Significant correlations emerged from the different parameters of the study, as shown in Table 10. All significant Pearson product-moment correlations reported in this section are considered large by Cohen’s standards (Privitera, 2012). Reported significance values are based on two-tailed values.

**Spontaneous motor tempo.** The only noteworthy correlation of any parameter with SMT (in ms) occurred with the SMT variance. The correlation coefficient was .593 ($t_{(22)} = 3.45, p = .002$). The SMT variance also significantly correlated with the overall SE-variance from the stimulus conditions. The correlation coefficient was .464 ($t_{(22)} = 2.46, p = .022$). No other strong and significant correlations existed with the SMT or the variance of the SMT.

**Synchronization error.** Much like the correlation between the SMT and the SMT variance, the SE-mean for each stimulus condition correlated positively with the SE-variance for the same condition. For the SR condition, the correlation coefficient between the SE-mean and SE-variance was .540 ($t_{(22)} = 3.01, p = .006$). The correlation coefficient for the MR condition was .563 ($t_{(22)} = 3.20, p = .004$), and the coefficient for the SM condition was .446 ($t_{(22)} = 2.34, p = .029$). The overall SE-mean also significantly correlated with the overall SE-variance ($r = .619, t_{(22)} = 3.70, p = .001$).
The overall SE-mean significantly correlated with the SE-variance for the SR condition \((r = .502, t_{(22)} = 2.72, p = .012)\), the MR condition \((r = .544, t_{(22)} = 3.04, p = .006)\), and the SM condition \((r = .604, t_{(22)} = 3.56, p = .002)\). Oppositely, the overall SE-variance significantly correlated with the SE-mean of each stimulus condition (SR: \((r = .492, t_{(22)} = 2.65, p = .015)\); MR: \((r = .6219, t_{(22)} = 3.72, p = .001)\); SM: \((r = .585, t_{(22)} = 3.38, p = .003)\)).

All correlations between the SE-means for the three stimulus conditions and the other stimulus conditions’ SE-means were significant at \(p < .001\). Correlation coefficients ranged from .675 to .856. The correlations between the SE-variances of the three stimulus conditions were also significant, and the correlation coefficients ranged from .518 to .706 \((p < .05)\).

Strong correlations also emerged between each condition’s SE-mean and the overall SE-mean, as well as between each condition’s SE-variance and the overall SE-variance. As the values for each condition contributed to the overall values, there is a great amount of co-linearity, and this result is not unexpected.

**SLUMS scores.** The negative correlation coefficients between SLUMS scores and the overall SE-mean and SLUMS scores and the SE-means for all individual conditions were significant. They ranged in value from -.473 to -.577. The correlation coefficient between the overall SE-mean and SLUMS score was -.577 \((t_{(22)} = -3.33, p = .003)\). The correlation coefficients between SLUMS scores and the overall SE-variance and the SE-variance for all conditions were significant, as well. Correlation values ranges from -.537 to -.647. Between the overall SE-variance and SLUMS score, the correlation coefficient value was -.647 \((t_{(22)} = -3.98, p = .001)\).
Years of education. A strong, negative correlation emerged between participants’ years of education and the overall SE-mean. The correlation coefficient between the overall SE-mean and participants’ years education was -.660 ($t_{(22)} = -4.12, p < .001$). There were also significant negative correlations between years of education and the SE-means of the two stimulus conditions with music. The correlation coefficient for the MR condition was -.552 ($t_{(22)} = -3.11, p = .005$), and the correlation coefficient for the SM condition was -.738 ($t_{(22)} = -5.13, p < .001$).

The negative correlation coefficient between the overall SE-variance and years of education was also significant ($r = -.576$, $t_{(22)} = -3.31$, $p = .003$). However, for individual stimulus conditions, only the SE-variance for the MR condition significantly correlated with years of education ($r = -.626$, $t_{(22)} = -3.77$, $p = .001$).

Separate from the synchronization data and the SMT data, it is important to note that the correlation coefficient between years of education and SLUMS score was significant in this study ($r = .534$, $t_{(22)} = 2.96$, $p = .007$).

Regression

Because the SE-means for all three stimulus conditions correlated significantly and strongly with each other and the overall SE-mean, the only regression model developed for the SE-means addresses the overall SE-mean. Similar strong, significant correlations emerged between the SE-variances between all of the stimulus conditions and the overall SE-variance. Therefore, the only regression model for SE-variance also uses the overall SE-variance. Both models results from linear regression modeling.

Variables available for incorporation into the models included age, years of education, years of musical training, SMT, SMT variance, and SLUMS score. Though
originally considered for the regression analyses, the variables of age, SMT, and years of musical training had no significant correlations between them and any SE-mean or SE-variance values. Additionally, the related literature surrounding SMT and years of musical training, and their relationship to SE values, did not substantiate their inclusion in the models. Also, the relationship between age and SE values is unclear, as the related literature offers conflicting data and interpretations. Conversely, the remaining variables (i.e. years of education, SMT variance, and SLUMS score) significantly correlated with either SE-mean and/or SE-variance values in this study.

SE-mean. The estimated model for predicting the overall SE-mean includes two variables: years of education and SLUMS score. SMT variance did not have a significant correlation with overall SE-mean or the SE-mean of any stimulus condition, and, therefore, was not included in the model. The equation for the estimated regression model is:

Overall SE-mean = 443.92 – 12.42 * (Years of Education) – 8.73 * (SLUMS Score).

Table 11

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>SE B</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years of Education</td>
<td>-12.42</td>
<td>4.59</td>
<td>-2.70</td>
<td>.013</td>
</tr>
<tr>
<td>SLUMS Score</td>
<td>-8.73</td>
<td>4.98</td>
<td>-1.75</td>
<td>.094</td>
</tr>
</tbody>
</table>

The overall estimated model was statistically significant \( F_{(2,21)} = 10.80, p = .001 \). The multiple correlation coefficient was .71, indicating a strong relationship between the observed values and the predicted values of the regression model. The overall model suggests that years of education and SLUMS scores are good predictors of
SE-mean values. The model indicates that for each additional year of education past high school, the SE-mean will decrease by 12.42 ms, suggesting an increase in accuracy with increased education. The SE-mean also negatively correlated with SLUMS scores, indicating a decrease of 8.73 ms in the SE-mean for every additional point scored on the SLUMS Examination.

The estimated slope of years of education predicting overall SE-mean (after holding SLUMS score constant) was -12.42 with a standard error of 4.60, and is statistically significant ($t_{(21)} = -2.70, p = .013$). The estimated slope of SLUMS scores predicting overall SE-mean (after holding years of education constant) was -8.73 with a standard error of 4.98. This slope was not significant ($t_{(21)} = -1.75, p = .094$). Lastly, the intercept of 443.92 ($SE = 122.97$) was also statistically significant ($t_{(21)} = 3.61, p = .002$).

**SE-variance.** The estimated model for predicting the overall SE-variance includes three variables: years of education, SLUMS score, and SMT variance. The estimated regression model equation is:

Overall SE-variance = 129,236 – 2,441 * (Years of Education) – 4,221 * (SLUMS Score) + .361 * (SMT variance).

Table 12

<table>
<thead>
<tr>
<th>Overall SE-variance Regression Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Years of Education</td>
</tr>
<tr>
<td>SLUMS Score</td>
</tr>
<tr>
<td>SMT Variance</td>
</tr>
</tbody>
</table>

The overall model was statistically significant ($F_{(3,20)} = 11.92, p < .001$). The multiple correlation coefficient is .80, indicating a strong relationship between the
observed values and the predicted values of the regression. The overall model suggests that years of education, SLUMS scores, and SMT variance are good predictors of SE-variance values. Similar to SE-mean, years of education and SLUMS scores negatively correlated with the SE-variance, indicating more education and higher SLUMS scores decrease SE-variance. For each additional year of education, SE-variance decreases by 2,441, and for each additional point scored on the SLUMS, SE-variance decreases by 4,221. Conversely, SMT variance correlated positively with SE-variance, indicating that an increase of 1 in SMT variance predicts an increase of .361 in SE-variance.

The estimated slope of years of education predicting overall SE-variance (after holding SLUMS score and SMT variance constant) was -2,441 with a standard error of 1350, and was not statistically significant ($t_{(20)} = -1.81, p = .086$). The estimated slope of SLUMS scores predicting overall SE-variance (after holding years of education and SMT variance constant) was -4,221 with a standard error of 1,462. This slope was significant ($t_{(20)} = -2.89, p = .009$). The estimated slope of SMT variance predicting overall SE-variance (after holding years of education and SLUMS score constant) was .361 with a standard error of .125, and was also statistically significant ($t_{(20)} = 2.882, p = .009$). Lastly, the intercept of 129,237 ($SE = 36,238$) was also statistically significant ($t_{(20)} = 3.57, p = .002$).

Both regression models rely heavily on the cognitive proficiencies of the participants to predict the SE outcomes. The variable ‘years of education’ does reflect choices made by the participants to seek post-secondary education, and it is a variable under participants’ control. However, age and disease affect individuals despite choices they make and affect the variable indicative of current cognitive functioning level (i.e.
SLUMS score). Therefore, the overall cognitive components of the regression models represent the influences of both nature and nurture.

For the SE-variance regression model, the variance of SMT may be a good predictor because the SMT variance represents an individual’s natural timing errors and variance. Consequently, including the SMT variance into the model for SE-variance of the auditory rhythmic entrainment exercises increases prediction accuracy as well as accounts for non-synchronization differences that exist between participants. Both models are strong, statistically, but could be stronger with additional variables or other methods of regression not explored in this study.
Chapter 5

Discussion

The purpose of this study was to examine motor entrainment behaviors to
rhythmic auditory stimuli in older adults, aged 70 to 90 years. The study examined the
timing difference, or synchronization error (SE), between presented auditory stimuli and
the corresponding finger-taps. Derived from individual SE values, the dependent
variables included both the mean and the variance of the synchronization errors for each
participant. This data came from repeated measures based on finger tapping entrainment
to three different auditory stimulus conditions of varying stimulus complexity (Simple
Rhythm, Music and Rhythm, and Simple Music). In addition to comparing SE values for
different stimulus complexities, the study also compared differences in SE values
between elderly participants of two different cognitive functioning levels, the
independent variable. Participants included elderly individuals with cognitive
impairments (Elderly w-CI) (i.e., MCI and early AD) and elderly individuals without
cognitive impairments (Elderly no-CI).

Twenty-five elderly participants completed all study tasks. Participants
completed a short demographic questionnaire that included information about education,
occupation, musical training, gender, and age. The researcher administered the St. Louis
University Mental Status Examination (SLUMS) to each participant to determine
cognitive functioning. Then, each participant tapped their finger on the screen of an iPad
Mini© at their preferred tempo to determine their spontaneous motor tempo (SMT).
After determining SMT, the participant attempted to finger tap in synchrony, at their
SMT, to three types of auditory stimuli: Simple Rhythm (metronome beat), Simple Music (simple folk tune), and Music and Rhythm (folk tune with metronome overlaid).

Data analyses utilized data from 24 participants, and the analyses included two repeated measures 2 x 3 mixed-design ANOVAs, correlations between many variables, and two linear regressions. A one-way ANOVA compared the mean synchronization error (SE-mean) for the SMT and each of the three stimulus conditions. Another one-way ANOVA also compared the variance of the synchronization errors (SE-variance) for the SMT and each of the three stimulus conditions. Lastly, correlational analyses also compared cognitive functioning levels along with other demographic variables.

This chapter will discuss the interpretation of these analyses by examining the proposed research questions as well as significant findings not addressed by the original research questions. The chapter also lists possible study limitations and considers theoretical and practical implications of the study results. Finally, the chapter presents recommendations for future research before providing a summary and conclusions.

**Discussion of Research Questions**

The research questions in this study attempted to target differences in the accuracy of finger tapping to rhythmic auditory stimuli in older adults when comparing differing levels of stimulus complexity and differing levels of cognitive impairment. Three of the research questions inquired about the entrainment accuracy of finger tapping to the three different rhythmic auditory stimulus conditions in older adults with cognitive impairment (questions #1, #3, and #5). Three additional research questions (#2, #4, and #6) compared the entrainment accuracy between older adults with cognitive impairment and older adults without cognitive impairment for each of the three different auditory
stimulus conditions. The final research question (#7) addressed the differences amongst all the stimulus conditions for elderly individuals with cognitive impairments. Aside from the proposed research questions, important information about stimulus complexity and entrainment accuracy in older adults without cognitive impairments emerged, as well as overall differences and similarities between those with and without cognitive impairments.

**Comparison of entrainment accuracy in elderly individuals with and without cognitive impairments.** Two main findings arose from the comparison of entrainment accuracy for Elderly w-CI and Elderly no-CI based on the individual stimulus conditions. First, in terms of SE-mean values, there was no overall significant difference and no significant differences for the individual stimulus conditions between the Elderly w-CI and the Elderly no-CI groups. Therefore, in terms of SE-mean, the entrainment accuracy of older adults with cognitive impairment is similar to that of older adults without impairment, at least within the context of this study. Previous research demonstrates that older adults with cognitive impairments typically have slower reaction times to auditory stimuli compared to those without cognitive impairment (Müller et al., 1991). However, the lack of significant differences in SE-mean values in this study implies that the Elderly w-CI participants, like the Elderly no-CI participants, can generally anticipate or predict the upcoming beat based on previous beat information and do not rely on merely reacting to the sounds. This signifies general entrainment abilities remain intact for those with MCI or early AD.

A second finding, however, indicated a significant difference between the Elderly w-CI and the Elderly no-CI groups in a comparison based on SE-variance. Participants
in the Elderly w-CI group displayed significantly greater SE-variance compared to participants in the Elderly no-CI group, regardless of stimulus condition. Therefore, individuals with cognitive impairment are not as accurate in their entrainment accuracy of finger-tapping compared to individuals without cognitive impairment on the basis of SE-variance. The effect size of this finding was moderate to large ($\eta^2_p = .25$), indicating important practical significance for the difference between the two groups in regards to SE-variance.

The design and results of this study cannot determine the cause of the increased SE-variance for individuals with MCI or early AD. However, potential causes, as outlined in the related literature, may include problems with timing, motor control, auditory processing, and cognition (including attention and executive function). Problems with timing, in particular, are difficult to examine, as the lack of consensus in the literature on how internal timing mechanisms work complicates speculation on where the timing breakdown occurs. It is particularly difficult to hypothesize how timing mechanisms may cause increased SE-variance for individuals with cognitive impairments. Though the cerebellum and basal ganglia are integral to the perception of timing intervals and the production of rhythmic movements (Harrington et al., 1998; Rao et al., 2001), the basal ganglia do not appear to succumb to the effects of AD in the same manner as the cerebellum (Langlais et al., 1993; Sjöbeck & Englund, 2001). Additionally, atrophy of the cerebellum is progressive in AD, and the atrophy present during the MCI or early AD stages is minimal.

Individuals with AD demonstrate significant delays in both the processing of auditory information, as well as the accumulation of neurofibrillary tangles in the
associated auditory areas of the brain that drive behaviors related to auditory processing (Lewis et al., 1987; Swartz et al. 1992). Perhaps early accumulation of neurofibrillary tangles in the associated auditory areas impacts the accuracy of motor behaviors paired with auditory stimuli in individuals with MCI or early AD, but significant accumulation of tangles do not appear until well into the disease. Even more than the auditory areas of the brain, the motor centers in the brain do not exhibit significant accumulations of beta-amyloid plaques and neurofibrillary tangles until well into the course of AD (Suvá et al., 1999), and this study cannot determine how these accumulations affect entrainment behaviors.

However, the hippocampus is one of the first areas affected by AD, and it plays a very important role in modifying behaviors based on sensory feedback (Reid & Evans, 2013). Therefore, the hippocampus (along with other areas of the entorhinal cortex) may be key in explaining the differences in SE-variances between older adults with and without cognitive impairment. The hippocampus is one of the only elements of the system that controls synchronization of motor movements to auditory stimuli that shows clear changes during MCI or early AD. Overall, teasing out and confirming the exact cause or causes of the differences in SE-variance will take significant amounts of further research as the mechanisms for synchronizing motor movements to rhythmic auditory stimuli are intricate and numerous.

**Summary of entrainment accuracy in elderly individuals with cognitive impairments.** Combining the SE-mean and SE-variance results, a picture emerges of entrainment accuracy for elderly individuals with cognitive impairments, especially in comparison to elderly individuals without cognitive impairments. Comparing the timing
of finger-taps relative to auditory stimuli, individuals with cognitive impairments display no greater average time between the two events but exhibit much more variance in attempting to match their finger-tapping to the beat of the stimulus. This is very similar to the archetype that emerges when comparing finger-tapping entrainment accuracy between young adults and older adults (Thaut et al., 1997). At moderate tempos, older adults exhibit greater SE-variance values than the younger adults, but there is no difference in SE-mean values. Therefore, the effects of cognitive impairment on entrainment accuracy emulate and amplify the effects of age by further increasing SE-variance while not affecting SE-mean.

Comparison of entrainment accuracy between differing levels of auditory stimulus complexity in elderly individuals. After exploring the entrainment accuracy of older individuals with MCI or early AD and comparing the results to older adults without cognitive impairments based on the first six research questions, the final research question addressed differences in entrainment accuracy amongst the stimulus conditions for elderly individuals with cognitive impairments. There were no significant differences between stimulus conditions for SE-variance values for all participants, including the Elderly w-CI group. Conversely, statistical analyses did indicate significant differences amongst the three auditory stimulus conditions in terms of SE-means. The difference in SE-means emerged for all participants, not just the Elderly w-CI group. Thus, all older adults experienced a main effect of stimulus complexity for SE-mean values, and the effect is moderate ($\eta_p^2 = .23$).

For all participants, the Music and Rhythm condition had the smallest SE-mean value. The next smallest SE-mean value occurred in the Simple Music condition, with
the largest SE-mean value resulting from the Simple Rhythm condition. The Music and Rhythm condition significantly differed from the other two conditions, but there was no significant difference between the Simple Rhythm and the Simple Music conditions. Therefore, the condition with the greatest stimulus complexity, Music and Rhythm, resulted in significantly smaller SE-mean values.

The significantly smaller SE-mean values from the Music and Rhythm condition (in comparison to the Simple Rhythm and Simple Music conditions) implies that combining musical and metronomic auditory information results in a greater anticipation of the beat. Anticipation of the beat, represented by a negative SE value, is typical, and is possibly due to the time it takes for sensory information to travel from touch receptors in the skin to the brain (Molinari et al., 2005; Thaut, Tian, et al., 1998). However, due to the timing delay introduced to the data by the technology in the current study, it is impossible to confirm that the results of this study mimic previous findings. However, if it were assumed that the results from this study would parallel previous studies after accounting for the technology delay, the Music and Rhythm stimulus condition creates an anticipatory effect that exceeds typical negative SE values.

Several factors may contribute to anticipation of the beat. First, individuals typically compare their expectations to actual events as they happen and update their future expectations based on their assessment of the accuracy of their initial expectations. In the context of this study, that means participants had to compare the expected beat with the actual beat and their motor response to assess their entrainment accuracy. The participants’ assessment of accuracy would then inform their next motor action based on their assessment of if they were ahead of or behind the beat. However, the increased
amount of auditory information in the Music and Rhythm condition may interfere with or overload this expectation and assessment process. If unable to carry out this process, individuals may rely more on generalized expectations without assessing and updating expectations. In a similar fashion, individuals with AD rely more on their expectations of future cues than purely reacting to them in reaction timing tests (Müller et al., 1991).

Additionally, perceived small variances in timing resulting from the combination of music and metronome may have led to increased SE-variance. Although the metronome and MIDI sequenced music should be precisely aligned as a result of the software’s design, any percussive sound has unique attack and decay sonic profiles, including a sampled metronome sound (as used in this study). The synthesized keyboard MIDI patch has its unique sound characteristics, as well. Therefore, participants may have perceived a difference in the alignment of beats between the music and metronome. Also, precise, computerized alignments of percussive beats to the music may be in contrast to musical expectations for melodic folk music where musical phrasing may seem contradictory to the precise and mechanical application of beats. No participants commented on a misalignment or said the two did not match, but a few participants did ask if they were to follow the beat or the music, especially when the Music and Rhythm condition was the last condition presented due to the randomization of the condition order.

It is important to note that the main effect of stimulus complexity emerged from all participants and there was no significant main effect of cognitive functioning level on SE-variance or any interaction effects between stimulus conditions and cognitive functioning level. Although the research questions did not directly address stimulus
complexity for older adults without cognitive impairments, this finding is an important contribution to the literature for all older adults. The finding that the auditory stimulus condition with the greatest level of stimulus complexity created an anticipatory entrainment effect suggests the need for future research on the complexity of auditory stimuli for older adults, as stimulus complexity may be a factor in the effectiveness of music therapy interventions. Research should address how higher levels of stimulus complexity may create different reactions and explore an optimum level of stimulus complexity for different types of music therapy interventions with older adults.

**Effects of cognitive functioning on entrainment accuracy.** Because the increase in SE-variance occurred in the group with cognitive impairments and the highest level of stimulus complexity appeared to create an anticipatory effect, cognition may have a significant impact on auditory rhythmic motor entrainment. This concept has two differing, and sometimes conflicting, lines of research. Research demonstrates that motor entrainment tasks that require increased demand on attention, executive function, and computational skills cause increases in motor synchronization variability (Hausdorff et al., 2005; Krampe et al., 2005; Turgeon et al., 2011). However, research supporting the technique of Rhythmic Auditory Stimulation relies on the direct influence of auditory input on central pattern generators in the spinal cord, bypassing cognition on the initial level (Thaut, 2005; Thaut et al., 1999).

A possible resolution to these two conflicting ideas may lie in a model of motor synchronization to rhythmic auditory stimuli that involves a multi-layered approach by the central nervous system in typical individuals. In this model, proposed by the researcher, some auditory information immediately bypasses cognitive processing and
directly influences central pattern generators in the spinal cord during all entrainment
tasks to rhythmic auditory stimuli. If the entrainment task is simple (i.e. finger-tapping or
walking), the stimulus complexity of the rhythmic auditory stimulus is simple (i.e. simple
metronome), and the individual’s cognitive functioning is typical, the central nervous
system allows the auditory stimuli to continually drive the simple motor behaviors
through its influence on spinal neurons. However, if the task and/or stimulus complexity
increases, or the individual has cognitive impairments, the central nervous system
actively engages the higher order areas of the central nervous system to perform the
motor entrainment behaviors. If the auditory stimulus has a high level of stimulus
complexity, as with the Music and Rhythm condition in this study, the additional auditory
information requires processing by the auditory areas in the brain, and, therefore, the
initial means of bypassing cognitive processing is no longer valid. If the task includes
more complex elements, such as performing a verbal task while walking or performing
two different motor actions simultaneously (i.e. dual tasks), the simple means of
entrainment via spinal cord influence is interrupted. Lastly, if the individual has
cognitive impairments, such as AD, and relies on compensatory behaviors and/or cortical
reorganization to perform any motor or sensory processing task, the central nervous
system does not function in a typical manner, and even basic motor entrainment to
auditory stimuli relies on alternate means for completion.

While this basic model of a multi-level approach by the central nervous system
fits with the existing body of literature and the results of this study, a comprehensive
model merging the different outcomes from entrainment research is not a well-examined
area. Existing research explores the simple process of auditory stimuli’s influence on
central pattern generators and the overall changes in synchronization behaviors to differing types of auditory stimuli, but little or no research attempts to merge these two areas to form a unified theory.

Lastly, although the primary analyses and research questions did not include additional demographic variables such as age, gender, and years of education, many of their correlations to SE values proved both statistically significant and large. Significant correlations also arose between SE values and individual SLUMS scores. Both SLUMS scores and years of (post-secondary) education significantly correlated in a negative direction with the overall SE-mean. Significant negative correlations emerged between these two independent variables and the overall SE-variance. Though it is unclear if the relationship between cognitive abilities (represented by SLUMS scores and years of education) and entrainment accuracy is causal or circumstantial, cognitive abilities may, in fact, contribute to entrainment accuracy via attention and executive function skills, such as tracking and comparing. Additionally, individuals seeking education beyond high school, and especially those seeking graduate degrees, may have inherent qualities that heighten attention to detail and motivate them towards higher levels of accuracy and precision.

From both theoretical and statistical perspectives, SLUMS scores and years of education were logical choices for inclusion in the regression models for overall SE-mean and overall SE-variance. In addition to these two variables, an interesting but important element of the regression model for overall SE-variance was the variance of the SMT. Much like individuals having different SMTs, individuals may also have differing natural levels of timing variance in finger tapping based on the regular use and quality of fine
motor skills, former musical training, and/or general attentional abilities. Since the correlation between SMT variance and overall SE-variance was large ($r = .593$) and significant ($p = .002$), SMT variance may be a good predictor of SE-variance by accounting for individuals’ natural variances in timing. Therefore, the researcher included SMT variance in the regression model for overall SE-variance. Though both regression models are moderately strong, future research should investigate additional variables to improve the prediction capabilities of entrainment accuracy.

**Study Limitations**

Several elements within the study limit the generalization of the study’s results and warrant future research before using the study’s results to guide clinical practice. Limitations include sample size, the sample’s partially inaccurate representation of the older US population, and environmental inconsistencies. An additional limitation involves the timing delay introduced by the data collection method that does not allow direct comparison to other studies.

The first limitation of this study was the small sample size. Although this study produced significant results with some moderate effect sizes, a greater number of participants would increase the ability to generalize to the US population. Additionally, more participants in equally sized groups would ensure reliable results with, perhaps, greater effect sizes and/or power. The high correlations among the repeated measures do allow for greater power with fewer participants, but the study should still be repeated with greater numbers.

The study sample also differs from the general population on several demographic measures. First, due to recruiting through a lifelong learning center and the wellness
center at a large private university, participants had much higher levels of education than the general population. Only one participant in 24 did not have education beyond high school. Therefore, the sample was not a true representation of the population in terms of education. Additionally, women were overrepresented in this study compared to the US population. Though analyses in this study, as well as some other studies, did not find an effect of gender on synchronization accuracy, significant differences in life expectancies and disease acquisition between genders signifies a need to ensure there are no differences between the genders, as a difference would have a significant impact on designing treatments using auditory rhythmic entrainment protocols. Lastly, although the researcher did not formally collect and analyze data on participants’ ethnicity, the ethnicity of the sample was overwhelmingly Caucasian compared to United States’ averages.

The average SMTs of participants in this study were faster than those found in previous studies by approximately 10 beats per minute, or up to 100 ms. This may be a result of inconsistencies in the data collection circumstances or just an artifact of this particular sample. Participants may have been influenced by the speech rate or energy level of the researcher, and the inclusion of more than one researcher would help mitigate any of these effects. Additionally, the task of completing the SLUMS prior to completing the auditory rhythmic entrainment exercises may have increased stress or energy levels and influenced SMT values. However, it was necessary to complete the SLUMS first so that participants scoring below the cognitive threshold did not complete the rest of the study tasks.
Data collection took place in homes, a skilled nursing facility, a university classroom, a small office, and a public atrium. These differing data collection environments present a significant limitation to all variables in the study, including SMT. Some participants took part in the study after a two-hour academic class or after watching an hour of TV, while other participants had come straight from a cardiovascular workout or yoga. With the variable data collection sites, participants’ experiences differed in terms of background noise and activity, ability to concentrate on cognitive testing, and public versus private interactions. Consistent environmental conditions would standardize the results and increase their application to the general population.

Lastly, the iPad© and software designed for the study introduced a timing delay whose exact value is unknown, albeit consistent, to the recorded finger-tap times. Although this delay did not affect comparison between participants within this study and the different stimulus conditions, it does limit its comparison to other studies, especially in terms of SE-mean values. Therefore, this study is limited in adding to the literature unless it is replicated using the exact same software and hardware. This limitation affects the comparison of SE-variance from this study to other studies less than comparisons of SE-mean values between studies, as the SE-variance calculation does not depend on the absolute timing of the auditory stimulus and the finger-tap. However, comparison to other studies should be performed with caution.

Theoretical Implications

With a significant difference emerging in SE-variance between elderly individuals with and without cognitive impairments, cognitive impairments may, in fact, affect the durability of entrainment mechanisms. Cognitive impairments further the effects of
aging on variance, which confirms prior research (Duchek et al., 1994) and extends the premise of a breakdown in the consistency of synchronization from mere aging to the arena of cognitive decline. Further research must confirm these preliminary findings.

Significant findings on SE-mean differences between types of rhythmic auditory stimuli also have implications for the ability of all older adults to entrain motor behaviors to auditory stimuli. Increased stimulus complexity, especially in the form of music and metronome combined, creates more of an anticipatory than reactionary motor response. Previous findings indicate that adding more information to an auditory stimulus, such as providing simple music compared to just a simple beat, increases entrainment accuracy (Thaut et al., 1997). However, the present study showed no differences between the Simple Rhythm and Simple Music conditions. Additionally, the significant differences between the Music and Rhythm condition and the other two conditions demonstrates, an upper echelon to the amount of additional information that is helpful for synchronizing movements to rhythmic auditory stimuli may exist.

**Practical Implications**

The finding from this study that older adults with MCI or early AD produce significantly greater variance during rhythmic motor entrainment to auditory stimuli may provide evidence that music therapy techniques relying on auditory rhythmic entrainment may not be appropriate for individuals with cognitive impairments that are due to a neurocognitive disorder. This finding reflects the results of earlier studies that showed Rhythmic Auditory Stimulation did not improve gait parameters for those with AD (Clair & O’Konski, 2006; Nishikawa, 2009). However, further research should investigate if continual use of rhythmic motor entrainment to auditory stimuli throughout the course of
cognitive decline can reduce variance in motor responses and improve the effectiveness of music therapy protocols that rely on auditory rhythmic entrainment.

Additionally, although this study focused on individuals with cognitive impairments and addressed deficits that occur during the onset and progression of AD, results from the study indicate that there may be such a thing as “too much information” for older adults without cognitive impairments. Combining simple folk music and a metronomic beat increased motor response timing anticipation compared to music or metronome alone in adults not exhibiting cognitive impairments. Therefore, music therapists using techniques that rely on precise timing, such as Rhythmic Auditory Stimulation and, to a lesser extent, Patterned Sensory Enchantment and Therapeutic Instrumental Music Performance, with cognitively typical older adults should consider limiting the use of auditory rhythmic stimuli to either simple music or simple metronome. Combining the two types of stimuli may overload cognitive processing abilities for older adults or introduce perceived timing differences between the two that cause an increase in timing variance.

**Recommendations for Future Research**

Future research addressing auditory rhythmic entrainment and cognitive functioning levels should first address the limitations of this study. This includes repeating this study with a larger sample size and obtaining a sample that more directly reflects the overall population, especially in terms of ethnicity and education level. Data collection environments should also be more standardized and, perhaps, data collection should only take place in one location.
Additional future research should also expand upon the current study and investigate other factors and their influence on auditory rhythmic entrainment in the elderly. Continued research in this area should expand the parameters for cognitive impairment levels and range from cognitively typical to those with full dementia and not just mild cognitive impairments. This would create a clearer picture of the effects of cognitive decline on entrainment abilities and provide a stronger evidence base for clinical applications. Additional research between cognition and entrainment accuracy should also investigate a possible connection between attention and entrainment to see if attention is a significant factor that affects entrainment accuracy. Also, since attention may be an oscillatory process, future research should study the use of entrainment protocols to address deficits in attention.

Other directions for future research include both long-term studies as well as the investigation of other ways music therapy may assist in the maintenance of skills and independence for those with AD. Long-term studies should examine if continual ‘practice’ of auditory rhythmic entrainment during the progression of MCI to AD can improve entrainment accuracy (specifically, variance), or at least slow the decline in accuracy. In a similar fashion, long-term studies should also investigate if Rhythmic Auditory Stimulation can slow the deterioration of walking abilities, even if RAS cannot improve gait parameters in those with AD. Lastly, the concept of maintaining independence longer into the progression of AD is important, and future research should inquire about alternate ways the inherent properties of music and/or the use of music therapy may aid in that objective.
Summary and Conclusions

The purpose of this study was to compare motor entrainment accuracy to different rhythmic auditory stimuli in older adults with and without cognitive impairments (MCI and early AD). Twenty five participants between the ages of 70 and 90 filled out a demographic form, took the St. Louis University Mental Status Examination, and tapped a finger to three different rhythmic auditory stimulus conditions: Simple Rhythm, Music and Rhythm, and Simple Music. Two mixed-design ANOVAs, correlation analyses, and two regression models analyzed the SE values in terms of SE-mean and SE-variance.

Analyses revealed findings of both statistical and practical significance. SE-variance values reflected the presence of cognitive impairments but the mean timing differences between an auditory stimulus and its paired motor response did not. In addition, all older adults responded to the highest level of auditory stimulus complexity with smaller SE-mean values, implying an anticipation of the beat during the stimulus condition with the highest level of stimulus complexity. Lastly, significant correlation and regression analyses indicated the importance of cognitive abilities in predicting entrainment accuracy. Increases in years of education and scores on the cognitive exam (i.e. SLUMS) significantly correlated with decreases in SE-mean and SE-variance values.

Despite the limitations of this study, the results provide an important basis for understanding the effect of cognitive decline (due to a neurocognitive disorder) on entrainment abilities. The presence of mild cognitive impairments does affect entrainment abilities in terms of variance, but the possible influence of practice over time and the exact deficits that cause the decrease in accuracy require further investigation. The results of the study also demonstrate an influence of stimulus complexity on
entrainment accuracy relative to SE-mean values for all older adults and suggest there may be an upper limit to the amount of information in rhythmic auditory stimuli that assists in improving entrainment accuracy. In conclusion, both stimulus complexity and cognitive impairment affect the accuracy of rhythmic motor entrainment to auditory stimuli and should be taken into consideration during the use of techniques requiring motor entrainment with older adults.
References


Appendix A

Recruiting Flyer

- Study #: 2014790   Approval Date: 10/10/2014

Seeking **OLDER ADULTS** (with and without minor cognitive/memory impairments) to finger-tap in a study on rhythmic-motor responses to sound

**COME TAP WITH ME!**

**Participant Requirements:**
- Between 70 and 90 years old - Fluent in English -
- Typically Functioning OR Experiencing Minor Cognitive/Memory Impairments -
- Free of Symptoms of Parkinson’s Disease - Adequate Hearing (Hearing Aids OK) -

**Study Location:** This study is available as an in-home visit, at the Frost School of Music (University of Miami), or at select community locations in Miami.

**Time Requirement:** 30 minutes, 1 meeting

**For more Information please contact:**
Emily Duglas Lambert, MT-BC
- Email: emilylambert@umiami.edu
- Phone (call or text): (612) 327-4939

This study is in partial fulfillment of the requirements for a Master’s degree in Music Therapy from the Frost School of Music at the University of Miami.
Appendix B

Saint Louis University Mental Status Examination Form

VAMC
SLUMS EXAMINATION
Questions about this assessment tool? E-mail aging@slu.edu

Name ____________________________________________ Age __________________________

Is the patient alert? _____________________________ Level of education ________________

1. What day of the week is it?
2. What is the year?
3. What state are we in?
4. Please remember these five objects. I will ask you what they are later.
   Apple  Pen  Tie  House  Car

5. You have $100 and you go to the store and buy a dozen apples for $3 and a tricycle for $20.
   1. How much did you spend?
   2. How much do you have left?

6. Please name as many animals as you can in one minute.
   0 0-4 animals  1 5-9 animals  2 10-14 animals  3 15+ animals

7. What were the five objects I asked you to remember? I point for each one correct.

8. I am going to give you a series of numbers and I would like you to give them to me
   backwards. For example, if I say 42, you would say 24.
   0 87  1 648  2 8537

9. This is a clock face. Please put in the hour markers and the time at
ten minutes to eleven o’clock.
   1 Hour markers okay
   2 Time correct

10. Please place an X in the triangle.

Which of the above figures is largest?

11. I am going to tell you a story. Please listen carefully because afterwards, I’m going to ask
    you some questions about it.
    Jill was a very successful stockbroker. She made a lot of money on the stock market. She then
    met Jack, a devastatingly handsome man. She married him and had three children. They lived
    in Chicago. She then stopped work and stayed at home to bring up her children. When they were
    teenagers, she went back to work. She and Jack lived happily ever after.
    1 What was the female’s name?
    2 What work did she do?
    3 When did she go back to work?
    4 What state did she live in?

TOTAL SCORE

<table>
<thead>
<tr>
<th>SCORING</th>
<th>Less than High School Education</th>
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<tr>
<td>21-26</td>
<td>Mild Neurocognitive Disorder</td>
</tr>
<tr>
<td>1-20</td>
<td>Dementia</td>
</tr>
<tr>
<td>1-19</td>
<td></td>
</tr>
</tbody>
</table>

CLINICIAN’S SIGNATURE ____________________________ DATE ____________________________ TIME ____________________________

SH Tariq, N Tunosa, JT Chibnall, HM Perry III, and JE Morley. The Saint Louis University Mental Status
(SLUMS) Examination for detecting mild cognitive impairment and dementia is more sensitive than the Mini-
Appendix C

Participant Information Form

Participant Information Form

Participant: 
Date: 

Basic Information

Age: __________
Gender (circle): Male Female
What hand do you write with (circle one): Left Hand Right Hand

Education/Occupation Information

What is your highest level of education completed (circle):
Some High School High School Diploma/GED
Some College/Trade School Bachelor’s Degree
Master’s Degree Doctoral Degree

Current Occupation(s) (if applicable): ____________________________
Previous Occupation(s) (if applicable): ____________________________

Musical Background Information

How many years of formal music training have you had, if any: __________
What instruments do you/did you play, if any, and do you still play (circle Y/N):
________________________ Y / N __________________________ Y / N
________________________ Y / N __________________________ Y / N

Do you currently perform solo music or take part in an ensemble: __________
If yes, briefly explain/list: _______________________________________

Voluntary Diagnosis Information

Have you received a formal diagnosis of Mild Cognitive Impairment or
Early/Possible Alzheimer’s disease (Y/N): ______
If yes, what is your diagnosis: ________________
Approximate date of diagnosis: ________________
Appendix D

Music for *Simple Music* (SM) and *Music and Rhythm* (MR) Conditions
Appendix E

Informed Consent

UNIVERSITY OF MIAMI
CONSENT TO PARTICIPATE IN A RESEARCH STUDY
“The Effect of Auditory Stimulus Complexity on Rhythmic Motor Entrainment in Elderly Persons with Cognitive Impairment”

PURPOSE OF STUDY:
You are being asked to participate in a research study. The purpose of this study is to study motor responses to sound in elderly individuals.

PROCEDURES:
If you choose to participate, it will take about 30 minutes. There are 3 steps to the study:

Step 1: Fill out an information form – about 5 minutes.
You will be asked to provide basic information about yourself on a short information form.

Step 2: Take a memory quiz – about 10 minutes.
You will be asked several questions to test your memory. (Questions are from the St. Louis University Mental Status Examination). You will answer most questions verbally but will have to complete a few questions using a pencil and paper.

Step 3: Tap your finger to different sounds – about 10 minutes.
You will be asked to tap your index finger on an iPad screen. The researcher will model this for you. You will have to tap 4 times, either in silence or to sound, each lasting for 30-60 seconds.

RISKS AND/OR DISCOMFORTS:
You may experience minor discomfort or frustration while answering some of the questions on the memory quiz.

BENEFITS:
There is no direct benefit to you from your participation in this study.

CONFIDENTIALITY:
The investigators and their assistants will consider your records confidential to the extent permitted by law. The U.S. Department of Health and Human Services (DHHS) may request to review and obtain copies of your records. Your records may also be reviewed for audit purposes by authorized University or other agents who will be bound by the same provisions of confidentiality. Identification codes will be used in place of
names for all electronic files, and all electronic files will be stored on password-
protected devices.

**COMPENSATION:**
You will not be compensated for your participation in this study.

**RIGHT TO DECLINE OR WITHDRAW:**
Your participation is voluntary. You may choose not to participate in the study, and you may leave the study at any time. The researchers may also remove you from the study at any time if they feel it is in your best interest.

**CONTACT INFORMATION:**
1. If you have any questions about the study, please contact the co-
investigator, Emily Dugas Lambert, MT-BC. Ms. Lambert may be contacted at
(612) 327-4939 or emilylambert@umiami.edu. The principal investigator of this
study is Teresa Lesiuk, Ph.D., MT-BC. Dr. Teresa Lesiuk may be contacted at
the University of Miami at (305) 284-3650.

2. If you have any questions about your rights as a research participant, you may contact the Human Subjects Research Office at the University of Miami at (305) 243-3195 or acoltes@umiami.edu.

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

_________________________________________  ____________________
Signature of Participant                        Date

_________________________________________
Printed Name of Participant

_________________________________________  ____________________
Signature of Person Obtaining Consent          Date