THESIS

THE USE OF AUDITORY, TACTILE, AND SIMULTANEOUS AUDIO-TACTILE STIMULATION TO ENHANCE GAIT TRAINING FOR CHILDREN WITH DISABILITIES

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Music

Colorado State University

Fort Collins, Colorado

Summer 2013

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ABSTRACT

THE USE OF AUDITORY, TACTILE, AND SIMULTANEOUS AUDIO-TACTILE STIMULATION TO ENHANCE GAIT TRAINING FOR CHILDREN WITH DISABILITIES

Given that the prevalence of developmental disabilities is rising in U.S. children and acknowledging that these children show lower gross motor outcomes than their typically developing peers, it is necessary to investigate potential treatments that enhance children's physical functioning. The present study examined the effects of external auditory, tactile, and audio-tactile stimuli on gait parameters in children with developmental disabilities. Participants were asked to walk a 10 meter walkway while being exposed to these three different stimuli in a randomized order. A pretest served to gather cadence, which was then programed into the external rhythmic sources. Gait parameters including cadence, velocity, and stride length were gathered during each walk by two raters. Each participant served as their own control and received all experimental stimuli conditions. A cross analysis of the raw data showed a tendency towards auditory rhythmic cueing as the most likely stimuli to show synchronization; however, no evidence was found to support that children with developmental disabilities can entrain to an external rhythmic stimuli. Although changes were observed in gait parameters, no clear evidence was found to support that children with developmental disabilities show benefits in gait functioning from the addition of external rhythmic facilitation. Suggestions for future research are discussed.

ACKNOWLEDGMENTS

Dr. Blythe LaGasse: Words cannot express how grateful I am for your supervision and guidance throughout this project. I know I am a better therapist because of you. Thank you!

Dr. William Davis: Thank you for your suggestions and encouragement through this project. Thank you for taking time out of your very busy schedule to consider my questions and review my many, many drafts. Thank you!

Dr. Ray Browning: You certainly challenged me to think scientifically throughout this project and I am a better therapist for it. Thank you for your detailed suggestions and revisions through this process. Many Thanks!

Adam Veteto: To my husband, you are the bread to my life and the life to my bread and I love you for all that you are and the strength you encourage in me each day! Thank you for the smiles!

Melinda Whiteman: To my mother who taught me never to give up and who has encouraged me every step of this project with famous words of wisdom "it will all get done, don't stress." I love you and I thank you.

Vince Whiteman: To my daddy, you have taught me so much about life and loving life even when you have to work hard at it. For always reminding me that life is all about what you enjoy and about enjoying what you do! I love you!

Kayla Whiteman: To my sister who always loves me even when I seem too busy to call and who always reminds me that things will get done in their time and in God's time.

Rev. Steve: I thank you for the encouragement and the sincere thoughtfulness you bring to every conversation we have. I thank you!

Family and Friends: To all of you, you know exactly when to send a thoughtful card, text, or message to encourage me. For your friendship I thank you!

To my GOD: You are what gives me strength to continue when all feels worthless. You are my strength and my ever constant companion and to YOU I give my heart and my life to Your will!

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CHAPTER ONE

Introduction

Statement of the Problem

According to a recent publication supported by the Center for Disease Control (CDC) and the Health Resources and Services Administration (HRSA) the prevalence of developmental disabilities in U. S. children ages three to seventeen years was 13.87% (Boyle et al., 2011). According to the DSM-IV, developmental disabilities include, but are not limited to intellectual disabilities, learning disorders, motor skill disorders, communication disorders, pervasive developmental disorders including Autism Spectrum Disorder, attention-deficit, disruptive behavior disorders, and many others. Between 1997 and 2008, developmental disabilities had increased 17.1% over the last twelve years, which accounts for an increase of roughly 1.8 million children. With current evidence that developmental disabilities are not only present but rising in our society, it is essential that we take action to increase the level of independence for these children.

Children with developmental disabilities show a variety of cognitive, emotional, and physical deficits including lower gross motor outcomes than those of their typically developing peers (Westendorp et al., 2011). Such motor deficits have been correlated with a disruption in ascending sensory and descending motor pathways leading to an array of motor disabilities in the prime developmental years (Diamond, 2000; Hoon et al., 2009). According to this disruption in neuronal areas linked between sensory input and motor output, a variety of motor deficits can be present in children with developmental and intellectual disabilities affecting their motor learning and performance. A significant relationship between motor development and cognitive functioning exists (Burns, O’Callaghan, McDonnel, & Rogers, 2004; Diamond, 2000;

Westendorp et al., 2011; Woodard & Surburg, 2001), especially for those children exhibiting high-risk characteristics (Piek, Dawson, Smith, & Gasson, 2008). Researchers suggest that children identified as being at risk of developing learning disabilities could benefit from a timely and targeted motor intervention (Vuijk et al., 20111).

Common gross motor interventions used with this population include physical therapy and orthopedic surgical procedures, both of which can be quite invasive and are often coupled with orthotic management to correct musculoskeletal abnormalities and enhance locomotion (Perry & Burnfield, 2010). Although these interventions show benefits for some populations, due to the vast number of diagnoses and symptoms under developmental disabilities, most children need a combination of several different therapeutic interventions to fully target their gross motor needs, especially those with sensory deficits (Hoon et al., 2009). Some researchers suggest that special education and rehabilitation programs could benefit from providing sensory integration therapy with motor training (Elbasan, Kayihan, & Duzgun, 2012). These researchers found increased independence in daily living activities for these children when provided opportunities for sensory integration.

Rhythmic facilitation is a non-invasive, gait rehabilitation technique that is motivational, affordable, and accessible to this population. Rhythmic facilitation, specifically Rhythmic Auditory Stimulation (RAS) has been shown to improve gait in some rehabilitation and habilitation populations (Fernandez del Olmo & Cudeiro, 2003; Jensen, 2009; Kwak, 2007; Thaut & McIntosh, 2006; Thaut et al., 1993; Thaut et al., 1997). Though the research available for using rhythmic facilitation with children with disabilities to improve gait is limited (Jensen, 2009; Kwak, 2007), there is sufficient evidence that timing is important in motor learning and execution, and may show benefits when children are learning motor behaviors (Halsband & Freund, 1993).

Thaut et al. (2009) remarked that “Rhythmicity plays an important role in learning, development, and performance of cognitive and motor functions” (p. 44). Researchers investigating motor learning have also emphasized the importance of timing in motor control and subsequent motor learning behaviors (Halsband & Freund, 1993). The timing component of music, namely rhythm, characterizes a metric quality that is intrinsic and not learned (Kenyon & Thaut, 2003; Marieb, 1989; Thaut, 2005). This intrinsic rhythm is characteristic of standard gait, as well as many other motor performance characteristics used in daily life (Marieb, 1989; Thaut et al., 2009). Thaut (2005) further explains that rhythm is what binds sound patterns into structural organization and the coupling or synchronization of the rhythmic cue and the rhythmic motor response are achieved almost instantaneously. This synchronization of auditory input and motor output has been extensively studied and a link identified in the spinal cord, specifically the reticulospinal pathway, as being important for this interaction (Miller et al., 1996; Paltsev & Elner, 1967; Rossingol & Melvill Jones, 1976; Thaut, 2005). Other researchers have also found a direct interaction between auditory input and motor output observable through increased activation of cortical regions (Bengtsson et al., 2009; McIntosh, Brown, Rice, & Thaut, 1997). .

Researchers have provided ample evidence of this synchronization effect in rehabilitative outcomes (Hurt et al., 1998; Kadivar et al., 2011; McIntosh et al., 1997; Thaut et al., 1996; Thaut et al., 1999); however, no conclusive evidence has been published using rhythmic auditory facilitation for motor outcomes in children, specifically children with a variety of developmental disabilities. Two studies have explored the use of RAS with children with cerebral palsy (CP), and found that these children do synchronize their motor responses to external auditory stimuli and show some improved gait parameters as a result, however more evidence is needed to generalize these outcomes (Jensen, 2009; Kwak, 2007).

Researchers suggest that children with developmental disabilities show deficits in ascending sensory and descending motor pathways, thus highlighting the importance of the sensorimotor cortex (Hoon et al., 2009). In considering these sensory and motor dysfunctions, researchers suggest that increased excitability of the sensorimotor cortex may enhance outcomes with this population, specifically when integrating both auditory and tactile modalities in a multisensory method (Riquelme & Montoya, 2010). Other researchers report the importance of tactile and proprioceptive integration as playing an important role in gait rehabilitation programs, specifically with children showing coordination disorders (Elbasan, Kayihan, & Duzgun, 2012). Further studies recognized that while there are different neural mechanisms underlying auditory and tactile processing, many common brain regions exist along the sensory motor pathway for these two stimuli including the somatosensory, premotor, and insular regions of the brain (Hegner, Lee, Grodd, & Braun, 2010). This suggests that simultaneous integration of auditory and tactile stimuli may have an excitatory effect on motor output (Brochard et al., 2008; Elliot, Wing, & Welchman, 2010; Foxe et al., 2002; Gillmeister & Eimer, 2007; Ro, Hsu, Yasar, Elmore, & Beauchamp, 2009; Wilson, Braida, & Reed, 2010).

Significance of the Study

The above review highlights an increase in the prevalence of children with developmental disabilities in the U.S., many who are affected by motor deficits that prevent them from living fully independent lives. Current therapeutic interventions used with this population to improve gait parameters are often invasive and not always effective with this population. By acknowledging that children with developmental disabilities may have deficits in sensory processing it is reasonable to respond with sensory integration strategies. Rhythmic auditory facilitation utilizes specific cortical pathways between auditory and motor regions to target motor output in a non-invasive manner. While this technique has shown benefits with rehabilitation populations and shows sufficient timing characteristics effective in motor learning, no conclusive benefits have been found with children with a variety of developmental disabilities. Though there is evidence that this population can entrain to an external stimulus, the standard use of auditory facilitation has shown inconclusive results. As a result of further analysis, current research suggests that this population may show greater benefits from a multi-sensory approach to rhythmic facilitation. It is the hope of the researcher that the current study will provide preliminary evidence into a modified rhythmic facilitation method using multi-sensory stimuli to improve gait performance in children with developmental disabilities.

Research Questions

The present study aims to examine the effects of external auditory, tactile, and audio-tactile stimuli on gait parameters in children with developmental disabilities. To this effect the following research questions will be addressed:

1) Do gait parameters in children with developmental disabilities change upon cueing of a rhythmic auditory stimulus?
2) Do gait parameters in children with developmental disabilities change upon cueing of a rhythmic tactile stimulus?
3) Do gait parameters in children with developmental disabilities change upon cueing of a rhythmic audio-tactile stimulus?

CHAPTER TWO

Review of Literature

Developmental Disabilities

Diagnoses and Characteristics

According to the Center for Disease Control and Prevention (CDC), developmental disabilities are a group of conditions due to an impairment in physical, learning, language, or behavior areas. Developmental disabilities are included in the Diagnostic and Statistical Manual of Mental Disorders - 4th Edition (DSM - IV) which utilizes a coding system designed to correspond with codes from the International Classification of Diseases (ICD). It is this manual that is used to diagnose developmental disabilities from infancy. According to the DSM-IV, developmental disabilities include, but are not limited to intellectual disorders, learning disorders, motor skill disorders, communication disorders, pervasive developmental disorders including Autism Spectrum Disorder, attention-deficit, disruptive behavior disorders, and many others.

Developmental disabilities are common and were reported in approximately 1 in 6 children in the United States from 2006 to 2008. A recent publication reported that the number of children with developmental disabilities has increased, requiring more health and education services. This recent publication conducted by the CDC used the Family Core and Sample Child Components of the National Health Interview Survey (NHIS) from 1997 to 2008 (Boyle et al., 2011). The survey results showed a prevalence of any developmental disability in 1997 to 2008 was 13.87% and ranged from 0.13% for blindness to 7.66% for learning disabilities. A total of 15% of children aged 3 to 17 years, or nearly 10 million children from 2006 to 2008 had a developmental disability. A prevalence increase of 17% was reported over this 12-year period representing roughly 1.8 million more children with developmental disabilities in 2006 to 2008 than a decade earlier. Needless to say, developmental disabilities affect a significant proportion of children in the United States.

Learning disabilities (LD) represent the largest proportion of developmental disabilities reported at 7.66% (Boyle et al., 2011). Researchers have found that children with LD perform worse than their typically developing peers in gross motor skills (Hartman et al., 2010; Vuijk et al., 2011; Westendorp et al., 2011; Woodard & Surburg, 2001). Vuijk et al. (2011) conducted their research on a heterogeneous sample of 137 school-aged children with LD between the ages of 7 and 12 years attending two elementary special needs schools in the Netherlands. They utilized a standardized gross motor development assessment known as the Movement Assessment Battery for Children (MABC) and administered it individually at the children's schools to assess the associations between academic and motor performance. Results showed that compared to the norm scores, 52.6% of the children tested performed below the 15th percentile on manual dexterity, 40.9% on ball skills, and 33.7% on balance skills. These positive correlations reveal the association that the larger the learning lag, the lower the motor skill performance. Results from a similar study by Hartman et al. (2010) found that not only do children with intellectual disabilities (ID) score significantly lower for motor skills than their typically developing peers, but those children classified with mild ID score significantly lower for motor skills than children classified with borderline ID, suggesting a relationship between severity of intellectual delay and locomotor performance. This study evaluated motor performance using the Test of Gross Motor Development -2 (TGMD-2) to assess 12 gross motor skills and the Tower of London task (TOL) to gauge executive capacity.

Westendorp et al. (2011) conducted a similar study in the Netherlands using 104 children between the ages of 7 and 12 years with confirmed LD and correlated them with 104 aged-matched typically developing peers. This study also utilized the TGMD-2 to assess gross motor skills and correlated it with the Child Academic Monitoring System (CAMS) to determine associations between academic performance and motor skills. Results revealed that the LD group scored significantly lower on both gross motor subtests compared to the comparison group, reflecting poorer gross motor skill performance. Similar results were found by Woodard and Surburg (2001) who compared gross motor performance on the TGMD-2 for children age 6 to 8 years old with LD with typically developing children. Results from this study also found poorer performance on both TGMD-2 for children with LD when compared to their typically developing peers. With a clear association between motor and cognitive functioning, some researchers suggest this may be due to a coupling of brain structures (Diamond, 2000). Further analysis suggests that these associations lie in the cerebellum and pre-frontal cortex and in the neural pathways between these areas. Researchers suggest that dysfunction of these brain structures and/or pathways may express themselves in motor and cognitive problems (Diamond, 2000).

Therapeutic Needs

It is reasonable to recognize a relationship exists between cognitive development and motor ability. With that, the therapeutic benefits of improved locomotor performance don’t just stop at functional living, but may also facilitate cognitive functioning (Burns, O’Callaghan, McDonell, & Rogers, 2004; Murray et al., 2006). Murray et al. (2006) sampled 104 subjects age 33-35 years who underwent a neuropsychological test battery including tests of executive function and other learning and memory tasks. Results found a significant linear relationship between age of learning to stand and adult categorization. These results suggest that early development in gross motor domains is associated with better adult executive functioning. Burns, O'Callaghan, McDonnel, & Rogers (2004) found that motor development of extremely low birthweight (ELBW) children who are born less than 1000g at 12 months was strongly associated with cognitive development of the same children at 4 years of age. Specifically, those children classified as having minimal and mild movement problems reported significantly lower cognitive scores than those classified as normal. Piek, Dawson, Smith, & Gasson (2008) researched similar motor and cognitive performance skills in typically developing school aged children and only found a significant positive correlation between gestational age and school aged fine motor performance. These researchers suggest that the inverse relationship of gross motor performance and cognitive delays may be stronger for those children exhibiting high-risk characteristics such as low birth weight. These results align with what other researchers suggest regarding a link between school failure and the severity of minor neurological, motor, and coordination problems (Burns, O'Callaghan, McDonnel, & Rogers, 2004). We can conclude that 1) a high prevalence of developmental disabilities exists in the United States, specifically LD, 2) there is evidence for an association between cognitive functioning and gross motor performance, and 3) such associations may be even stronger among children with high-risk characteristics, including low-birth weight and possibly developmental disabilities. Therefore, there is a need in this population to increase gross motor performance to enhance overall functioning and quality of life.

Treatment

After reviewing research that suggests a link between cognition and gross motor performance, it is important to note that some researchers suggest that children who have been identified at a young age as being at risk of developing learning disabilities could benefit from a timely and targeted motor intervention (Vuijk et al., 2011). Piek et al. (2008) found a strong relationship between early gross motor and later school aged cognitive development, especially processing speed and working memory. Other researchers have found similar results by identifying that locomotor scores were positively and significantly related with decision time (Hartman et al., 2010). As a whole, those children with lower gross motor scores had shorter decision times and lower executive functioning skills (Hartman et al., 2010). Researchers have found that poorer motor control results in poorer executive functioning and vice versa, which suggests a need for timely motor interventions fostering motor and cognitive development in this population.

According to Perry and Burnfield (2010), “Locomotion is a complex task influenced by interactions between bony alignment, joint range of motion (ROM), neuromuscular activity, and the laws of physics” (pg. 341). In children, developmental disabilities, congenital deformities, and degenerative changes can disrupt these interacting factors and cause diminished gait efficiency. The most common group of children with developmental disabilities showing gait abnormalities are those with cerebral palsy (CP) and myelomeningocele. Though these populations are the most common with gait abnormalities, previous research has shown that children all along the spectrum of developmental disabilities can show lower gross motor skills than those of their typically developing peers (Hartman et al., 2010; Vuijk et al., 2011; Westendorp et al., 2011; Woodard & Surburg, 2001). Teachers and clinicians working in the public school system often see a wide range of developmental needs, especially those serving children with severe and profound developmental disabilities. These children are often between the ages of 5 and 21 years and present with a variety of developmental disabilities compounded with gross motor deficits. Some children ambulate independently while others need assistive devices.

Two common therapeutic interventions to correct gait abnormalities with this population include physical therapy and orthopedic surgical procedures (Perry & Burnfield, 2010). Physical therapy interventions are often ordered by the student's primary physician and carried out in the school and home environment. However, when less invasive therapies are ineffective, orthopedic surgeries may be employed to correct musculoskeletal abnormalities affecting gait. In both cases, orthotics are often specially designed for each child depending on his or her physical needs. Appropriate orthotic management can lead to improvements in walking patterns in select patients; however, gait and functional deficits often persist even with bracing (Perry & Burnfield, 2010, pg. 345). Because of the vast number of diagnoses and symptoms under developmental disabilities, most children will need a combination of several different therapeutic interventions to fully target their gross motor needs. One such technique showing potential benefits with rehabilitative populations and some habilitative populations is rhythmic facilitation.

Rhythmic facilitation is a non-invasive gait rehabilitation technique that is motivational, affordable, and accessible to these students. Rhythmic facilitation, specifically Rhythmic Auditory Stimulation (RAS) has been shown to improve select kinematic measures and motor unit firing patterns in some muscles associated with gait (Fernandez del Olmo & Cudeiro, 2003; Thaut & McIntosh, 2006; Thaut et al., 1993; Thaut et al., 1997). RAS is a neurologic technique using the physiological effects of auditory rhythm on the motor system to improve the control of movement in rehabilitation and therapy (Thaut, 2005). "The basic neurological enhancement of gait through RAS is mediated by a rhythmic entrainment effect in which the rhythm, as an external timekeeper, entrains desired movement frequencies and retains motor programs through anticipatory cuing of functional movement patterns" (Thaut, 2005, pg. 139). RAS can be used in two different ways; as an immediate entrainment stimulus and as a facilitating stimulus for training. The majority of research lies in the area of rehabilitation efforts with only two studies examining the use of RAS with a habilitation focus (Jensen, 2009; Kwak, 2007).

Rhythmic facilitation is an appropriate treatment intervention to consider when treating locomotion because gait itself is intrinsically rhythmic. Marieb (1989) suggests that gait is at least partially regulated at the level of the brainstem and spinal cord, in neural circuits called central pattern generators (CPGs) that are inherited, not learned (as cited in Thaut, 2005, pg. 89). CPG's are neuronal circuits present in the spinal cord that allow humans to perform rhythmic activities such as walking, without cortical input (Cohen, 1999). Thaut et al. (1999) found support for this innate rhythmicity by observing gait to be biologically rhythmic in nature (through CPGs) and sequential arm-reaching to be rhythmically organized within a set time structure. After examining EMG recordings of activity from the muscle groups involved in walking, Thaut (2005) also reports finding a specific sequence of muscle activations that are repeated in time with each step of the gait cycle. With sufficient support for the presence of CPG interaction with motor responses and a proposed connection between auditory and motor pathways, while also acknowledging that an important element of music is to communicate time, we have basis to further assess this rhythmic characteristic of music as a functional treatment for gait.

Neuronal Contributions for Rhythm and Motor

Neuronal Activations

Neuroscience research suggests that the somatosensory cortex, premotor and motor cortices, insula, and cerebellum play an important role in the perception of rhythm through a variety of sensory modalities in both children and adults (Bengtsson et al., 2009; Chen, Penhune, & Zatorre, 2008; De Guio, Jacobson, Molteno, Jacobson, & Meintjes, 2012; Giabbiconi, Trujillo-Barreto, Gruber, & Müller, 2007; Wilson, Braida & Reed, 2010). The perception of rhythm is processed in a variety of neuronal areas, many of which are involved in motor planning and output. Perception-action mediation or the "mirror neuron system" describes this phenomenon where simply listening to music automatically engages action-related processes (Koelsch, 2009). Bengtsson et al. (2009) found this mediation to be present, wherein they found premotor and motor cortices to be automatically engaged when simply listening to rhythms. Koelsch (2009) not only found neuronal activations of premotor areas during perception but also during motor output suggesting a shared neuronal system between the two. To further support the activation of these neuronal areas during perception input and motor output, De Guio et al., (2007) report that in active rhythmic tapping adults and children recruit primary motor cortices, premotor cortices, and cerebellum regions. Thaut et al. (2009) also found that different areas of the cerebellum were activated during conscious tracking of rhythmic patterns and in motor output control. To sum up the presence of perception-action mediation, Koelsch (2009) concludes from current research that: 1) the late stages of perception input may overlap with the early stages of motor output, 2) neuronal activity in premotor areas induced by music listening can be observed in musicians and nonmusicians, and 3) the premotor cortex is a critical structure for perception-action mediation.

The premotor cortex has been found to be specifically sensitive to the metric structure of auditory input (Chen et al., 2008). Rhythm's inherent metric quality can powerfully influence perception mechanisms. This inherent characteristic can 1) determine, assign, and build time relationships between events in the perceptual process, 2) provide a temporal ordering process by creating anticipation and predictability, and 3) form and shape memory (Thaut, 2005). Chen et al. (2008) also found the premotor cortex to be integral in mediating higher-order movement selections in a temporally organized manner. Rhythm, being processed in the premotor cortex, may increase activation of the motor cortex, which in return may improve movement execution (Bengtsson et al., 2009). Thaut (2005) adds that the more neurons firing together in synchrony in response to rhythmic stimuli, the greater and more powerful the activations in the motor cortex will be. Other researchers found a direct link between the level of activation in the motor cortex and the threshold for executing a movement (Bengtsson et al., 2009). Thus, rhythmic stimuli can lower this threshold by increasing activation of the motor cortex, thus positively affecting motor output, specifically in reference to timing parameters (Bengtsson et al., 2009). Rhythm may be best described as a sensory timer that utilizes the physiological connections between the auditory and motor systems in the brain to influence movement (Thaut, 2005).

Synchronization

The fundamental building process of rhythm is synchronization. According to the Merriam-Webster dictionary, the word synchronous means to happen, exist, or arise at precisely the same time. With regard to rhythm and motor, we investigate the neural mechanisms by which motor responses may be synchronized to an auditory rhythm, frequently referred to as entrainment. Thaut (2003) found that rhythmic motor synchronization is a composite of auditory and motor neuronal areas. He continues by suggesting two popular rationale points for entrainment: 1) a direct link at the level of the brainstem and spinal cord between auditory input and motor output, and 2) as a ring circuit that interacts with the basal ganglia or cerebellum (Thaut, 2005). It is possible that these two areas of thought are not mutually exclusive from one another but rather integral depending on the complexity of the stimuli and desired output response. There is however, substantial evidence for the existence of an auditory-motor pathway via the reticulospinal connections in the spinal cord (Miller et al., 1996; Paltsev & Elner, 1967; Rossingol & Melvill Jones, 1976; Thaut, 2005). It is suggested that this link could influence threshold excitability of motor neurons, creating a priming effect for the motor system. Although evidence for this cortical interaction is substantial, it is most likely that the neuronal and anatomical mechanisms behind entrainment are much more complex than present understanding.

In order for this entrainment to occur two goals have to be met: to move at the same frequency and with no time difference between the beat and motor response. Thaut (2005) reports current findings regarding this phenomenon: 1) steady and stable couplings between the rhythmic cue and the rhythmic motor response are achieved almost instantaneously, within one or two repetitions of the stimulus, 2) rhythmic formation is interval-based in an anticipation-corrections process where the brain recognizes the periodicity pattern of the rhythmic stimuli and synchronization is achieved by an anticipatory response, 3) small deviations in synchronization alignments do not need to be corrected by overcorrections, and 4) the motor output system recognizes and responds to synchronization changes even at or below conscious awareness.

Sufficient evidence exists to support the existence of entrainment mechanisms by demonstrating that the human body innately responds to rhythm and creates rhythm through movement. Through a variety of neuronal and cortical pathways, researchers have observed a direct link between external auditory input and motor output. Bengtsson et al. (2009) found evidence for this relationship by observing that rhythmic stimuli can increase activation of the motor cortex. Other researchers suggest that rhythmic stimuli may excite spinal motor neurons through the reticulospinal pathway which then coordinates axial and proximal motor output

(McIntosh, Brown, Rice, & Thaut, 1997). Although the exact anatomical location of this transfer is widely debated, researchers agree that a relationship exists. Researchers have provided support for this entrainment mechanism for adults and children (Jensen, 2009; Kwak, 2007; Molinari et al., 2005; Thaut et al., 1999). Thaut et al. (1999) found that patients, in spite of very differing neuropathologies, were able to synchronize their motor responses to auditory rhythm. Knowing that a relationship exists between music's inherent rhythmicity and gait's inherent metric nature, we can conclude that rhythmic facilitation could be used to improve gait parameters in a variety of clinical populations.

Motor Responses to Auditory Stimuli

Contributions in Rehabilitation

Clinical research of this entrainment mechanism has been studied in a variety of rehabilitation modalities to improve gait parameters (Freedland et al., 2002; Kadivar, Corcos, Foto, & Hondzinski, 2001; Kenyon & Thaut, 2000; McIntosh et al., 1997; Thaut, 1997; Thaut et al., 1996). Freedland and colleagues used a metronome at the subject's average cadence in patients with Parkinson's disease. Results from this study showed a significant increase in step length and improvements in cycle time (Freedland et al., 2002). More evidence for using this technique was found by other researchers using a variety of musical additions who found similar effects with Parkinson's patients when using RAS (Kadivar et al., 2011; McIntosh et al., 1997; Thaut et al., 1996). One such study targeted multidirectional step training in a 6 week training course using RAS and a control group receiving no RAS. Results of this study found performance improvements with RAS and the ability to maintain such improvements above baseline measures for at least 8 weeks (Kadivar et al., 2011). Another study working with Parkinson's subjects with and without dopaminergic medications found improvements in freeze behavior (McIntosh et al., 1997). Such subjects were observed entraining to the rhythm and found gait velocity, cadence, and stride length improvements. With the addition of RAS those subjects without medication turned smoothly and retained rhythmic synchronization when they had previously froze in the non-auditory trials. The authors highlight this result as evidence that the rhythmic stimulus may by-pass the disordered basal ganglia in people with Parkinson's disease (McIntosh et al., 1997). RAS has also shown positive effects when used in home-based training settings with people with Parkinson's disease (Thaut et al., 1996).

The use of RAS with other adult populations including those inflicted by a stroke (Thaut et al., 1997), with Hunington's disease (Thaut, Miltner, Lange, Hurt, & Höemberg, 1999), and those subjects with traumatic brain injury (TBI) (Hurt, Rice, McIntosh, & Thaut, 1998). One study with hemiparetic stroke subjects used rhythmic facilitation accompanied by digitally manipulated music set to match each subject's cadence (Thaut et al, 1997). Results showed significant differences between the RAS and control subjects in gait velocity and stride length with noticeable improvements in stride symmetry. An important finding in this study was the restoration of swing symmetry after RAS which allowed for a more normal gait (Thaut et al, 1997). RAS with subjects with Huntington's disease showed interesting results due to the unresponsiveness of the most severe disability group and which showed a clear impact of the disease progression on gait parameters (Thaut et al., 1999). Carry-over effects of RAS did provide evidence that the general mechanisms of rhythmic entrainment remain intact despite the disturbance of precise timing in patients with Huntington's disease. These results highlight the neuronal link between auditory stimuli and motor output despite the progression of the disease. Thaut (2003) later reported on this direct frequency entrainment of inherited motor responses to entrain within one to two repetitions of a rhythmic stimulus.

Researchers using RAS techniques in a long-term training program with TBI subjects have found increases in gait parameters for normal and fast walks with statistically significant increases in velocity, cadence, and stride length during normal walking (Hurt et al., 1998). This study used RAS with subjects no longer making progress in conventional physical therapy and observed significant improvements in gait over this period of time, providing sufficient support for using rhythmic facilitation in long-term rehabilitation facilities. RAS has also shown significant improvements with persons with CP in the areas of pelvic and hip movements and overall gait parameters (Kim, Kwak, Park, & Cho, 2012; Kim et al., 2011). In one specific study with adults, RAS was compared with traditional neurodevelopmental treatment. Results reported improved gait parameters including cadence, velocity, stride length, and step length, with added alleviation of excessive anterior tilt of the pelvis and dynamic deformity of hip flexion (Kim et al., 2012). We can conclude that RAS has shown reliable benefits for some client populations to target rehabilitation of gait.

Contributions in Habilitation

An area not explored until recently involves the use of RAS in gait training for those with a developmental disability or congenital disability developing functional gait patterns in a habilitation model. Two studies have been completed that examined the use of RAS with children (Jensen, 2009; Kwak, 2007). One account used RAS integrated into a music program and found improvements in gait performance on some, but not all parameters when using music and drums along with a metronome to target gait in children with CP (Kwak, 2007). This study utilized a control group, a therapist-guided training group (TGT), and a self-guided training group (SGT). The control group participated in traditional gait training with a physical therapist, and the TGT and SGT groups received RAS. Results showed a statistically significant difference from pre to posttest measures for stride length (p = 0.014), velocity (p = 0.016), and gait symmetry (p = 0.048) for the TGT group. It is important to note that all children in this study were designated ambulatory and did not require assistive gait trainers or devices. This study also presented with a number of confounding variables including a large age range which affects the ability to generalize results. The authors of this study reported that training with this age range should fit between 10 and 20 minutes and found that with this population, some gait parameters improved despite the lack of an increase in cadence (Kwak, 2007). This presents a contrasting idea to research using RAS in rehabilitation which emphasizes the importance of cadence improvements (McIntosh et al., 1997). The authors highly emphasize the importance of maintaining cadence to stabilize internal timing with this population along with the need for more research with children using RAS (Kwak, 2007).

A second study was an unpublished master's thesis by Laura Jensen in 2009. This pilot study included five children ages 7-13 diagnosed with spastic diplegic CP. All participants ambulated without assistive devices and exhibited limitations in gait parameters. Dependent variables included synchronization error (SE), absolute period error (APE), stride time symmetry, stride length symmetry, knee extension at foot contact, and variability of knee extension at foot contact. All data was collected in the Center for Gait and Movement Analysis (CGMA) at The Children's Hospital in Denver, Colorado. This study utilized a 12-camera Vicon MX motion capture system to record measures and was an immediate entrainment study as part of a larger project. The four conditions in this study were self-selected speed normal walk (SS), self-selected matched with music at the same cadence (SSM), fast walk (F), and fast matched with music at the same cadence (FM). Auditory stimuli included pre-recorded music played through wireless headphones. It is important to note that the walking trials were not randomized in this study.

Results showed that 4 out of 5 participants anticipated the beat in the SSM condition by exhibiting negative synchronization errors and continued to entrain during fast speed conditions by demonstrating a positive synchronization error. No significant differences were found for stride time symmetry or stride length symmetry between the no-music and music conditions. An average stride time symmetry increase was observed from SS to SSM trials and average stride length symmetry increase from F to FM, although none were significant. No significant changes were observed in knee extension at foot contact. Recommendations from the author regarding future studies of its kind include examining gait cadence, stride length, and velocity measures. Clinical implications from this study embrace the importance of maintaining a steady tempo when working on gait parameters with children to allow the client to continue to synchronize their step period. In conclusion, children with spastic diplegic CP have the ability to synchronize their gait patterns with and external auditory rhythmic stimulus. We can conclude from the research available that the responses to RAS show different benefits for populations learning and developing gait as opposed to rehabilitating gait patterns. It is safe to say that more research is needed to make accurate conclusions regarding the therapeutic benefits of RAS with children, specifically children with developmental disabilities.

Motor Responses to Tactile Stimuli

As we consider this impact of rhythm on motor output, it is important to acknowledge other sensory modalities capable of providing such rhythmic facilitation. The somatosensory system from early development is highly active. The tactile system in infants has been shown to be the most primed at birth and may provide an important link to learning in early childhood

(Shibata et al., 2012). One study, which analyzed the neuronal responses to a variety of tactile stimuli in newborns, found that tactile stimuli activated temporal and parietal regions of the brain (Shibata et al., 2012). As a result of this regional activation, we can conclude that these temporal and parietal areas might reflect the activation of somatosensory and motor regions, those similarly activated by auditory input discussed previously. Hegner et al. (2010) also found that tactile stimuli are processed in similar neuronal regions as auditory stimuli including areas of the somatosensory, premotor, and insular regions of the brain. Other researchers have found similar activations present in the primary and somatosensory cortices as a result of vibrotactile stimulation (Schürmann, Caetano, Hlushchuk, Jousmäki, & Hari, 2006). Giabbiconi et al. (2007) also found that vibratory stimuli, when presented to the right and left index fingers, are mediated in the primary somatosensory cortex. Further support recognizes that while there are different neural mechanisms underlying temporal and tactile spatial processing, many common brain regions exist along the sensory motor pathway for these two stimuli (Hegner, Lee, Grodd, & Braun, 2010).

Acknowledging that a neuronal relationship exists between the tactile and motor pathways, we now access the effects of rhythmic tactile stimuli on motor output responses. Using rhythmic tactile stimuli can positively affect gait parameters in rehabilitation populations. van Wegen et al. (2006) found that when using tactile vibration as a rhythmic somatosensory cue in subjects with Parkinson’s, such cueing effectively modified stride patterns. In this study, subjects walked on a treadmill to maintain walking speed and received rhythmic somatosensory cueing provided by a vibrating cylinder attached under a wristband that pulsed steadily every 400 ms. Subjects were instructed to step at the rhythm of the vibration. Results showed an increase in stride length; that is, a decrease in stride frequency with the automatic maintenance of walking speed via the treadmill equates an increase in stride length (van Wegan et al., 2006). This too provides evidence that rhythmic sensory facilitation has the potential to bypass the basal ganglia in people with Parkinson’s disease as observed with RAS (McIntosh et al., 1997; van Wegen et al., 2006). Vibrotactile stimulation training is also used with subjects who suffer chronic dizziness and body sway (Basta et al., 2011). This recent study used a vibration stimulator tailored to each subject’s balance deficits at the hip region, providing vibratory stimuli in all four quadrants (front, back, left, and right) to improve postural control in stance and gait situations. Results showed significant effects on body sway in pitch and roll directions and in stability in the treatment group only. A carry-over effect was also observed at a three-month follow-up (Basta et al., 2011). This sensory facilitation aligns with spatial effects found from auditory input (Kenyon & Thaut 2003).

A variety of tactile or vibrotactile stimuli have been shown to provide benefits for rehabilitation and habilitation populations as a forced tactile cue to improve gait, one such tactile source is a mechanical treadmill (Chrysagis et al., 2012; Kurz, Stuberg, & Dejon, 2011; van Wegen et al., 2006). Treadmill training provides a continuous rhythmic cue, increased opportunity for repetitions for the entire gait cycle, and may facilitate an improved gait pattern in some populations. A recent study by Kurz, Stuberg, and Dejong (2011) examined twelve children with CP who participated in a 12-week body weight supported treadmill training routine. Results from this study found a significantly faster walking speed ($p = 0.02$), longer step length ($p = 0.03$), and improvements to their Gross Motor Function Classification Scores ($p = 0.01$). Other studies have found similar improvements in response to treadmill training (Chrysagis et al., 2012). This study by Chrysagis et al. (2012) examined 22 adolescents with physical disabilities who were randomized to either an experimental or control group. The experimental group participated in a treadmill program without body weight support while the control group received conventional physiotherapy. This 12 week program found significant improvements in self-selected walking speed ($p = 0.000$) and gross motor function ($p = 0.007$). This type of tactile training with children has been shown to increase walking speed over a 10 meter distance and improve general gross motor skills (Willoughby, Dodd, & Shields, 2009). Recommendations from a recent systematic review suggest that this type of training is safe and feasible for children, specifically children with gross motor deficits.

Motor Responses to Sensory Overlap

We can conclude from previous research that 1) similar neuronal areas are activated by both auditory and tactile external stimuli, 2) both stimuli have shown an effect on motor output, and 3) both have implications into therapeutic modalities. When considering each stimulus separately, research supports some therapeutic implications, but the question is raised as to the implications of simultaneous presentation of both auditory and tactile stimuli in a multi-sensory or dual-sensory approach (Baram & Miller, 2007). A recent study provided evidence that both auditory and tactile stimuli were equally effective at improving gait. This study, by Nieuwboer et al. (2009) utilized auditory, visual, and somatosensory cues with subjects with Parkinson's disease and found that all cueing showed significant improvements in turn time except visual (Nieuwboer et al., 2009). The auditory stimulus was delivered through earphones as a single tone, while the tactile stimulus was a pulsed vibration worn on a wristband. Auditory was most effective for faster turn times, however for the total group, auditory was equally as effective as somatosensory cueing (Nieuwboer et al., 2009). In this clinical example, both auditory and tactile stimuli were equally effective in reducing freeze episodes. Further support was found when subjects were asked to tap to a beat and given auditory and tactile sensory stimuli separately; subjects were able to extract the meter structure from tactile rhythmic cues as efficiently as from auditory cues (Brochard, Touzalin, Després, & Dufour, 2008). With sufficient evidence that external auditory and tactile stimuli are perceived in a comparable manner, we can now consider the neuronal foundations for this multi-sensory approach.

Neuronal Activations

Neuronal areas activated as a result of auditory and tactile stimuli overlap include the somatosensory and auditory cortices (Foxe et al., 2002; Renier et al., 2009). When presented with overlapped vibrotactile and auditory stimuli, co-activation occured in areas of the auditory cortex, specifically the left superior temporal gyrus (Schürmann et al., 2006). Some consider the medial frontal gyrus and the insular cortex to be multi-sensory integration centers (Renier et al., 2009), while others universally accept the midbrain and specifically the superior colliculus to be important in multi-sensory integration (Stein & Meredith, 1993). Renier et al. (2009) suggest that excitatory convergence of somatosensory and auditory input have been found in the subregions of the auditory cortex, which correlates with previous findings that these two stimuli neuronally overlap (Foxe et al. 2002).

Although there are many areas of thought regarding the exact location of this sensory overlap, researchers agree optimization of neuronal activation occurs as a result of such an overlap (Elliot et al., 2010; Fox et al., 2002; Schurmann et al., 2006). Elliot et al. (2010) report that these two stimuli are temporally similar and are evaluated together by the CNS creating an optimization effect. Schürmann et al. (2006) also found support for increased activation by observing considerably larger clusters in fMRI images in the auditory cortex when stimuli were presented together. Other support for this notion was found by Wilson and colleagues who report supra-threshold stimulus levels between auditory and somatosensory systems suggesting a strong frequency relationship exists during convergence of the two stimuli (Wilson et al., 2010). With evidence supporting optimized neuronal activations, researchers have also observed an increased detection of stimuli localization, specifically when provided to the same side of the body (Ro et al., 2009). Others have found that auditory stimuli accompanied by synchronous tactile vibrations are judged as louder than when presented in isolation and result in improved motor output performance (Gillmeister & Eimer, 2007). An overall significantly greater activation in neuronal areas are present when both auditory and tactile modalities are provided simultaneously as compared to each constituent independently (Elliot et al., 2010; Fox et al., 2002).

Contributions to Clinical Application

Current research suggests that the combination of both sensory stimuli may have an excitatory element on motor output (Brochard et al., 2008; Elliot, Wing, & Welchman, 2010; Foxe et al., 2002; Gillmeister & Eimer, 2007; Ro, Hsu, Yasar, Elmore, & Beauchamp, 2009; Wilson, Braida, & Reed, 2010). That being said, our primary concern in this analysis is gait, and by understanding that gait and human posture require integration of visual, vestibular, and somatosensory information, it is customary to analyze the current research using multi-sensory integration in clinical practice. Research suggests that presenting auditory and tactile (haptic) cues simultaneously improves motor coordination in normal subjects (Kelso, Fink, DeLaplain, & Carson, 2001). This study integrated rhythmic auditory cues through a metronome and haptic cues of touching the participants' fingers to investigate motor output responses. Different trials consisted of haptic cues in either synchronization with the rhythm; at the counter phase point to the rhythm, at both points of flexion and extension, and no contact cues. The results clearly indicated that participants were drawn to synchronize their movements when both the auditory and tactile cues coincided in time. Kelso et al. (2001) suggests that these two sensory modalities are “bound or neurally integrated into one coherent action-perception unit” (p. 1211).

Other clinical integration research targets subjects who are visually impaired. As previously described, vision is not a rhythmically reliable sense and thus it is appropriate to investigate the use of multi-sensory integration with visually impaired subjects to allow for concentration of the auditory and tactile senses utilized in gait (Nieuwboer et al., 2009; Patel et al., 2005). A recent study with non-sighted subjects supports the idea that integrated auditory and tactile stimulation shows greater improvements in postural stability (Magalhães & Kohn, 2011). Stability and balance is essential to functional gait, especially at the point of single limb support during the third phase of the gait cycle where body weight shifts to align over the forefoot (Perry & Burnfield, 2010). Magalhães & Kohn (2011) found that the addition of vibratory noise to haptic (tactile) stimuli show more efficacy with posture than haptic supplementation alone. This study suggests the addition of vibratory noise to walkers, canes, and other assistive devices may aid in locomotion and stability. It was hypothesized that the added noise to the source of haptic information may activate more specialized mechanoreceptors and thus improve the input signals that reach the CNS (Magalhães & Kohn 2011). This is an intriguing idea when considering the potential benefits of auditory and tactile integration in functional mobility.

Limitations of Sensory Overlap

Current research supports the notion that simultaneous convergence of auditory and tactile stimuli may provide implications for enhanced motor output, however, it is important to consider the limitations. Such limitations for sensory overlap arise in two dimensions; frequency and temporality. An important limitation to take into account when providing sensory overlap is the fact that stimulus perception is a two-way bias, meaning that task-irrelevant auditory input can bias and attract away from tactile input, and task-irrelevant tactile input can bias and attract against tactile input (Bresciani & Ernst, 2007). This two-way bias is important to take into consideration when considering both frequency and temporal effects. When stimuli are not synchronized, auditory input is more reliable than tactile when considering stimuli frequencies (Bresciani & Ernst, 2007). This particular study found that with loud beeps audition was more reliable than touch and with quiet beeps, tactile evoked the bias of audition (Bresciani & Ernst, 2007). This auditory-dominant effect was also found when an auditory metronome was neuronally identified as more reliable even with its high irregularity (Elliot et al., 2010). Gillmeister & Eimer (2007) also found a frequency limitation reporting that tactile enhancement effect was more pronounced in lower rather than higher auditory intensities. Further support for this notion was found when congruent sounds (same frequency) and incongruent sounds (different frequencies) were administered, resulting in an increase in discrimination performance for congruency and a decrease in discrimination performance for incongruency (Ro et al., 2009). This frequency-specific effect should be taken into account when implementing multi-sensory stimuli into therapeutic applications.

A similar temporal-specific effect is also found in literature (Elliot et al., 2010; Ro et al., 2009). When the probability of stimuli integration are not closely related or rather far enough apart, they are processed separately rather than integrated and can have the same negative effect as seen when the stimuli are incongruent in frequency (Elliot et al., 2010; Ro et al., 2009). The probability of the stimuli temporal congruency is another potential limitation in therapeutic application of multi-sensory input to improve motor output. When the two input stimuli are temporally reliable they optimize together and hypothetically enhance motor production (Elliot et al., 2010). Through this analysis we can conclude that the integration of sensory inputs, when integrated in regard to frequency and temporal characteristics, may provide increased excitability of sensory input and improved motor output. Such integration has the potential to further enhance posture and gait, specifically in those populations with disabilities (Magalhães & Kohn, 201; Neuwboer et al., 2009). This is of specific interest to the current analysis which aims at investigating the use of simultaneous auditory and tactile stimulation with children with developmental disabilities.

Implications in Motor Learning

Information to specifically integrate into this analysis includes characteristics of gait and motor output in children, specifically with developmental disabilities. With specific respect taken for the process of motor learning rather than rehabilitation, it is important to acknowledge that time structures seem of primary importance for facilitating learning, specifically when considering automatic performance of motor output (Halsband & Freund, 1993). This provides support for the importance of temporal factors in motor learning, as presented in motor rehabilitation (Thaut, 2003). Adult-like capacity for motor performance is not reached until late childhood, and thus the differences should be taken into account (Halsband & Freund, 1993). A significant difference exists between adults and children in regard to motor functioning. Although entrainment to a rhythmic stimulus is inherent and variably observed in children over the age of 7 (Jensen, 2009), motor learning involves cognition, and thus must be taken into account when working on motor functioning with children (Halsband & Freund, 1993; Marieb, 1989; Thaut, 2005). When engaged in finger tapping, children have a much higher irregularity than adults when motor output is cognitively controlled as it is in upper extremities (De Guio et al., 2012). It is also important to note that children recruit additional motor and premotor areas than adults in rhythmic tapping (De Guio et al., 2012). Although children as young as five can complete a task of putting a cup on a shelf, their rhythmic regularity is less smooth than that of an adult (Traynor, Galea, & Pierrynowski, 2012). This suggests a cognitive control of the rhythmic activity due to the non-inherited nature of upper extremity motion (Marieb, 1989; Traynor, Galea, & Pierrynowski, 2012). Ergo, cognition is an integral part of motor learning at this age and, although rhythmic facilitation is inherent in a feed-forward system, the cognition component is essential to motor learning and must be taken into consideration when presenting rhythmic facilitation to enhance motor learning (Halsband & Freund, 1993). Support for this notion suggests that it is important to take the child's cognitive processing capacity into account when designing therapeutic models for motor learning (Sidaway, Bates, Occhiogrosso, Schlagenhaufer, & Wilkes, 2012).

Contributions for Children with Disabilities

With specific regard to children with disabilities, it is important to again note that children with learning disabilities score significantly lower in gross motor outcomes than those of their typically developing peers (Westendorp, Hartman, Houwen, Smith, & Visscher, 2011). Children with disabilities, specifically those with speech and language impairments display significantly less sensitivity than control subjects to auditory rhythmic timing cues (Corriveau & Goswami, 2009). This study looked at the difference in rhythmic cuing responses between children with language impairments and their typically developing matched control peers. Children included in this study were between the ages of 7 and 11 years. The children were asked to tap to one of three rhythms in the metronome task for both a paced condition (where they heard a beep) and an unpaced condition (where they did not hear a beep). Results showed that children with language impairments exhibited poorer performance than controls when tapping at the slower rates of 1.5 and 2 Hz in the paced condition. In the unpaced condition no significant difference was found between groups, suggesting that all children at this age exhibit variability in tapping when no external rhythmic cue is present. This current study suggests a possible rhythmic processing deficit in children with language impairments, possibly providing evidence for the comorbidity between language and motor impairments present in this population.

Along with observable motor delays, this population also shows disruptions in ascending sensory pathways and descending motor pathways (Hoon et al., 2009). This emphasizes the importance of the sensorimotor cortex and the presence of sensory processing deficits in children with motor dysfunction, such as CP. Children with CP specifically show hypersensitivity to touch and pain sensation (Hoon et al., 2009). Other research supports this overreaction (hyper-responsivity) and under-reaction (hypo-responsivity) to stimuli in children with CP (Clayton, Fleming, & Copley, 2003). This study introduces the importance of high threshold (habituation) and low threshold (sensitization) stimulation of the nervous system in children with CP. This discrepancy between high and low stimulation thresholds remains important for the current analysis when introducing new stimuli to the nervous system. Children exhibiting habituation to a stimulus may display behaviors of under-reaction while those with sensitization may display behaviors of over-reaction such as fear (Clayton et al., 2003). In considering such sensory and motor dysfunction, researchers suggest that addressing these deficits through increased excitability of the sensorimotor cortex may prove to be highly effective with this population, providing further support for the use of integrated sensory input to excite motor output (Riquelme & Montoya, 2010).

When implementing sensory input with this population, it is important to recognize that individuals show better processing of events at a given body location when their attention is focused on that body area (Giabbiconi et al., 2007). To add to this, Ro et al. (2009) found that when integrating both auditory and tactile stimuli to the same side of the body, increased detection of that stimulus was present. This point begs the question of how one better attends to a certain body area. Hesse and colleagues (2010) further this idea by providing evidence that we attend to external stimulation more than self-mediated stimulation by activating the feed-forward system when external stimuli are introduced. Thus, one is more apt to attend to an auditory or tactile stimulus when their motor system is not engaged in providing the stimulation but instead is presented from an external source (Hesse, Nishitani, Fink, Jousmäki, & Hari, 2010). This may also be reason why children have a higher variability for tapping in unpaced conditions as there is a lack of external stimuli (Corriveau & Goswami, 2009).

Statement of Hypothesis

In conclusion, research supports the use of rhythmic facilitation to improve gait parameters relying on the intrinsic connection of rhythmic input, the CNS, and motor output. Although there is much research to support the use of such techniques in rehabilitation with adults, there is little research investigating the impact of RAS in children, specifically in children with disabilities. RAS has shown improvements in gait with a variety of populations; however the implementation of standard RAS has shown little research for support in motor learning with children with disabilities. Through this analysis it is apparent that those populations with disabilities may respond in an excitatory manner to sensory integration of auditory and tactile input. Taking into consideration a child’s cognitive processing capacity, possible sensorimotor sensitivity found in children with disabilities, and the enhanced integration of sensory stimuli, the evidence presented can conclude that a sensory integrative method of rhythmic facilitation is a viable and sound method when researching motor and specifically gait parameters in children with disabilities.

The purpose of this study is to examine gait parameters of children with disabilities to determine the effects of auditory, tactile, and auditory-tactile stimulation on motor functioning, specifically on gait parameters. The following null hypotheses will be tested: (a) there will be no difference in gait parameters for children with disabilities to synchronize to an external auditory stimulus, (b) there will be no difference in gait parameters for children with disabilities to synchronize to an external tactile stimulus, and (c) there will be no difference in gait parameters for children with disabilities to synchronize to a simultaneously integrated external auditory-tactile stimulus.

CHAPTER THREE

Method

Participants

Seven children (N = 7) were recruited to participate in the current study in the Central Missouri area. All participants attended a state school for persons with severe and profound developmental disabilities. The age range and mean for recruited children was 11 years, 0 months to 17 years, and 3 months (*M* = 14.10). All children were diagnosed with a developmental disability under the DSM-IV classification including intellectual, physical, sensory processing, or multiple disabilities and could ambulate 10 meters without assistive devices. Diagnoses were identified and confirmed by an inclusion questionnaire confirmed by the participant's legal guardian (Appendix A). All participants were female. Recruitment of participants commenced following approval from the Colorado State University Institutional Review Board for the protection of human subjects on March 20, 2013. Informed consent was obtained from the participant's legal guardian, as well as verbal or gestural assent from the participant prior to the pretest. Participant demographics are outlined in Table 1.

Table 1

Participant Descriptors

Participant	Age	Sex	Diagnosis
1	11	F	Cohen Syndrome, Hypotonia, Microcephaly, Intellectual Disability
2	16	F	Angelman Syndrome; Intellectual Disability
3	15	F	Seizure Disorder, Intellectual Disability
4	16	F	Autism; Mood Disorder
5	15	F	Asthma, Diabetes, Intellectual Disability
6	12	F	Cerebral Palsy, Microcephaly, Seizure Disorder, Intellectual Disability
7	17	F	General Intellectual Disability

Note: All participants attend a local state school and must have a cognitive disability of at least 4 standard deviations below the general population to attend this school.

Measures

This immediate entrainment study utilized a 10-meter walking distance to analyze changes in gait parameters with different stimuli. A 10-meter walking distance was deemed appropriate by the researcher because this distance has shown good reliability for assessing gait parameters in adults and children (Hurt et al., 1998; Jensen, 2009; Kim et al., 2011). The 10-meter walkway was marked with red tape on a solid, flat floor. The participants were instructed to begin walking 2-3 steps prior to the beginning mark and instructed to stop 2-3 steps past the ending mark. This was to ensure that the steps calculated were at the participant's natural walking pace. The participant's walking was timed with a stopwatch upon the point at which they reached the starting marker and stopped upon reaching the ending marker. The 10-meter walkway was a portion of a long hallway. In order to capture accurate walking calculations, the investigator used a solid red marker board which was raised above the participant's head to identify the point at which the participant crossed the beginning marker. The end marker was clearly seen on the video recordings.

Gait Parameter Measures

Gait parameters measured included cadence, velocity, and stride length. Such parameters assess a person's overall gait function and can be compared to normal gait parameters found in the general population. In the current study, cadence is defined as steps per minute and was derived from multiplying stride frequency by 60 to determine steps per minute. Stride frequency was derived from recording the amount of time in seconds it took the participant to walk 10 steps (5 strides). Velocity is defined as distance per minute and measured in meters per second. According to Perry & Burnfield (2010), velocity (or walking speed) is the fundamental gait measurement. Velocity was derived from dividing 10 (distance walked) by the amount of time, in seconds, it took the participant to walk the 10 meters. Stride length is defined as distance per stride and measured in meters. Stride length was derived from dividing velocity by stride frequency. Refer to Table 2 for gait parameter calculations. Sample data collection worksheets can be found in Appendix B (pretest) and Appendix C (conditions).

Table 2

Gait Parameter Calculations

	Measurement	Calculations
Cadence	(C = SFx60)	SF x 60 = Cadence (steps/minute) or (bpm)
Stride Frequency	(SF = 5/Y)	Steps (5) / __time (sec) = ____ Hz
Velocity	(V = 10/X)	Distance (10 meters) / ___time (sec) = ___m/s
Stride Length	(SL = V/SF)	Velocity / Stride Frequency = ___ m

Note: X = time (sec) for the 10m walk; Y = time (sec) to take 10 steps (5 strides)

Video Recording

Video footage for timed tasks was taken using a Canon VIXIA HFR400 camcorder. Video footage was not captured during the practice walk but was in all other trials. During the pretest, the researcher used a stopwatch to determine how much time it took each participant to take 10 steps (5 strides) in order to calculate each participant's cadence for all subsequent trials. The researcher later viewed the video recordings to time all other walking conditions: (a) time it took the participant to walk 10 steps (*X*), and (b) time it took the participant to walk the 10 meters (*Y*). An inter-rater observer was used to enhance reliability for the current study and gathered the same calculations (*X & Y*) as the researcher for all participant trials through the video recorded trials.

Condition Measures

There were two separate metronomes utilized during this study, one for the auditory stimulus and another for the tactile stimulus. The auditory stimulus for the current study utilized one Peterson BBS-1 BodyBeat Synch Pulsating Wireless Metronome using the auditory only setting. The auditory source, carried by the therapist, was presented continuously with the participant as they walked the 10 meters to ensure that the stimulus was heard throughout the walk. The auditory source was not attached to the wall and was instead held by the therapist during the walk, as the auditory stimuli would have been heard differently across the 10 meters if attached to the wall in the current study's available environment. The tactile stimuli for the current study utilized a second Peterson BBS-1 BodyBeat Synch Pulsating Wireless Metronome using the tactile only setting. The tactile source was placed on the participant's right hip.

The audio-tactile stimuli for the current study utilized two Peterson BBS-1 BodyBeat Synch Pulsating Wireless Metronomes set at a synchronized beat to the participant's original cadence recorded during the pretest. To synchronize the two stimuli, the current study used a specialized function of the Peterson BBS-1 BodyBeat Synch Pulsating Wireless Metronome to synchronize wirelessly two Peterson BBS-1 BodyBeat Synch Pulsating Wireless Metronomes together within a 75 yard radius. One metronome was set as the "master" or the "sync" unit and the other as a group member. The "sync" unit controlled the metronome level while the second metronome followed. The researcher utilized this function by programming the participant's original cadence into the "sync" unit serving as the auditory stimuli and the second metronome was synchronized and presented the tactile stimuli. Both the auditory and tactile sources were presented continuously but not on congruent sides. Due to the location and functionality of the research area in the state school, it was difficult to present the auditory and tactile stimuli on congruent sides. Previous researchers have found the greatest results when both stimuli were presented on congruent sides of the body; this remains a limitation to the current study (Ro et al., 2009). In the current study, the auditory stimulus was presented on the left/back side while the tactile stimulus was consistently presented on the participant's right hip.

Procedure

Participants were recruited from a local state school roster and contacted by telephone. Recruitment flyers were sent home to each participant's legal guardian and a follow-up telephone call from the researcher to answer any questions regarding the current study. Prior to participant involvement, each participant's legal guardian completed the appropriate Institutional Review Board (IRB) form to participate in the current study. Due to the nature of the current study and the age of the participants, consent was gathered from the participant's legal guardians and assent from those participants able to understand information about participation in the study. Following approval to participate, background information was gathered for each participant through a Screening Questionnaire for Inclusion (Appendix A). A number was assigned to each participant prior to the pretest to assure anonymity of the participants.

Prior to data collection, the 10-meter walkway was marked out with red tape on the floor at the starting marker and the ending marker, as well as extended markers to ensure normal walking speed. Data collection was also preceded by a period of familiarization for the participant regarding walking instructions and marker placement. During this familiarization period, the participant was asked to walk the length of the 10 meters as a practice walk to ensure that the participant could complete the walk and to familiarize the participant with the length. Once all markers and equipment were placed and familiarization was finalized, the initial recording was gathered for the no stimulus pretest that served primarily to gather the participant's original gait parameters including starting cadence, which was utilized in the experimental conditions to follow.

Design

The current study utilized a single system repeated measures design with a pretest to determine normal gait parameters (cadence, velocity, and stride length) followed by four conditions: (a) no stimulus, (b) auditory only, (c) tactile only, and (d) simultaneous audio-tactile. The experimental design is represented in Table 3. Each participant served as his/her own control. The independent variable was rhythmic facilitation using auditory, tactile, and audio-tactile stimuli. The dependent variables included the following measures obtained from the 10 meter walking task while exposed to one of the conditions: (a) cadence, (b) velocity, and (c) stride length. The participants were seen twice (session 1 & 2). Each session was administered identically with the pretest presented first to determine original gait parameters followed by the four randomized conditions. At each session, the participant was first asked to walk one length of the 10 meter area as a practice. No data was taken during this walk. A pretest was administered following the practice walk to gather cadence in order to input the auditory and tactile stimuli sources. During this pretest, the participant was asked to walk one 10 meter length in order to gather their original cadence. The four conditions were then presented to each participant in a randomized order following the pretest. The randomization of the condition order utilized a computerized randomized table with pre-determined sets and was completed prior to data collection. The randomized sets used are represented in Table 4.

Table 3

Experimental Design

	Pretest	Condition 1	Condition 2	Condition 3	Condition 4
Session 1	O	X_1	X_2	X_3	X_4
Session 2	O	X_1	X_2	X_3	X_4

Table 4

Randomized Table of Conditions

	Session	
Participant #	1	2
1	1, 4, 2, 3	4, 1, 2, 3
2	3, 4, 2, 1	1, 3, 2, 4
3	2, 1, 3, 4	3, 1, 4, 2
4	2, 4, 1, 3	1, 3, 4, 2
5	3, 2, 4, 1	4, 1, 3, 2
6	4, 2, 1, 3	1, 3, 4, 2
7	2, 4, 1, 3	3, 2, 1, 4

Note: 1 = no stimulus; 2 = auditory only; 3 = tactile only; 4 = simultaneous audio-tactile

Five data sets (1 pretest and 4 conditions) were taken for each participant at each session resulting in a total of 10 data sets for each participant used in data analysis procedures for the entire study. The participants were asked to walk the length of 10 meters for each condition. Data collection was done twice with each participant resulting in a total of two sessions at least one week apart. Session 1 was administered first and session 2 was administered 7 days after session 1. The second session was administered in order to gather more data and was randomized in a different order to control for (a) order effects and (b) effects of conditioning.

Reasons for administering the experimental design in two separate sessions (session 1 & session 2) include: (a) to allow a suitable rest period for the participant, (b) to gather more data in an effort to increase the reliability of the results, and (c) to account for the participant's normal routine at the school. The researcher deemed that a week was a long enough period of time to rest and normalize gait parameters but not long enough to observe a conditioned or learned response between session 1 and session 2. Each participant was asked to walk a total of 120 meters (12 lengths of a 10 meter walk distance) which includes practice walks (20 meters), pretests (20 meters), and conditions (80 meters). A pretest trial and 4 condition trials (1 trial/condition) were administered for session 1 and 2, equaling a total of 2 pretests and 8 trials for each participant for the entire study. Video footage was captured in all 10 walking segments.

Data Analysis Procedures

Data analysis was performed using IBM SPSS Statistics software package using the adjusted Greenhouse-Geisser corrections to more accurately analyze the small sample size of the current study. Procedures for the independent variables included a cross analysis of all participants together and separately. By analyzing the trials separately it was more feasible to identify changes in the dependent variables in response to the experimental conditions. A within-subjects repeated measures analysis of variance (ANOVA) was conducted to determine statistically significant changes among the dependent variables. An alpha level of 0.05 served as the threshold for significance for the repeated measures ANOVA and 0.001 for inter-rater reliability. Data was collected by the researcher and an inter-rater observer and a correlation was obtained by comparing the two raters data sets for all trials to determine inter-rater reliability. The analysis indicated a high degree of agreement between the two raters [$r = .99 < p$ 0.001].

CHAPTER FOUR

Results

The independent variables (IV) in the current study were the rhythmic facilitation conditions. The four conditions included no stimulus (N), auditory-only (A), tactile-only (T), and simultaneous audio-tactile (AT). The dependent variables (DV) were cadence (Cad), velocity (Vel), and stride length (SL). To determine the effects of the IV on the DV, cross analysis was performed for all participants across all trials. Participants were categorized into 1 of three groups (fast walker, slow walker, and typical speed walker) by their initial pretest in each session. A participant was considered a fast walker (F) if their initial pretest cadence was above the typical range (>120 steps/min). A participant was considered a slow walker (S) if their initial pretest cadence was below the typical range (< 105 steps/min). Finally, a participant was considered a typical speed walker if their initial pretest cadence was within the typical population range (between 105 and 120 steps/min). This was done to further analyze the effects of each condition across participants. The only participants that were not consistent with their category placement across sessions were Participant 3 and Participant 6. Table 5 depicts participant categories based on initial cadence by session.

Table 5

Participant Categories Based on Initial Cadence by Session

	Session	
Participant #	1	2
1	F	F
2	S	S
3	S	T
4	S	S
5	S	S
6	T	F
7	T	T

Note: *F = Fast Walker; S = Slow Walker; T = Typical Walker*

Table 6 provides raw data for velocity across participants. Typical parameters for velocity in the general population are 1.3 meters/second, with women walking at approximately 1.25 meters/second (Perry & Burnfield, 2010). All participants walked slower than this typical range during their pretest measures for session 1 and session 2. In the current study the data for velocity was analyzed by locating changes between pretest and condition values. When looking at these raw values the AT condition showed the least change in velocity across sessions for all participants with 7 out of 14 trials identified as the most similar to the pretest for each session. The N condition showed the most change with only 5 out of 14 trials showing the most similarity across conditions. The A and T conditions showed moderate change with 6 out of 14 trials showing similarities. When looking at the individual sessions, the AT condition exhibited the least change (4/7 trials) of all the other conditions with regards to velocity for session 1; however, in session 2 it exhibited the most change (3/7 trials). It is important to note that although the AT condition exhibited the most change in session 2, it was only 1 trial ratio different than session 1, suggesting an overall less variability for velocity across sessions. The opposite was true for the N condition which exhibited the most change (0/7 trials) in session 1 and the least change (5/7 trials) in session 2. With such a dynamic change with regards to the ratio of trials, the N condition showed high variability across condition velocity values. The A and T conditioned remained consistent across session 1 and session 2 with regard to similarities between pretest and condition velocity values.

Table 6

Raw Data for Each Participant For Velocity by Condition

	Participants													
	1		2		3		4		5		6		7	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Pre	1.1	1	0.8	0.9	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.8	0.6	0.7
N	1.5	0.9	1	0.9	1.2	0.6	1.1	0.7	1.1	1.2	0.6	0.7	0.7	0.8
A	1.5	0.9	1.2	1	0.9	0.5	1	0.5	1	0.5	0.6	0.7	0.6	0.8
T	1.5	0.7	0.8	0.9	1.4	0.7	0.5	0.7	0.5	0.6	0.4	0.5	0.6	0.7
AT	1.1	0.9	0.8	0.9	0.9	1.2	0.9	0.5	0.9	0.7	0.5	0.6	0.5	0.8

Note: *Pre = pretest; N = no stimulus; A = auditory only; T = tactile only; and AT = simultaneous audio-tactile*

Table 7 provides raw data for stride length across participants. Typical parameters for stride length in the general population are 1.4 meters, with women averaging 1.28 meters (Perry & Burnfield, 2010). All participants walked with a shorter stride length than the typical population parameter. Stride length values were therefore analyzed for a change, above or below their pretest for each session. From the raw data, the N condition showed the most increase in stride length of all the conditions (8 out of 14 trials) with the A conditions exhibiting an increase in stride length in 6 out of 14 trials. An increase in stride length was observed in 4 out of 6 trials with the N condition in consistently slower walkers (participants 2, 4, and 5) and in 3 out of 6 trials with the A condition. Although consistency was observed under the N and A conditions for increased stride length, no clear pattern was observed across all participants. When looking for similarities in the raw data, the N and A conditions showed the least amount of change, with the AT condition showing the most change of all the conditioned stimuli.

Table 7

Raw Data for Each Participant for Stride Length by Condition

Participants

	1		2		3		4		5		6		7	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Pre	0.98	0.82	0.96	1.08	0.94	0.64	0.90	0.86	0.70	0.60	0.58	0.78	0.70	0.68
N	0.96	0.80	1.06	1.08	1.06	0.64	0.78	0.90	1.02	1.18	0.62	0.70	0.72	0.82
A	1.06	0.78	1.18	1.14	0.92	0.60	0.82	0.80	0.96	0.64	0.68	0.72	0.66	0.70
T	0.98	0.74	0.98	1.04	1.16	0.82	0.84	0.86	0.60	0.76	0.56	0.56	0.64	0.72
AT	0.90	0.94	0.92	1.04	0.86	1.10	0.86	0.82	0.86	0.80	0.52	0.62	0.56	0.74

Note: *Pre = pretest; N = no stimulus; A = auditory only; T = tactile only; and AT = simultaneous audio-tactile*

To analyze the effects of the stimulus conditions on gait parameters, the current study looked at stimulus matching. Stimulus matching refers to the event when the condition cadence matches or is close to the stimulus cadence (pretest). Table 8 provides the raw data by session for cadence across all participants. From the raw data, 5 out of 14 trials showed a higher rate of consistency between the stimulus cadence and the condition cadence with the A condition, whereas 4 out of 14 in the N condition and 3 out of 14 in the T and AT condition showed a higher rate of consistency between the stimulus cadence and the condition cadence. When looking at consistently slower walkers (participants 2, 4, and 5) 3 out of 6 trials showed more consistency in the T condition, whereas only 1 out of 6 trials with the A condition showed consistency. No consistency was observed for stimulus matching in the faster walkers, nor the typical speed walkers.

Table 8

Raw Data for Each Participant for Cadence by Condition

Participants

	1		2		3		4		5		6		7	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Pre	129	140	100	100	82	107	73	89	95	95	110	128	109	119
N	180	129	109	103	139	121	87	89	130	128	109	112	113	121
A	170	115	122	106	118	103	84	82	124	92	113	113	107	132
T	178	116	100	103	143	100	83	90	100	99	95	107	118	124
AT	139	109	105	101	122	131	83	77	122	100	106	110	101	125

Note: *Pre = pretest; N = no stimulus; A = auditory only; T = tactile only; and AT = simultaneous audio-tactile*

Figure 1 and 2 depict the cadences for “fast walkers” across both sessions. In session 1, Participant 1 showed the most consistency with the AT condition, whereas in session 2 both Participant 1 and 6 showed a similar trend with the AT condition being the least consistent with the stimulus. Figures 3 and 4 depict the cadences for “slow walkers” across both sessions. In session 1, the T condition was the most consistent with the stimulus cadence among slow walkers in 3 out of 4 trials. In session 2, no consistency among trials was observed. Figures 5 and 6 depict the cadences for “typical speed walkers” across both sessions. In session 1 and session 2 for typical speed walkers, the N and A conditions were observed being the most consistent in 2 out of 4 trials.

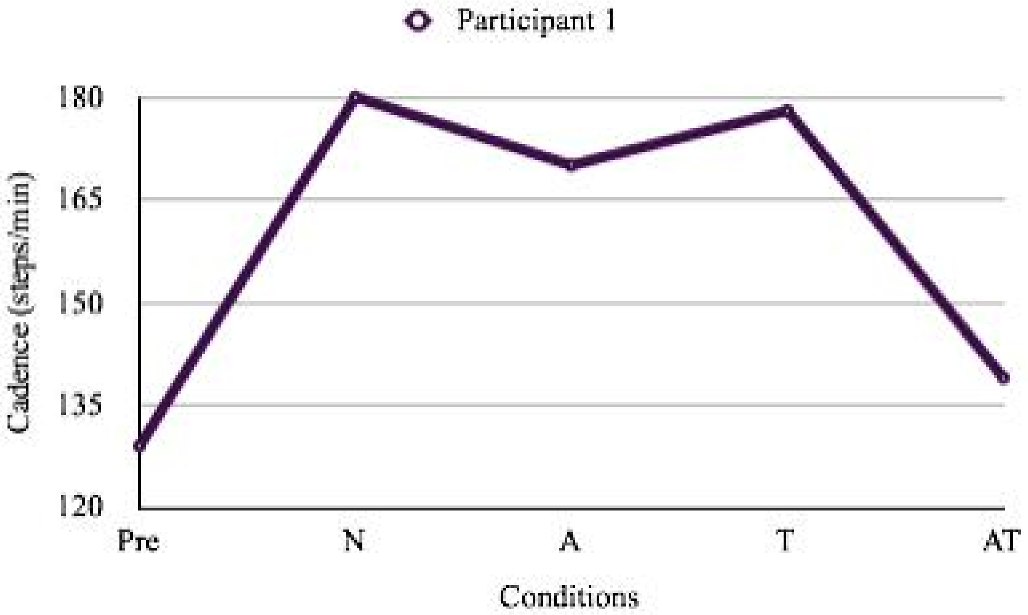

Figure 1. Session 1 Cadence Values for Fast Walkers
Note: N = no stimulus; A = auditory only; T = tactile only; AT = simultaneous audito-tactile

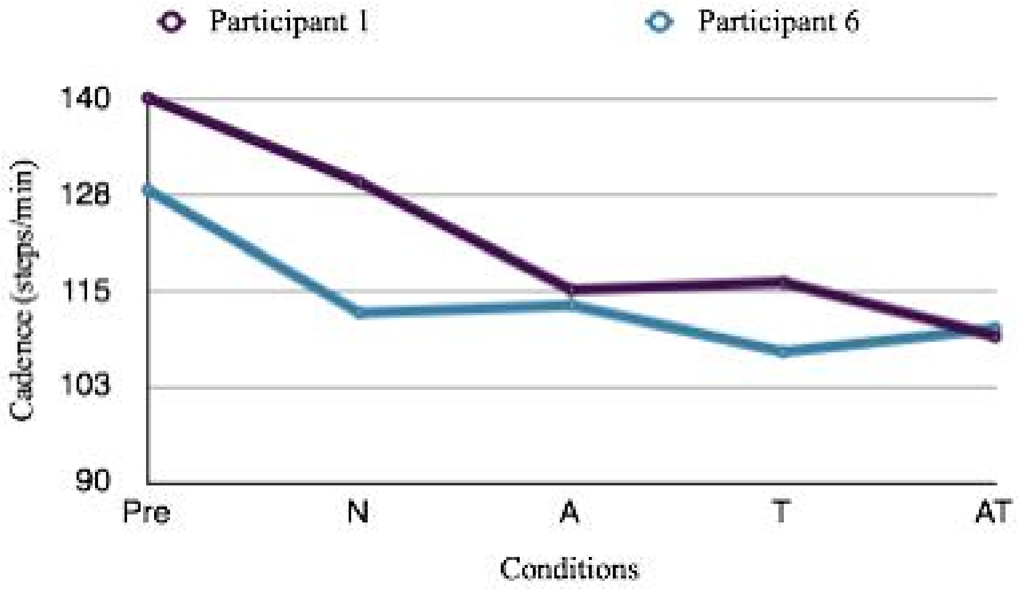

Figure 2. Session 2 Cadence Values for Fast Walkers
Note: N = no stimulus; A = auditory only; T = tactile only; AT = simultaneous audito-tactile

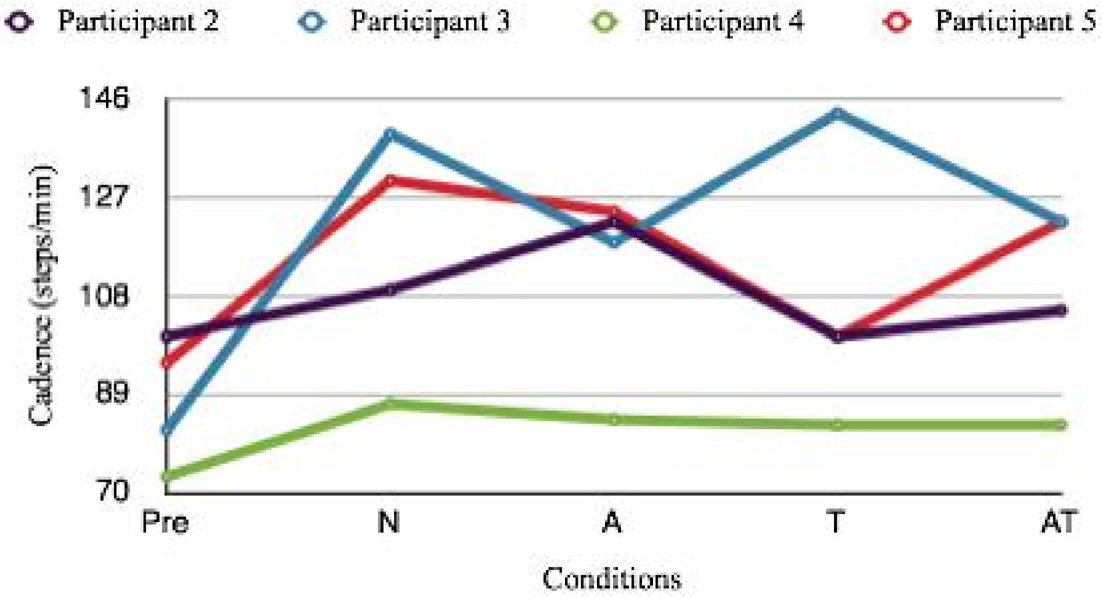

Figure 3. Session 1 Cadence Values for Slow Walkers
Note: N = no stimulus; A = auditory only; T = tactile only; AT = simultaneous audito-tactile

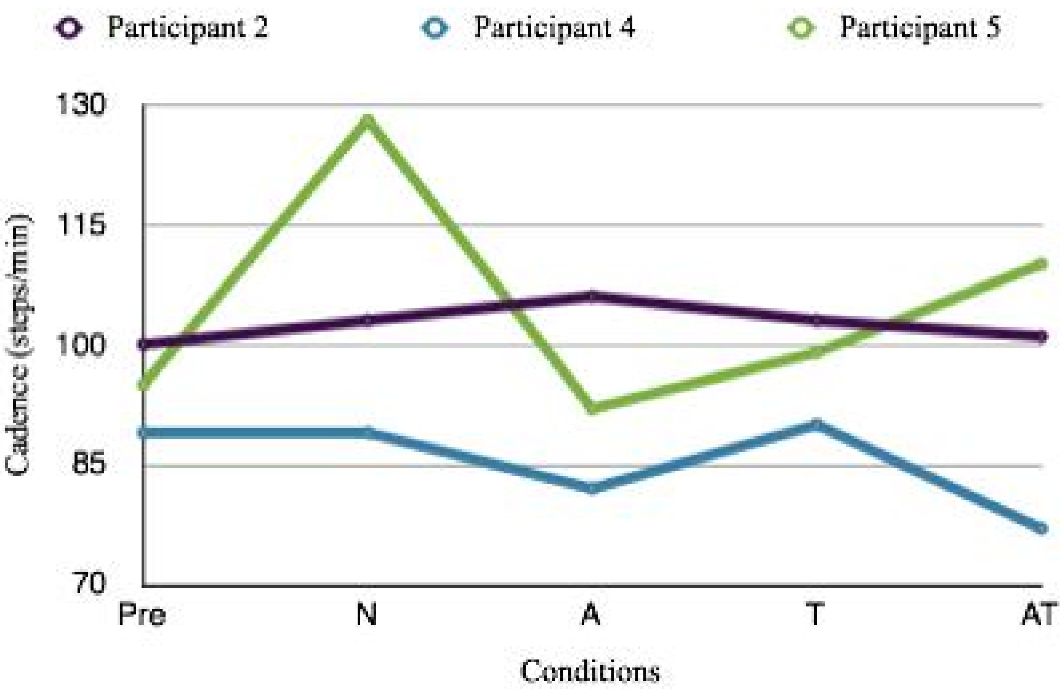

Figure 4. Session 2 Cadence Values for Slow Walkers
Note: N = no stimulus; A = auditory only; T = tactile only; AT = simultaneous audito-tactile

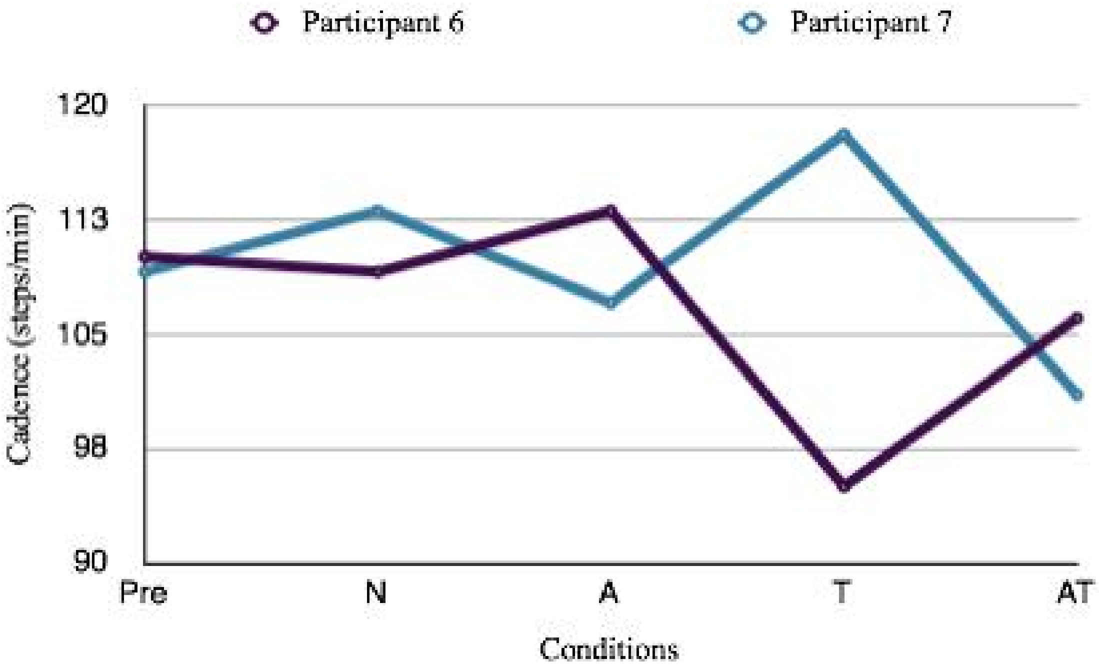

Figure 5. Session 1 Cadence Values for Typical Speed Walkers
Note: N = no stimulus; A = auditory only; T = tactile only; AT = simultaneous audito-tactile

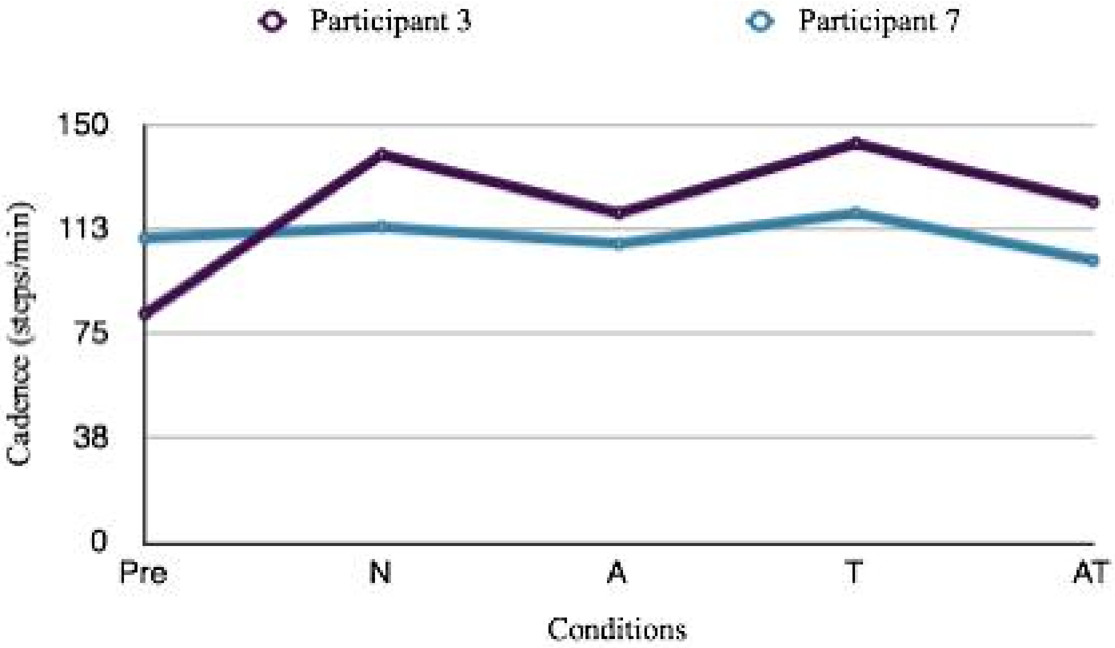

Figure 6. Session 2 Cadence Values for Typical Speed Walkers
Note: N = no stimulus; A = auditory only; T = tactile only; AT = simultaneous audito-tactile

Table 9 provides the results of the within-subjects repeated measures ANOVA. Due to the small sample size in the current study, adjusted data was used for statistical analysis using the Greenhouse-Geisser corrections. This analysis yielded no significant differences across dependent variables.

Table 9

Results of the Within-Subjects Repeated Measures ANOVA

	Session					
DV	1			2		
	df	F	*p*	*df*	F	*p*
Cad	1.958	3.804	0.054	2.374	1.038	0.391
Vel	2.384	3.026	0.073	2.388	1.032	0.394
SL	2.061	1.891	0.192	2.171	1.112	0.363

Note: *Cad = Cadence; Vel = Velocity; and SL = Stride Length. Significance found when ($p < 0.05$). DV = dependent variables. Data analysis used adapted Greenhouse-Geisser corrections.*

CHAPTER FIVE

Discussion

The present study sought to examine if children with developmental disabilities altered their gait with rhythmic cueing in the form of auditory, tactile, and audio-tactile stimuli. This chapter will expound on the statistical data reported in the results section. The results will be analyzed in greater detail and compared to other research presented in the review of literature. Clinical implications, limitations of the study, and recommendations will also be presented.

Discussion of the Research Questions

Research Question #1: Do gait parameters in children with developmental disabilities improve upon cueing of a rhythmic auditory stimulus?

Sufficient evidence exists to support the existence of a direct link between external auditory input and motor output in adults and children (Jensen, 2009; Kwak, 2007; Molinari et al., 2005; Thaut et al., 1999); however, the use of external cuing for individuals with developmental disabilities has not been studied. The current study sought to identify if changes in motor patterns would occur with the addition of external rhythmic cuing in persons with developmental disabilities. If motor synchronization were to occur the condition cadence would closely match the stimulus cadence. From the raw data presented in the results section, the A condition showed a higher rate of consistency between the stimulus cadence and the condition cadence in 5 out of 14 trials. Although the A condition was more consistent for cadence and changes were observed in velocity and stride length, no clear patterns were found across all participants.

Corriveau & Goswami (2009) suggested that children with disabilities, specifically those with speech and language impairments, display significantly less sensitivity than control subjects to auditory rhythmic timing cues. The lack of clear patterns in the current study may support this statement (Corriveau & Goswami, 2009). The present study demonstrated that gait parameters for children with developmental disabilities did change in conditions that included an auditory rhythmic stimulus; however, the data do not support synchronization to the stimulus. Therefore, research question 1 is accepted with the limitation that changes may not have been conducive to gait patterns.

Research Question #2: Do gait parameters in children with developmental disabilities change upon cueing of a rhythmic tactile stimulus?

From the raw data presented in the results section, the T condition showed a low consistency with the stimulus cadence across participants in only 3 out of 14 trials; however, among slow walkers, the T condition was the most consistent in 3 out of 4 trials with the stimulus cadence. Across all participants, no clear patterns were observed for the T condition. The T condition did induce changes in 5 out of 14 trials for velocity and stride length. Although changes were observed for velocity and stride length under this condition, no clear patterns were observed across participants. Kurz, Stuberg, and Dejong (2011) found that when using a rhythmic tactile stimuli with children with CP, they observed significantly faster velocity and longer stride length. The current study did observe a slight increase in velocity and stride length; however, no clear patterns were found. Therefore, research question 2 was accepted with the limitation that changes may not have been conductive to gait patterns.

Research Question #3: Do gait parameters in children with developmental disabilities change upon cueing of a rhythmic audio-tactile stimulus?

From the raw data presented in the results section, the AT condition showed a low consistency with the stimulus cadence across participants in only 3 out of 14 trials. The AT condition also showed the most change or less similarity of all conditions with regards to cadence. The AT condition did induce changes in velocity and in stride length; however, no clear patterns were observed for the AT condition across all participants. Evidence in the literature suggests that an overall significantly greater activation in neuronal areas are present when both auditory and tactile modalities are provided simultaneously as compared to each constituent independently (Elliot et al., 2010; Fox et al., 2002). Other researchers have specifically found that presenting auditory and tactile cues simultaneously improves motor coordination in typically developing participants (Kelso, Fink, DeLaplain, & Carson, 2001). Data in the current study indicated that the AT condition yielded the least consistent cadence, suggesting that the convergence of both stimuli was not beneficial with this population. Therefore, research question 3 was accepted with the limitation that changes may not have been conductive to gait patterns.

Although all conditions changed gait, no significant changes were observed. The inconsistency of the data makes it difficult to conclude that the participants synchronized to the stimulus. Some participants demonstrated improvements in the no stimulus trial, further making it difficult to draw conclusions on the impact of the added external stimuli. Researchers have previously observed a high synchronization with an external auditory stimulus in children with CP (Jensen, 2009; Kwak, 2007). In the current study, the A condition showed the most likely evidence of stimulus matching; however, this was only demonstrated in 35% of participants. Previous research studies also showed greater activation in neuronal areas when both auditory and tactile modalities were presented simultaneously (Elliot et al., 2010; Fox et al., 2002); however, this was not observed in the current study. Across all participants, little evidence was found that the changes that did occur in gait parameters were helpful in terms of synchronization or uniform changes to gait patterns.

Clinical Implications

The current study is among the first to examine the use of external rhythmic facilitation with children with a variety of developmental disabilities. It is also the first of its kind to examine the effects of external tactile facilitation and external audio-tactile facilitation for stimulus matching. There have been only a few recent studies using rhythmic facilitation with children (Jensen, 2009; Kwak, 2007) and no conclusive evidence supporting that this facilitation, specifically RAS, is an effective technique to use in a habilitation model or that rhythm can synchronize gait in children with developmental disabilities. Although researchers suggest that children of 11 years and older can entrain to an external stimulus (Jensen, 2009), there is not enough evidence to demonstrate that persons with developmental disabilities entrain to an external stimulus.

One difference between previous research and the current study is the level of cognitive functioning of the participants. Jensen (2009) and Kwak (2007) conducted their research with children with CP with no identified cognitive delays, whereas the participants in the current study presented with severe and profound cognitive delays. The presence of protracted cognitive and physical functioning in this population may impact their neuronal ability to use the external sensory information to impact motor planning and execution. Therefore, clinicians interested in using rhythmic facilitation for gait training with this population should consider the client's cognitive and physical functioning when designing therapeutic interventions.

The current study was conducted in a real world clinical setting where there were some confounding variables. Trials were conducted in a school hallway where environmental distractions may have overwhelmed the participants and negatively impacted the trials. Although conclusive results were not identified, clinicians conducting research or treatment in similar settings should consider the impact of the environment on the client's ability to engage in treatment.

Although the current study did not find conclusive evidence that children with developmental disabilities entrained to an external rhythmic stimulus or received benefits from the addition of external rhythmic facilitation for gait parameters, the current study may raise awareness of clinicians in the field regarding the use of a multi-sensory approach with this population. The current study did observe participants responding differently to the condition stimuli, therefore the addition of external cueing should be considered on an individualized basis. Taking into consideration that children with developmental disabilities can present with a variety of cognitive and physical deficits, therapeutic treatment should likewise be individualized. For some children, the integration of multiple senses may be too distracting, while others may show improvements in functioning. Gait improvements can also be variable among individuals and need to be taken into account when considering the addition of a multi-sensory approach for gait functioning. It is essential to consult with the child's treatment team to identify the gait improvements appropriate for that child.

Limitations of the Current Study

Limitations of the current study include the small sample size, the differences within the population, confounding variables, and technological limitations. First, with a sample size of seven, an overall lack of power was observed for statistical analysis. Secondly, population characteristics and diagnoses were highly variable. When analyzing the participant's disability categories, the most consistent diagnosis was a general intellectual disability followed by seizure disorder and microcephaly. Children with learning disabilities score significantly lower in gross motor outcomes than those of their typically developing peers and present with disruptions in ascending sensory and descending motor pathways (Hoon et al., 2009; Westendorp, Hartman, Houwen, Smith, & Visscher, 2011). Since a general intellectual disability can present in a variety of different domain areas, the variability in results may link to the variability of cognitive, physical, and sensory processing abilities.

A few confounding variables were identified in the study procedures, including the placement of the external stimuli. Ro et al. (2009) found that when auditory and tactile stimuli were placed on the same side of the body, participants showed increased detection of the stimulus. Due to environmental factors, the auditory and tactile sources were not presented on the same side, but rather the auditory stimulus was heard on the participant's left/back quadrant and the tactile stimulus placed and felt on the participant's right hip. With previous research suggesting location may have a profound effect on the sensory integration of both stimuli, placement of stimuli warrants further investigation.

Another variable that was not expected was the novelty effect of the vibrating metronome. More familiarization of the metronome may have been helpful in decreasing any potential negative effects of wearing the metronome. Another limitation includes the use of simultaneous auditory and tactile stimuli and the difficulty to synchronize both, taking into consideration frequency and temporal parameters. Both frequency and temporal parameters have been shown to significantly effect motor performance when incongruent (Bresciani & Ernst, 2007; Elliot, Wing, & Welchman, 2010; Ro et al., 2009). Although the researcher took extra precautions to synchronize these stimuli with the sync function on the Peterson BBS-1 BodyBeat Synch Pulsating Wireless Metronomes, the stimuli may have been "out of synch" at a level below conscious perception, which may have impacted the participant's response in the AT condition.

Environmental factors may also have led to the inconsistencies in the data. The 10 meters were marked off in a long hallway at the local state school where the participants attended. This long hallway was the only area available to work with the participants for such a length and was in a high traffic area in the school. The researcher noted several interruptions from other students and staff traveling in and out of classrooms during the testing period. The hallway was also lined with windows to the playground and some participants were observed being distracted by other students and staff outside. The researcher took steps to eliminate environmental interruptions by: (a) posting "Research In Progress" signs on all sides of the hallway to inform those wanting to use the hallway, (b) completing the research trials at lower traffic times during the day (9:45-11am and from 12:45-2pm), and (c) giving the participants a focal point at the end of the hallway to concentrate on with verbal reminders to look forward, if necessary. Even with the precautions, environmental interruptions were inevitable in this testing location. It was the intent of the researcher to use an experimental procedure that would be accessible to clinicians working with this population using a testing area as close to "real life" as possible, however this may show implications in the variability of the results.

A final limitation of the current study was technological restrictions. Although the inter-rater analysis indicated a high degree of agreement among timed observations [$r = .99 < p .0001$], the gait parameters themselves may not be detailed enough to form concrete conclusion. A more detailed kinematic approach to gathering gait parameters may lend itself more appropriately to identifying key gait changes with regards to synchronization.

Recommendations for Further Research

Future researchers should consider the experimental design, participant characteristics, potential confounding variables, and appropriate measurement tools when examining external rhythmic cueing in children with developmental disabilities. First, with regards to design, replication of the study should include a pilot study focused on feasibility and identifying any potential trends in outcomes. Future studies should also extend the length or number of trials taken to better analyze overall impact of condition on gait parameters. Secondly, replication of this kind should identify specific participant diagnoses to better determine the effectiveness of external rhythmic cueing on gait parameter changes.

Potential confounding variables to consider include the placement of the auditory and tactile stimuli, while also considering the participants dominant side. Other considerations include the familiarization of the tactile stimulus to decrease the novel effect of the vibrating metronome. In addition, future studies should consider reducing environmental distractions in the testing area, as this clinical population show sensory deficits which may include a lack of attention with high levels of responses to distractions. Lastly, researchers should take into consideration using more specific measurement tools to determine if there are changes that are not perceivable in observation.

Conclusions

The current study illustrates that the addition of external rhythmic stimuli changes gait parameters in children with developmental disabilities, however no clear patterns were observed. Overall, this preliminary study indicates that children with developmental disabilities may react to the addition of external rhythmic stimuli, however no conclusive evidence was found to support that this population can entrain to an external stimuli. The findings from the current study illustrate that a more detailed study design was needed to effectively research the use of external rhythmic facilitation to improve gait parameters for children with developmental disabilities.

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APPENDIX A

Screening Questionnaire for Inclusion

PARTICIPANT NUMBER: ______________________ DATE: ________________________

DATE OF BIRTH: ______________________________ AGE: _________________________

PRIMARY DIAGNOSIS/DISABILITY:

____

____

____

1. Is the participant between the ages of 11 and 17 years? Yes No

2. Is the participant diagnosed with a developmental disability by a licensed professional?
   Yes No

3. Does the participant ambulate independently? Yes No

4. Is the participant able to ambulate the distance of a short hallway without a break?
   Yes No

APPENDIX B

Data Collection Worksheet (Pretest)

PARTICIPANT NUMBER ___________________ DATE ___________________

SESSION # _______________

Data:

Distance = _______________ meters (constant = 10M)

(X) Time of 10M = _________________seconds

(Y) Time of 10 steps = _________________seconds

Formulas:

Stride Frequency (SF = 5/Y):

Strides (5)/ ______________ (Y)sec. = ____________________Hz

Cadence (C = SF x 60):

_________________Hz x 60 = ___________________steps/min (bpm)

Velocity (C = 10/X):

Distance (10 meters) / _________ (X) sec. = ________________m/s

Stride Length (SL = V/SF):

________________(velocity) / _________________ (SF) = ___________________m

---

Cadence = ____________________steps/min **Velocity** =

_____________________m/s

Stride Length = __________________m

Cadence set in metronome = _____________________bpm

APPENDIX C

Data Collection Worksheet (Conditions)

PARTICIPANT NUMBER ___________________ DATE ___________________

SESSION # _______________ CONDITION # ________________

Stimulus (circle): no stimulus auditory only tactile only audio-tactile

Data:

Distance = _______________ meters (constant = 10M)

(X) Time of 10M = _________________seconds

(Y) Time of 10 steps = _________________seconds

Formulas:

Stride Frequency (SF = 5/Y):

Strides (5)/ ______________ (Y)sec. = ____________________Hz

Cadence (C = SF x 60):

_________________Hz x 60 = ___________________steps/min (bpm)

Velocity (C = 10/X):

Distance (10 meters) / ________ (X) sec. = ________________m/s

Stride Length (SL = V/SF):

________________(velocity) / _________________ (SF) = ___________________m

----

Cadence = ____________________steps/min **Velocity** = _____________________m/s

Stride Length = __________________m