RHYTHMIC AUDITORY-MOTOR ENTRAINMENT OF GAIT PATTERNS IN ADULTS WITH BLINDNESS OR SEVERE VISUAL IMPAIRMENT

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by
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RHYTHMIC AUDITORY-MOTOR ENTRAINMENT OF GAIT PATTERNS IN ADULTS WITH BLINDNESS OR SEVERE VISUAL IMPAIRMENT

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ABSTRACT

The following study investigates the impact of a rhythmic cue on the observational gait parameters of a population of adults with blindness or severe visual impairment. Forty-six adults who had sight loss significant enough to require the use of a long cane for mobility purposes participated in the study. Participants were between the ages of 18 – 70 years. The study design was a within-subjects, repeated measures design with two levels for the independent variable of the metronome (uncued versus cued) and two levels for the independent variable of tempo (normal walk versus fast walk). Dependent variables of cadence (steps per minute), velocity (meters per minute), and stride length (cadence ÷ (velocity ⁄ 2)) were recorded. Within-subjects repeated measures statistical analyses identified a main effect for the independent variable of the metronome; subsequent analysis revealed that the metronome had a significant effect on the dependent variable of cadence.

The presence of a rhythmic cue seemed to improve observational gait parameters for many of the study participants. A more in-depth investigation reveals the complex interrelationship of gait parameters, as well as the need to differentiate between the clinical importance of the study and the need for additional basic scientific research. While compelling clinical inferences can be drawn from this study, there continues to be a need to establish rhythmic auditory-motor entrainment as a sound theoretical framework upon which further research and clinical protocol development for this sample population can be based.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Graduate Studies, have examined a dissertation entitled "Rhythmic Auditory-Motor Entrainment of Gait Patterns in Adults with Blindness or Severe Visual Impairment," presented by Della Molloy-Daugherty, candidate for the Doctor of Philosophy degree, and certify that in their opinion it is worthy of acceptance.

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This is dedicated to my two children, Lauren and Isaac.

We did it!

I love you both…more!

CHAPTER 1

INTRODUCTION

Demographic data collected by three government agencies provide a recent snapshot of the number of adults and children in the United States who have a level of vision loss that impacts daily functioning. The *National Center for Health Statistics* (NCHS) survey (2011), found that approximately 21 million adults, or 9% of the adult population, reported to have vision trouble, defined as "trouble seeing, even with glasses or contact lenses" (Schiller, Lucas, & Peregoy, 2012, p.7). This includes adults with *total blindness* (no light perception), adults with *legal blindness* (20/200 visual acuity with best correction, or a visual field of 20 degrees or less), adults with *severe visual impairment* (a visual loss significant enough to interfere with daily activities such as reading, working, attending school, or travel), and adults who merely report having significant trouble seeing (Huebner, 2003).

The American Printing House for the Blind maintains an annual register of children age birth through 21 years who meet the definition of legal blindness. Their 2012 annual report stated that 59,193 children in the United States met the criteria (American Printing House for the Blind, 2013). The 2011 American Community Survey (ACS) within the United States Census Bureau found that 518,382 children age birth through 18 had vision difficulty in the United States (United States Census Bureau, 2013). This number includes the children who qualify as legally blind, totally blind, or severely visually impaired (B-SVI).

The number of individuals who are B-SVI seems small in proportion when compared to the 12% of Americans reported to have a disability (United States Census Bureau, 2013). However, the impact sight loss has on an individual can be profound. Visual disabilities impact two areas of daily life in a major way: Access to print information, and independent travel within one's environment. Locomotion, the ability to move safely and freely from one place to another, presents a major challenge in the daily life of a person with B-SVI.

Locomotion at its most fundamental level refers to safe, fluid, and efficient movement. Individuals with B-SVI may use a long cane, dog guide, or human guide when walking from one point to another. Locomotion involves additional skill sets to ensure safe movement from place to place. A person with B-SVI must detect and navigate obstacles in their path and have vigilance to auditory surroundings, such as crosswalk warning signals and traffic sounds. They must also create mental mapping for places of importance (e.g. the relationship of the restroom to the classroom) and be able to walk on changing surfaces, terrains, and gradients, such as a transition from wood floor to carpet, sidewalk to grass, and walking on snowy or rainy surfaces, as well as up and down hills. People with B-SVI must also be responsive to continually updated, yet rapidly changing sensory information regarding the body's position in space, and the body's position in relation to objects and trajectories in the environment as the body is moving. Of the different ways one can demonstrate locomotion (walking, running, skipping, hopping), the most commonly used throughout daily life is walking.

Walking, or gait, in individuals who are B-SVI has been a topic of considerable interest. Visual observation of an individual traveling with assistance (human guide, long cane, or guide dog), illustrates movement through space that differs from a sighted person. Professionals and researchers have described observed gait differences of travelers who are B-SVI (Dawson, 1981; MacGowan, 1983; Mason, Legge, & Kallie, 2005; Ramsey, Blasch,

& Kita, 2003; Ramsey, Blasch, Kita, & Johnson, 1999; Rosen, 1997) and have compared their gait characteristics with those of sighted individuals (Johnson, Johnson, Blasch, & De l'Aune, 1998; Nakamura, 1997; Nakata, Nakamura, Kakizawa, & Rahardja, 1990; Ray, Horvat, Williams, & Blasch, 2007). Interventions, strategies, or assistive devices have been tested in order to improve gait characteristics (Chin, 1988; Clark-Carter, Heyes, & Howarth, 1986; Hollyfield & Trimble, 1985; Larsson & Frändin, 2006; Siegel & Murphy, 1970). Inhibited locomotion can negatively impact learning in an educational environment (Molloy-Daugherty, 2010a, 2010b) and productivity in a work environment due to the inefficiencies in travel skills from one location to another. Interventions that may improve the quality of gait may also have an effect on the quality of life, independence, and success in school and work for an individual with B-SVI.

Services that address travel and locomotor issues include Orientation and Mobility (O&M) training, physical therapy, occupational therapy, and early intervention services. O&M trains individuals with vision loss to travel safely and efficiently. *Orientation* refers to a person's ability to use incoming sensory information to determine and maintain one's sense of position in space in relation to everything in the environment. *Mobility* refers to the techniques learned and utilized that allow people to travel safely and independently from one point to another. O&M lessons are provided by Certified Orientation and Mobility Specialists (COMS) and serve individuals across the lifespan in early intervention programs, public schools, residential schools for students with B-SVI, adult vocational rehabilitation programs, veteran's hospitals, and nursing care facilities.

In addition to O&M, physical therapists and occupational therapists address functional motor issues that support travel. Early intervention specialists target developmental motor needs with infants and early childhood-age children with B-SVI. Since vision plays a critical role in motor development, a visual impairment can have an adverse impact on this development (Adelson & Fraiberg, 1974; Bigelow, 1992; Brambring, 2001, 2006; Bouchard & Tétreault, 2000; Celeste, 2002; Elisa et al., 2002; Levtzion-Korach, Tennenbaum, Schnitzer, & Ornoy, 2000; Murphy & O'Driscoll, 1989; Ross & Tobin, 1997; Tröster & Brambring, 1993; Tröster, Hecker, & Brambring, 1994).

One tool that has been used to target walking deficiencies in a wide variety of clinical populations is rhythm. The *Harvard Concise Dictionary of Music* defines rhythm as "the aspect of music concerned with the organization of time" (Randel, 1978, p. 423). More broadly, rhythm is "movement or procedure with uniform or patterned recurrence of a beat, accent, or the like" (Dictionary.com, 2012). Research suggests that the musical element of rhythm functions as an external timekeeper for rhythmic movements such as walking (Thaut, 2005). Rhythm has been found to improve gait parameters in individuals with stroke, traumatic brain injury, Parkinson's disease, cerebral palsy, and Huntington's disease (Arias & Cudeiro, 2010; Hayden, Clair, & Johnson, 2009; Hurt, Rice, McIntosh, & Thaut, 1998; McIntosh, Brown, Rice, & Thaut, 1997; Thaut, Hurt, Dragon, & McIntosh, 1998; Thaut, Lange, Miltner, Hurt, & Hoemberg, 1996). Rhythm has been extensively researched as a timing mechanism to cue and improve walking in many disability and disease populations. It has yet to be substantiated as an effective intervention for individuals who are B-SVI.

Clinical experience suggests that music may be effective in improving both walking and motor skills in children with visual impairments. An elementary teacher at a residential school for the blind located in the Midwest expressed concern at the length of time it took for students to travel from the classroom to the music therapy room. For two students in particular, their impeded travel skills decreased academic learning time. Rhythmic cueing was utilized to target their travel time. Results indicated that an external rhythmic cue, embedded in a song about walking and presented at each student's frequency entrainment tempo, improved travel times of the two students (Molloy-Daugherty, 2010a).

During the first study it was observed that the two subjects displayed a significant need for additional training to address specific pre-walking skills. The music therapist, a physical therapist, and a music therapy clinical researcher embedded training techniques into a pre-existing elementary music curriculum that was adapted to the learning needs of the case study participants' entire class. Specific training on skills such as foot placement and weight shifting were integrated with music education targets, and seemed to be an effective model of co-treatment across disciplines, as well as a beneficial model of individualized instruction to meet diverse educational and therapeutic needs (Molloy-Daugherty, 2010b).

A subsequent systematic review of literature found an absence of music interventions that have been designed and tested which focus on pre-walking motor skills (Molloy-Daugherty, 2010c). Clinical case studies seemed to indicate that music functions in a fundamental way to facilitate better walking, more efficient travel, and more fluid movement (Molloy-Daugherty, 2010a; 2010b). Rhythm in particular appeared to better organize the movements of visually impaired individuals. Yet, there is no existing research indicating why this seems to be effective. Nor does published research document a specific music therapy technique designed to improve travel skills or pre-walking motor skills for this population. Thus, there is a significant need for a better understanding of the therapeutic mechanism that affected change in the case studies, as well as strong research to support the implementation of therapeutic interventions to facilitate improved gait and motor functioning for individuals with visual impairments.

There are several issues that contribute to the value of studying the relationship between rhythm and gait for people who are B-SVI. First, there exists a dearth of clinical research pertaining to music, travel, pre-walking motor skills, and individuals who are B-SVI. Second, a clinical case study suggested that an external rhythm cue improved travel skills for children with severe visual impairment (Molloy-Daugherty, 2010a). Third, the scientific foundation has been established for the use of rhythm as an external timekeeper for walking, as well as for smoothness and fluidity of movement for many different populations of individuals (Hayden et al., 2009; Hurt et al., 1998; McIntosh et al., 1997; Thaut et al., 1998; Thaut, Kenyon, Schauer, & McIntosh, 1999), but not for those with vision loss. Lastly, replication of scientific experiments examining gait that have demonstrated positive outcomes with other populations may also be effective for individuals with visual impairments. Hence, this study will examine whether an external rhythmic cue can function as an entrainment mechanism to impact gait parameters for adults who are B-SVI.

CHAPTER 2

REVIEW OF LITERATURE

The review of literature begins with a detailed explanation of the human gait cycle to create a context for the expected developmental trajectory of walking. A review of the published research studies targeting travel and locomotor needs will follow. Next, a review of related music and music therapy services and published research studies will be outlined. Last, the author outlines a scientific model of inquiry in order to arrive at the proposed research questions.

Human Gait

Walking is a highly typical human movement. In general, people walk throughout their entire lives once the developmental milestone is achieved, between the ages of 12-18 months. At first glance, it seems to be an effortless task that one does without thinking. It also seems initially that one does not “know” how to walk until the developmental milestone is reached. However, it has been found that walking is an incredibly complex feat with its foundation originating in a person’s neural circuitry at birth (Kolb & Whishaw, 2003).

It is widely agreed that people are born hard-wired with the innate ability to walk (Cohen, 1999; Grillner, 1975; Logan et al., 2010). Initial walking is a reflexive action that originates in the brainstem and spinal cord (Field-Fote, 2000). This can be observed in infants (who have not learned to walk, nor have they observed others walking) taking rhythmic, patterned steps with their lower extremities as if walking, when their weight is supported by a caregiver and their feet are placed on a treadmill. As infants begin to engage in purposeful movement, these reflexive patterns fade and give way to volitional movement patterns. The motor lexicons of movement sequences develop from reflexive movements to volitional movement through cognitive and sensorimotor development in early infancy, from primitive reflexes to purposeful, goal-directed movements (Dale & Sonksen, 2002; Rosen, 1997).

The act of walking is not one single motion, but a highly complex series of coordinated movements and efforts of multiple muscle groups and joints. This coordination is organized and maintained by a multitude of continuously firing nerve impulses. These muscle activation patterns are complex, and must function in organized and repetitive patterns rather than in separate, discreet movements. Ultimately and ideally, a typical adult walking pattern is sustained across the lifespan by the collaboration of neural networks and motor activation patterns (Kolb & Whishaw, 2003).

There is a clear distinction to be made regarding two understandings of the biological task of walking. First, lexicons of movements are organized into motor plans and are present at birth. These are observed in infants who have not learned how to walk. With sensorimotor developmental milestones and experiences, initial reflexive responses and movements gradually fade and transform into purposeful, goal-directed movements including walking (Strickling, 1998). The complex networking and neurological coordination of impulses and movements responsible for all human walking is a shared system, and remains a critical component of fluid movement throughout the lifespan. In short, the motor plans have always been present, and they support the lifelong task of walking as a purposeful, conscious movement. This distinction of walking will be described in more detail, as it is the observed human behavior that is the topic of the present study.

The Gait Cycle

Gait is a complex cycle of repeated sensory input and motor output, with both behaviors continually influencing the other. In fact, it has been said that all movement is based upon the continual intertwining of these two physical functions (Rosen, 1997). It is important to understand both parts of this cycle so that the impact of vision and of vision loss on gait is clear.

Sensory Input

The brain receives sensory input relevant to gait from the visual system and the somatosensory system. Vision is an enormous source of sensory input for the brain, as 55% of its entire cortical surface is involved in the receipt or processing of visual stimuli (Kolb & Whishaw, 2003). There are nine identified visual areas of the occipital cortex. These areas receive information from the eyes regarding detail such as color, size, form, motion, structure, position, and depth. Processing of visual information occurs in the occipital lobe and neural connections are projected through the entire cortex including the temporal, parietal, and frontal lobes for additional processing. In short, vision uses the largest amount of the cortex out of all other sensory processing (Kolb & Whishaw, 2003).

The other major source of sensory input impacting gait is the somatosensory input received from the proprioceptive and vestibular systems. These are body senses that coordinate the input from muscles, joints, tendons, and the middle ear regarding the body's position in space and how the body and its parts are moving in space. Proprioception is the perception of body position, body movement, and the movement of different parts of the body. Receptors are located in muscles, tendons, and joints. Movement provides ongoing sensory feedback. Proprioception is also involved with maintaining balance during movement. The vestibular system, located in the inner ear, is constantly aware of head position and works to maintain and regain balance (Strickling, 1998). Righting reactions tell the body and head how to align as well as telling the body which way is up (Batra, Sharma, Batra, Malik, & Pandey, 2011).

Input from the visual and somatosensory systems is not completely independent of each other. Rather, vision acts as an integrator of all incoming sensory stimuli (Rosen, 1997). Proprioceptive and vestibular sensory information received from the body's joints in the feet, legs, trunk, arms, shoulders, and head, is paired with visual input. This synthesis allows the brain both to define and to refine movement parameters such as speed, trajectory, and orientation of the body and head in space.

Motor Output

Two major phases exist in the output portion of the gait cycle, called the stance phase and the swing phase. The stance phase includes the heel-strike, the mid-stance position with the foot flat on the ground, and then a push-off. Sixty-two percent of the gait cycle occurs during the stance phase, where the body bears its weight and spends the most time. The remaining thirty-eight percent of the gait cycle is called the swing phase. It is marked by the swinging forward of a leg in order for the body to take a step forward. A stride is an entire cycle from heel strike to heel strike on the same foot on the same side of the body (Chambers & Sutherland, 2002).

Temporal stride analysis is a stable and reliable means to measure gait parameters. The three gait parameters of *cadence, velocity,* and *stride length* are useful because they are easily observed, quantified, and provide information regarding a person's walking characteristics. Cadence refers to the number of steps taken per minute; velocity is the distance traveled per minute; stride length represents one complete gait cycle from heel-strike to heel-strike on the same foot. These parameters inform how many steps a person takes, how fast the person travels, and the size of a person's steps (Rancho Los Amigos National Rehabilitation Center, 2001).

A stable gait pattern has an observable fluidity and efficiency, with a natural and reciprocal arm swing. Sighted people typically exhibit a mature gait pattern by ages three to six, which is the same age that coordinated arm swing and running emerge (Rosen, 1997). A typical adult (ages 20-69 years) cadence is between 111-121 steps per minute, velocity ranges from 79-82 meters per minute, and a stride length varies from 1.32 to 1.48 meters (Rancho Los Amigos National Rehabilitation Center, 2001).

Pre-Walking Motor Prerequisites

For the body to move efficiently through space, certain pre-walking motor prerequisites must be present. Muscle tone, balance, posture, and coordination begin to emerge and develop in infancy, and are foundational for all locomotor behavior including gait. They are depended upon for walking throughout the lifespan (Rosen, 1997; Strickling, 1998).

Muscle tone is a baseline level of tension in the muscles of the body that supports a neurological readiness for movement (Rosen, 1997). Muscles continually receive a low level of neural impulses so that the body is primed for action. Adequate muscle tone allows the body to quickly respond to changing motor demands. Low or absent muscle tone creates a situation where the body is not primed to move, therefore requiring more sensory input, energy, and vigilance to respond to motor demands. Posture is muscle tone specifically utilized to place the body in an upright position for locomotion. The body requires this so that it can maintain its center of gravity, and then allow that center of gravity to change and move during walking (Strickling, 1998; Rosen, 1997).

Two other prerequisites are balance and coordination. Balance is the body's ability to remain stable within its center of gravity. Static balance refers to the balance required when in a sitting or standing position and not moving. During a standing position, the body keeps its center of gravity within its base of support. Dynamic balance is required during movement. Dynamic balance integrates sensory and motor input from visual, proprioceptive, vestibular systems, and muscle tone, and is crucial for the body to move through space. Static and dynamic balance are critical building blocks because walking is a continual process of losing and regaining balance as the body moves in space. Coordination allows the body to integrate sensory input, internal processes, and the external demands or its motor output. For ambulation, the body must very quickly and efficiently integrate all incoming sensory information to produce coordinated walking (Rosen, 1997).

The Impact of Vision on Locomotor Skill Development

Vision is not responsible for human locomotion or motor development. However, since it is a major source of sensory input, it does play an important role in the input/output loop of locomotion. Three important points must be articulated about the role of vision. These include *vision for action*, *prehension*, and *incidental learning*.

Vision for action.

Since the occipital lobe of the brain processes so much sensory input and then disperses it to every other lobe of the brain, there are different categories of visual phenomena. One is called vision for action, referring to the processing of incoming visual signals for directing and modulating one's movements accordingly (Kolb & Whishaw, 2003). Vision for action is constantly, instantly, and efficiently updated and synthesized for rapid response. Visual input regarding the body's orientation in space, the path of travel, and the location of and distance between objects in the environment is immediately available for quick response regarding speed, distance, and trajectory of travel. Vision also gives immediate information about objects, terrains, dangers, and obstacles that are out of physical reach of a person's body. Vision allows a person to make quick, even automatic decisions about ambulation based on this information (Kolb & Whishaw, 2003).

Prehension.

Human locomotor development begins in infancy with the initial reflex and volitional movements made by babies. Initial movement experiences are necessary to lifelong locomotor ability. Sighted infants engage in visually directed reaching for objects at 3-5 months of age. Known as prehension, it is thought that this initial reaching, motivated by a visual cue such as a caregiver or a desired object, begins the entire developmental locomotor sequence (Adelson & Fraiberg, 1974). Prehension subsequently stimulates rolling at 3-5 months, sitting at approximately 6-8 months, purposeful movement by crawling, creeping, or scooting at 6-8 months, standing unassisted at 9-11 months, cruising furniture at 9-11 months, and walking unassisted at about 15-18 months of age (Pogrund & Fazzi, 2002).

These motor experiences help babies develop muscle tone, posture, balance, and coordination, which are all prerequisites for walking and lay the foundation for an efficient gait cycle.

Incidental learning.

Nearly three-fourths of what humans learn is through vision, without deliberate instruction or conscious learning (Takashita, 2010). Called incidental learning, sighted individuals throughout their lifespan receive information about the world through vision. Incidental learning includes learning about movement by watching the movement of others. Visual models illustrate an enormous amount of information about what safe, efficient, and fluid gait looks like, as well as how speed, distance, and trajectory play a role in ambulation (Logan et al., 2010).

In summary, vision plays a major role in locomotor development, ambulation and gait cycle. Vision for action enables the brain to modulate motor plans regarding movement. Prehension is thought to jump start the entire locomotor developmental sequence in infants. Lastly, incidental learning comprises a large portion of what people learn about their environments (Adelson & Fraiberg, 1974; Kolb & Whishaw, 2003; Pogrund & Fazzi, 2002; Takashita, 2010).

The Gait Cycle for Individuals with Blindness or Severe Visual Impairment

Sensory input received for the gait cycle differs markedly for the visually impaired individual. First, visual input and subsequent vision for action is severely compromised or missing altogether. Instant visual information such as the path to be traveled, the distance, terrain, objects, potential obstacles, or the location of landmarks and buildings is not immediately accessible to the person who is B-SVI. Second, incidental learning through the visual modeling of movement throughout one's lifetime, continually received by sighted individuals, is unavailable to those without sight. Last, sensory input received from the visual, proprioceptive, and vestibular systems is integrated. A visual impairment breaks down this integration; the loss of vision contributes to the interruption of additional sensory input from the vestibular and proprioceptive systems (Strickling & Pogrund, 2002). In other words, input received from the proprioceptive and vestibular systems is more essential, yet is not as complete for the individual with B-SVI as it is for a sighted individual. Thus, the person with sight loss places a greater demand on somatosensory information to establish movement patterns, yet this information is compromised because it has not been paired with visual stimuli.

As a result of a markedly different sensory input experience, individuals with B-SVI may exhibit differences in their gait, the subsequent motor output part of the cycle. Whereas sighted individuals with typical developmental patterns exhibit a mature gait pattern by ages three to six, someone without sight may never fully develop a mature spatial gait pattern. In fact, the gait pattern may plateau at a level that is characteristic of a sighted toddler. This is illustrated in short stride lengths, wide base of support, slower speed, decreased heel strikes causing a shuffling step, more pronounced out-toeing, and no reciprocal arm swing (Rosen, 1997).

The pre-walking motor skills of muscle tone, posture, balance, and coordination may also differ for people with blindness. Individuals may present less muscle tone (hypotonia), have weaker leg muscles (Wyatt & Ng, 1997), and exhibit postural deficiencies (Portfors-

Yeomans & Riach, 1995). Common postural deviations include lumbar lordosis (swayback), excess flexion at the hips, dorsal kyphosis (excessive forward bending of upper spine), scoliosis, or excess neck flexion or anterior head tilt (Sforza, Eid, Michielon, Fragnito, & Ferrario, 2003). Other postural abnormalities may include rounded shoulders; backward lean of the trunk, flat feet, knee hyperextension, foot eversion (outward rotation of the ankles, placing weight of body on the instep of the foot), and poor static balance (Bouchard and Tértreault, 2000; Pogrund & Fazzi, 2002; Rosen, 1997; Sforza et al., 2003). These gait descriptions and pre-walking motor characteristics are not directly caused by vision loss; yet, the loss of sight's influence on initial movement experiences in infancy, on vision for action, and on incidental learning can have a significant impact on the quantity and quality of an individual's movement and gait (Elisa et al., 2002). As a result, the sensory-motor experience involved in gait is fundamentally different for sight-impaired individuals when compared to sighted individuals. Due to these differences, gait characteristics and pre-walking motor prerequisites may be fundamentally different for those with severe visual impairment or blindness.

Services Addressing Travel or Locomotor Skills

Travel skills are of such significance for individuals with blindness or severe visual impairment that an entire profession is dedicated to providing services to fulfill these needs. *Orientation and Mobility* (O&M) professionals train individuals with vision loss to travel safely and efficiently. Desired functional orientation outcomes include consistent awareness of one's body position in relation to other individuals and objects, demonstration of positional and directional concepts such as up/down and right/left, and mental mapping of room locations in familiar buildings. Functional targets for mobility include travel in familiar environments such as home, school, or work, travel in unfamiliar environments, crossing at street intersections, and using bus or air transportation (Ramsey, Blasch, & Kita, 2003). External supports may be utilized, such as the use of a human guide, long cane, and if appropriate, a dog guide. The long cane is an indicator of a range of vision loss, varying widely amongst individuals. Whether the loss is considered severe visual impairment with a small amount of usable vision, to functional blindness, the long cane is used for safety and efficiency during mobility (W. E. Daugherty, personal communication, November 15, 2011).

A long cane detects obstacles and dangers in one's path of travel but is also a critical sensory input device. The cane extends one's tactile sense to the space out in front of the traveler, to detect environmental information critical to the individual's safety and efficiency. This places additional sensory and motor demands on the traveler during walking (Ramsey, Blasch, Kita, & Johnson, 1999). The use of a long cane is considered to be an acquired motor skill requiring specialized training and practice. Certified Orientation and Mobility Specialists (COMS) teach long cane technique and focus instruction on areas such as touch technique, appropriate grip of the cane for optimal sensory input into the hand and arm, appropriate rhythm of the cane with the owner's walking rhythm, and appropriate arc of the cane as it moves in front of the owner (Wall, 2002).

Instructors in O&M receive training in motor development within their required coursework and training (Rosen, 1997). The O&M instructor may address motor skills as situations arise within a natural learning environment, such as traveling between classrooms in a school environment. Other therapists, such as physical, occupational, recreation, and music therapists, or adapted physical education instructors, may also address locomotor needs to augment O&M services. For example, a physical therapist may be recommended to target motor function directly, whereas O&M instructors might address those needs as they naturally occur within the framework of travel.

In order to address developmental issues with children and infants, early intervention is essential. This may be required in infancy for an individual with congenital blindness, as the occurrence of the very first self-initiated movement experiences begins the entire locomotor sequence (Adelson & Fraiberg, 1974; Bigelow, 1992). Prehension for a sighted baby may occur at four months of age, but for a baby with blindness, it may occur as late as ten months of age. This delay is due to the fundamental difference between visually motivated reaching and reaching for an object based on its auditory characteristics alone. The latter is known as the concept of object permanence; the concept of knowing and searching for an object that is not within sight. Without early intervention, a baby with B-SVI may not initiate movement until much later than a sighted infant, creating the initial delay in the developmental motor sequence. Such a delay may also exacerbate delays in transitional movements, which stimulate and support muscle tone, posture, balance, and coordination, and subsequently delay a mature gait pattern (Tröster & Brambring, 1993).

Review of Research Studies

Most quantitative gait research has been conducted with sighted populations, and very little has targeted sight impaired groups (Nakamura, 1997; Ramsey, Blasch, & Kita, 2003). Studies targeting populations with B-SVI include adults with acquired blindness (Larsson & Frändin, 2006), adults with congenital blindness (Nakamura, 1997), veterans (Ramsey, Blasch, & Kita, 2003), and sighted individuals who were blindfolded (Hallenmans, Beccu, Van Loock, Ortibus, Truijen, & Aerts, 2009a, 2009b; Nakata, Nakamura, Kakizawa, & Rahardja, 1990). Published research about children, gait, and vision loss is more scant. MacGowan (1983) conducted a kinematic analysis of the gait of children who were congenitally blind, comparing the group with sighted peers ages 6-10. Hallemans, Ortibus, Truijen, & Meire (2011) compared gait parameters of children and adults who were B-SVI, ages 1- 44 years, to a group of age-related sighted individuals. Outside of these studies, most research with children seems to be more directly related to motor development.

Longitudinal studies have concurred that children with vision loss or blindness may experience delays in attaining locomotor development milestones (Bigelow, 1992; Brambring, 2006; Murphy & O’Driscoll, 1989). Comparative studies between sighted children and children with low vision or blindness have identified differences in attaining developmental milestones (Bouchard & Tétreault, 2000; Levtzion-Korach, Tennenbaum, Schnitzer, & Ornoy, 2000; Pereira, 1990). Descriptive research designs have surveyed families and professionals about the motor development of children with B-SVI, and have found similar reporting of developmental delays (Celeste, 2002; Dale & Sonksen, 2002; Elisa et al., 2002; Ferrell et al., 1990; Stewart, 1997).

Descriptive and comparative studies have been conducted with adults, illustrating specific characteristics or comparing variables to sighted populations. Summarized findings have reported shorter step length, slower speed, shorter stride length, guarded posture, longer reaction time, and a longer time spent in the stance phase of the gait cycle (Johnson et al., 1998; Nakamura, 1997; Ramsey et al., 2003; Soong, Lovie-Kitchin, & Brown, 2004).

Researchers have investigated the interaction of profound vision loss, gender differences and fall risk (Ray & Wolf, 2010). It has been suggested that people with B-SVI may use different strategies to maintain balance (Horvat et al., 2003) and may actually move less than people with sight (Brambring, 2001; Ray et al., 2007), further contributing to decreased independent mobility.

Experimental studies have reported a variety of interesting findings. A structured exercise program for elderly people with B-SVI significantly improved functional balance measures when comparing a structured exercise group to a control group (Cheung, Au, Lam, & Jones, 2008). Body awareness and dance-based training improved gait speed, demonstrating improved travel speeds to a more normal range (Larsson & Frändin, 2006). Familiarity of a travel route has a direct and positive impact on gait parameters and mobility (Hollyfield & Trimble, 1985). Gait measurements were worse when blind or severely impaired subjects traveled independently without a sighted guide, but improved when blind subjects had increased non-visual preview using an electronic travel aid that identified objects in the walking path (Clark-Carter, Heyes, & Howarth, 1986). When sighted people were blindfolded, their gait parameters changed immediately and looked similar to individuals with late-onset blindness (Nakata, Nakamura, Kakizawa, & Rahardja, 1990).

The population of individuals with blindness or severe visual impairment is a challenging one on which to conduct research for many reasons. First, the overall occurrence of vision loss as a disability category is low compared to other disabilities. Second, the spectrum of vision loss, from mild to no light perception, is highly variable. Third, approximately two-thirds of children with a significant vision loss have additional disabilities

(Silberman, 2003), which present a challenge when trying to isolate variables for a research study. Fourth, the age of onset for vision loss, congenital, early onset (childhood) or late onset (after age 18), has a tremendous impact on characteristics and needs. Last, the cause of vision loss, whether from disease, heredity, or trauma, has wide implications for the individual holistically in terms of health and function. These many confounding variables complicate the design and replication of robust research studies that yield any sort of statistical power. These issues are reflected in the present landscape of the research literature.

Of the studies that were reviewed, four directly related to the proposed study. First, a gait study conducted by Nakamura (1997) utilized 45 subjects: 15 congenitally blind, 15 late blind, and 15 controls walked a pathway that was ten meters in length. Subjects walked the path independently, without the use of any assistive device such as a long cane, human guide, or dog guide. A motion analyzer system measured velocity, stride length, and length of time in the stance phase of the gait cycle. Markers were placed on the fifth toe, heel, ankle, knee, hip, shoulder, elbow, and wrist of each subject. Subjects walked the 10-meter path a total of three times. Results indicated that as the length of time an individual had lived with vision loss increased, the more measured gait parameters resembled the congenitally blind group, marking a loss of functional skill over time.

Second, Ramsey, Blasch, Kita, and Johnson (1999) conducted a study in which subjects walked a 7.6-meter path while simultaneously responding to a competing cognitive task. The task was to press a button whenever an audible tone was heard, while walking the path. Researchers measured wrist, hip, and knee range of motion, in addition to cadence, velocity, and stride length. Results indicated that participants' velocities were slower when the additional auditory task competed for attention. Participants also exhibited decreased hip flexion, which leads to the shuffle type of gait pattern often observed with people who are severely visually impaired. The study highlights the point that travelers with vision loss experience the added demand of competing cognitive tasks while walking. Whereas sighted travelers receive information instantaneously, visually impaired travelers must be more vigilant of all incoming sensory information in the environment. The heightened vigilance and additional cognitive demands therefore could slow down one's gait and create more of a shuffle step.

In a subsequent study, Ramsey, Blasch, and Kita (2003) were interested in whether or not orientation and mobility training following late onset blindness for veterans would decrease fall and injury risk. The veterans' gait parameters were collected with a high-speed video recording system that calculated all selected parameters using a 3D model. Participants walked 50 feet, with markers placed on top of each participant's head, chin, shoulder, elbow, wrist, hip, knee, and ankle. This study found no significant results, indicating that orientation and mobility instruction alone may be insufficient to prevent fall and injury risk to individuals who have incurred late-onset blindness or severe vision loss.

Researchers have also been interested in how blind travelers count steps, and how this impacts way-finding skills (Mason et al., 2005). The researchers were particularly interested in gait variability and the role of assistive devices such as a guide dog or cane. Participants were independent, confident travelers. The noteworthy aspect of this study is that the researchers used a metronome for fast and slow walking conditions. Participants used assistive devices if required, and previewed the 80-foot path to get accustomed to it. Findings, in contrast to the Nakamura (1997) study, found no significant difference in stride length between groups of sighted individuals and individuals with blindness. The noteworthy aspect of the Mason et al. study (2005) is that visually impaired participants used their assistive devices, yielding results that differed from Nakamura (1997), who did not utilize assistive devices.

Many important points arise from the four studies summarized. First, the loss of sight at any place along the lifespan, over time, can be detrimental to one's fundamental mobility skills. Second, locomotion for sighted individuals is an automatic process in that one is not required to actively think about it; an individual who is blind must be continually more vigilant to incoming sensory information not received through vision. Third, although O&M instruction is vital for anyone along the lifespan who has lost sight, it may not be sufficient to improve or maintain fundamental locomotor skills for increased safety from falls and injury. Lastly, in a study outside the field of music, a metronome was used to cue fast and slow walking, indicating some awareness that perhaps an external rhythm cue holds the possibility to cue locomotion. In addition, an individual's use of their usual assistive device (long cane or guide dog) may support the most efficient and natural travel skills in a research environment, versus the research of travel skills without any help from these devices.

In the continued search for a consistent protocol to directly address gait for individuals with blindness or severe visual impairment, it is evident that a technique must address several needs. A protocol should enhance the locomotor experience so that it is more natural and automatic and can be utilized anywhere along the lifespan. Including characteristics that pinpoint the exact need of gait improvement and that allow such a need to be isolated and tested in a research setting for objective analysis is key to advancement in effective protocol development.

Documented Use of Music for Individuals with Blindness or Severe Visual Impairment

Music has a long and rich history in the education and rehabilitation of children and adults with blindness or severe visual impairment (Codding, 2000; Corn & Bailey, 1991; Herlein, 1975; Kersten, 1981; Lam, 1982; Pilcher, 1964; Sabin, 1952). Music education has played a prominent role in the histories of residential schools for the blind. Lowell Mason, a pivotal figure in American music heritage, as well as the one credited with the inclusion of music education in American public schools, was the first music teacher at the Perkins School for the Blind from 1832-1836. Large bands, orchestras, and choirs were common at many of these residential schools (Sabin, 1952). In addition, vocational training in such careers as piano tuning, piano repair, and music performance was provided. Teachers of blind and visually impaired children stressed the importance of music in the lives of these individuals for lifelong leisure, expression, participation in society, and vocational prospects (Pilcher, 1964).

In 1975, Public Law 94-142, later to be known as IDEA, marked an exodus of students from residential schools for the blind to public schools (Codding, 2000). Music education programming at these schools underwent huge change as students began attending their neighborhood public schools and receiving itinerant services for instruction in braille and O&M. The student population at the residential schools changed markedly, as more students with severe and multiple disabilities attended these schools. Around this time individuals in the field of visual impairment wrote many articles about the use of music or music therapy with individuals with blindness, severe visual impairment, and additional disabilities (Corn & Bailey, 1988; Herlein, 1975; Hill, Brantner, & Spreat, 1989; Kersten, 1981; Lam & Wang, 1982; Steele & Crawford, 1982; Uslan, Malone, & De l'Aune, 1983).

Concomitant with the change in the landscape of student populations at residential schools for the blind, a music therapist conducted the first of three comprehensive literature reviews of music, music education, music therapy, and music in rehabilitation with people who are blind or visually impaired (Codding, 1988, 1996, 2000). In 1988, Codding stated:

> The beneficial effects of music on the behavior and physical development of the visually disabled persons has yet to be documented in the literature…the need for controlled research…is critical if music therapists are to effectively serve visually disabled individuals and achieve credibility as essential service providers. (Codding, 1988, p. 124)

Years later Codding (2000) reported a continued dearth of research in the field of music therapy with only three published research articles being identified in the *Journal of Music Therapy* (Ford, 1999; Greenwald, 1978; Madsen & Darrow, 1989). Three subsequent studies were published after 2000 (Darrow & Nowak, 2007; Kern & Wolery, 2001; Robb, 2003). One clinical practice case presentation, specifically targeting motor skills related to locomotion in a child with blindness and severe and multiple disabilities, was published in a text of music therapy treatment cases (Molloy-Daugherty, 2013). In light of the scarcity of research, some studies were located which were conducted outside the field of music, music education, and music therapy. Three articles specifically addressed dance or movement in the education and rehabilitation of individuals with blindness (Chin, 1988; Larsson & Frändin, 2006; Vise, 1972).

In the attempt to identify tested interventions targeting motor skills with children who are blind or severely visually impaired, Molloy-Daugherty (2010c) completed a synthesis of research encompassing the fields of music, children with vision loss, and motor skills. This systematic method of inquiry was devised in accordance with Cooper (1998). Findings were scant; six studies matched the explicit criteria for inclusion, with none being conducted within the field of music therapy. Silliman, French, and Tynan (1992) used recorded music in an intervention targeting motor skills for a child with severe and multiple disabilities including vision loss. In this case study, preferred music listening was a reward for compliance during motor exercises. The remaining five identified studies were diverse in nature and scope. Four studies (Adelson & Fraiberg, 1974; Harley, Wood, & Merbler, 1980; Jazi, Purrajabi, Movahedi, & Jalali, 2012; Rider & Candeletti, 1982) attempted to directly target motor skills by implementing and testing a specific intervention; however, the intervention was non-musical. Harris and Thompson (1983) designed a swimming program to improve gross motor skills in children with multisensory impairments.

Jazi et al. (2012) targeted the dynamic balance of children with visual impairment when they conducted their study with 19 subjects ages 8-14 years. Researchers used the Modified Bass Test of Dynamic Balance as a pre-test and post-test balance measure before and after the implementation of an 8-week dynamic balance training program. The children participated in 16, 1-hours sessions, twice weekly; each acted as his or her own control. The researchers found statistically significant improvements in the children's post-test scores on dynamic balance when compared to pre-test scores. They concurred that interventions that specifically targeted dynamic balance could have a positive impact.

A case study conducted by the present author became the catalyst for the path of inquiry leading to the present research paper. Molloy-Daugherty (2010a) used a music therapy treatment protocol known as Rhythmic Auditory Stimulation (RAS). 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, p. 139). RAS was used in a naturally occurring travel environment with two elementary age students who had blindness and additional disabilities. Both students demonstrated a significant need to improve travel skills from the classroom to the music room. Results indicated that RAS improved travel skills for these two students. The study led to a subsequent identification of the pre-walking motor skills that were lacking for the students (Molloy-Daugherty, 2010b). A systematic literature search found nothing that could be used as a clinical model (Molloy-Daughtery, 2010c).

Clinical research with children in a classroom setting presented a multitude of confounding variables that impeded a sound study design. Daily changes in staffing, fluctuating student mood, inconsistent attendance to music class, and behavioral issues, as well as the complexity and inconsistency of the musical stimulus itself, did not allow a reliable conclusion to be drawn as to whether or not RAS was an appropriate treatment protocol for this population. The clinical research protocol was inconsistent and did not have adequate basic science research supporting its hypothesis that RAS was appropriate and that it could be effective.

Several requirements were necessary in order for the creation of a sound research protocol that could more adequately capture the effects of rhythm on the walking behaviors of individuals who are B-SVI. Reducing confounding variables such as behavioral issues, inconsistent and complex musical cues, age and cognitive ranges, and fluctuations that occur in real-world classroom settings was warranted. Perhaps most importantly, a more basic and sound research question needed to be formulated: What is the impact of a rhythmic cue on the walking pattern of a person with B-SVI?

A more robust study would isolate the musical component of rhythm, down to its most basic existence of a repetitive stimulus or tick. The study would be grounded in a scientific framework. This framework would clarify the following: how humans walk, how humans elicit a motor response to rhythm, how these two human behaviors share a functional commonality. These connections are necessary in order to formulate an appropriate hypothesis about the impact of rhythm on walking for the population in question.

Rhythmic Auditory-Motor Entrainment

As previously established, people are hard-wired to walk at birth. A person's pre-programmed lexicon of movements is what allows babies to utilize the pincer grasp, to crawl, and to walk without being formally taught. These connections remain across the lifespan, but as babies begin to respond to incentives to move they develop more volitional, goal-directed movement. A good example of this is when a baby is learning how to walk. The motor plans involved in walking are present from birth, but it is the baby learning through her own movements and volition how to accomplish walking as her own controlled goal-directed behavior.

The neural motor activity, including walking, is highly organized and efficiently timed in order to produce movement; otherwise the complex feat of human walking could not commence. Since individuals do not require an external organizer outside the body to coordinate internal motor plans, then it follows that the timing, control, and organization must happen within the brain and down through the spinal cord (Thaut, 2000). Present within the central nervous system are internal neural oscillators that generate and control repetitive, sequential movements like walking. These Central Pattern Generators (CPGs) are dedicated neural networks that are responsible for coordinating the steady, uninterrupted, stereotypic, rhythmic neural activity of patterned movements such as locomotion (Cohen, 1999; Field-Fote, 2000; Grillner, 1975). CPGs orchestrate patterned movements without additional sensory input and without cognitive requirements.

In summary, CPGs allow people to walk without needing to consciously think about it. This occurs in the spinal cord through dedicated neural networks, which have been present since birth. The required neuromuscular orchestration is highly organized, repetitive, and rhythmic in structure. Since people do not require some sort of organizer, or oscillator, outside the body to do these tasks, it can be further concluded that internal oscillators are at work. Hence, walking is considered to be a biologically rhythmic movement (Cohen, 1999; Grillner, 1975; Kolb & Whishaw, 2003; Thaut, 2005).

The influence of rhythm on movement has been documented for years. One of the main functions of music in human culture is to elicit a physical response (Merriam, 1964). A function of rhythm, from an anthropological perspective, is that “it encourages physical reactions of the warrior and the hunter; it calls forth the physical response of the dance, which may be of prime necessity to the occasion at hand” (Merriam, 1964, p. 224). Rhythms in the form of chants and work songs have organized groups of people in a common work task such as rowing or marching. The term used to describe the phenomenon of groups of people synchronizing their motor activities is called entrainment.

Entrainment is a term referring to the synchronization of two different entities with independent pulses (Clayton, Sager, & Will, 2005). If a person hears a song with a strong beat, he may pat his legs to that beat, hence entraining with the external rhythm in the song. People who move rhythmically to music are usually not taught how to do so, rather, it is a spontaneous musical response to an external rhythmic stimulus. In musical terms, rhythm functions as an external cue to stimulate entrainment via clapping, patting, stepping, or moving to the beat.

Entrainment is not only an observable musical response to rhythm; it is a physiological response with stronger ties to the auditory system than to the visual (Parncutt, 1994; Patel, Iversen, Chen, & Repp, 2005; Thaut et al., 1999). People do not entrain to a rhythm presented in the visual modality alone; for example, one does not spontaneously tap the feet when watching a ball bouncing (Penhune et al., 1998; Zatorre, 2007). Auditory rhythms are felt; visual rhythms are not (Grahn et al., 2011; Parncutt, 1994). Entrainment studies comparing the presentation of visual or auditory stimuli consistently show that the auditory-motor pathway is superior to the visual-motor in terms of speed and accuracy of motor response to the stimuli (Grahn et al., 2011; Parncutt, 1994; Patel et al., 2005; Repp, 2003).

Observationally, when a person walks to a steady rhythmic pulse, it is identified as "walking to the beat" or "entraining to the beat." It appears as a cognitive thought process whereas the person is thinking about the auditory rhythm and consciously deciding when to take each step. However, in addition to this conscious thought process that transpires, it has been found that a steady external rhythmic pulse entrains the muscles, joints, and neurons to work together with the goal of having the most optimal and efficient pattern of movement. This is subcortical and below conscious thought processes (LaGasse, personal communication, April 7, 2013; Molinari et al., 2003; Thaut, 2005).

Direct neural pathways from the auditory cortex to the spinal cord serve as the pathway for auditory-motor coupling to occur. Auditory signals travel via the eighth cranial nerve to initial auditory projections in the medulla, in the lower brainstem (Kolb & Whishaw, 2003). From here, the auditory stimuli travel through the cochlear nuclei, through the superior olivary complex, to the inferior colliculus. It is here that a direct link is made to the spinal cord, as the inferior colliculi help to direct unconscious responses to sounds (LaGasse, 2013). Thus, rhythm has easy access to the spinal cord circuitry, as it passes through and is mediated by the audio-motor circuitry present at the reticulo-spinal level (Molinari et al., 2003; Thaut, 2000). Since the connections are direct links, the central nervous system is highly sensitive to time-ordered auditory information such as rhythm. It is these critical connections, or the coupling of internal rhythm present in CPGs with external rhythm present in a steady beat in music, that support the scientific model of rhythmic auditory-motor entrainment.

Scientific research documents this connection between auditory rhythm and motor systems (Pal’tsev & El’ner, 1967; Rossignol & Melvill Jones, 1976; Safranek, Koshland, & Raymond, 1982; Thaut, 2000). A sound stimulus arouses and raises the excitability of spinal motor neurons, both with a single sound event and with the patterned stimulus of a rhythm.

Pal’tsev and El’ner (1967) reported that a sound stimulus primes the motor system and readies it for action. This was physically measured in the excitability of the monosynaptic tendon reflex; the louder the sound, the greater the priming of the neurons. The best practical example of this is the human startle response; one may flinch if a loud unexpected noise is heard, indicating a direct auditory-motor link to prime the human body for action. This research is important in its support for an external auditory stimuli’s ease of access in influencing the motor system at a subcortical level.

Furthermore, external rhythmically structured patterns can entrain the firing of internal neural muscle activation patterns. Rossignol and Melvill Jones (1976) also used EMG readings to look beyond the single sound response documented by Pal’tsev and El’ner (1967). The researchers discovered that the repetition of a patterned rhythmic sound stimulus kept the motor system continually primed for action. This is referred to as “priming the auditory-motor pathway” (Thaut, 2005, p. 141). Not only does the motor system rapidly and subcortically respond to an external auditory stimulus, but it also remains primed for rhythmic activity if the sound stimulus is temporal and isochronous (evenly patterned) in nature. Additionally, the neural activity is evenly patterned at the same interval as the external auditory stimulus.

Additional findings by Safranek et al. (1982) also documented changes in EMG activity of two antagonist muscles (the biceps brachii and triceps brachii of the upper arm) under the influence of both even and uneven auditory rhythms. These authors contended that when an uneven auditory rhythm was presented in order for a participant to complete an upper arm motor task, the muscle EMG activity was highly variable. But, when a steady, isochronus rhythm was presented, the variability of the muscle activity decreased greatly "which may be explained by a more efficient recruitment order of motor units" (Safranek et al., 1982, p. 167).

The last two important concepts related to rhythmic auditory-motor entrainment are that of unconscious matching of the movement to the rhythmic stimulus and of priming of the movement period. Research has documented that during rhythmic entrainment studies involving both naturally patterned movements like walking and voluntary repetitive movement patterns, such as upper extremity reaching or finger tapping, people change their motor behavior to match the rhythmic stimulus even when the stimulus is changed so slightly that it is below their conscious perception (Patel et al., 2005; Stephan et al., 2002; Tecchio, Salustri, Thaut, Pasqualetti, & Rossini, 2000). In addition, the priming of the movement period means that when a person is performing a task that is rhythmic in nature and is provided with an external rhythm cue, the neural networks fire at the same rate as the cue, but occur in time just before the cue is given. In other words, the central pattern generators are anticipating the next rhythmic cue and are firing at an interval that is identical in size to the interval between rhythm cues, only just before the cues in the temporal domain (Aschersleben & Prinz, 1995; Thaut, Miller, & Schauer, 1998a; Thaut et al., 1999). Both are essential to the theory of rhythmic auditory-motor entrainment for gait. If the theory is plausible, then a person's walking pattern subconsciously changes when the rhythmic stimulus changes, even at such a small amount that it is not cognitively noticed. The coupling of the external rhythmic stimulus with the internal timekeeper of the central pattern generators, even when changing below the person's cognitive perception, indicates rhythmic auditory-motor entrainment (Molinari et al., 2003; Thaut et al., 1999; Thaut, 2003). The internal timing mechanism creates a template that exactly matches the duration of the patterned external stimulus. In anticipation of the next external rhythmic cue, the responsible neurons fire just before the next external rhythmic cue (Aschersleben & Prinz, 1995).

The proposed model of rhythmic auditory-motor entrainment provides the theoretical foundation for the present study, due to the established direct coupling of a temporal, patterned stimulus (rhythm), through a shared neural network. The shared neural network is that of the central pattern generators, the dedicated neural networks in the central nervous system that are responsible for the neurological priming and organization of rhythmic movement patterns that do not require cognition (walking). The establishment of these biological connections provides the “model of rhythmic auditory-motor entrainment in which the enhanced time information in the temporal structure of rhythm serves as an optimization function for motor planning, programming, and execution” (Thaut, 2002, p. 38).

The scientific potential of auditory-motor entrainment as a sound model for systematic inquiry with the population of adults who are B-SVI lies in its natural occurrence in the auditory sensory modality, with no visual requirement. The biological rhythmicity of gait, our auditory-motor brain circuitry, the neurological rhythmicity present at the brainstem and spinal cord level, and the superiority of the auditory modality to access motor function, all occur independent of visual input (Thaut, 2002; Zatorre, 2007). A person’s physical responses to music and to rhythm are auditory, not visual (Parncutt, 1994; Patel et al., 2005; Thaut et al., 1999). All humans are innately wired to walk and equipped with the initial lexicons of movement patterns; these too are not dependent upon vision (Field-Fote, 2000; Kolb & Whishaw, 2003).

The auditory-motor connection has been scientifically established in which an external patterned rhythmic stimulus can access and impact the internal oscillators that are responsible for repetitive movements like gait. The auditory-motor connection exists independent of vision. In summary, rhythm can easily access the neural and motor processes that comprise ambulation, regardless of the amount or quality of vision that an individual has. This occurs because of the naturally occurring phenomena of entrainment, in which the neural timing networks of the central pattern generators are highly sensitive to, and entrain with, an external rhythmic stimulus. Therefore, the study of rhythm's impact on gait in individuals with B-SVI may be justifiable due to the auditory-motor connection for repetitive movement and the limited involvement of vision.

Summary

The scope of gait development is compromised for someone with a visual impairment. Neurological and environmental implications must be taken into consideration in order to best support independent and safe mobility. Central Pattern Generators (CPGs) and pre-existing muscle activation patterns provide the biological and neurological foundations for ambulation. CPGs are the internal oscillators functioning as a neural network in synchrony with one another to coordinate the necessary components of walking. CPGs exist and function independent of any sensory input, and they are innate in people (Field-Fote, 2000). As people grow, primitive motor reflexes fade and are replaced with volitional movement, and ambulation formally develops, vision becomes a major player in the gait cycle. It provides a significant amount of sensory input, and also integrates all incoming sensory stimuli. A person with blindness has nothing comparable to this and misses the sensory input and integration that benefit motor patterns (Cohen, 1999; Rosen, 1997).

Orientation and Mobility (O&M) is a major service for individuals with blindness or severe visual impairment (Rosen, 1997). Certified Orientation and Mobility Specialists (COMS) receive instruction in motor development and gait but only address these needs as it pertains to the lesson and the tasks at hand (Ramsey, Blasch, & Kita, 2003). Research illustrates that there is much interest in and attention given to the differences in gait and in pre-walking motor development between sighted and sight impaired populations. Gait studies do exist, but they are scant. Even fewer gait studies exist with children.

Music has a long and rich history with individuals who are blind or severely visually impaired. The scope of music education for this group has changed over the years, particularly with the implementation of P. L. 94-142, now referred to as the Individuals with Disabilities Education Act (IDEA). Mainstreaming in public education changed the landscape of the population of students served at residential schools for the blind, thereby changing from a place with large musical ensembles to one serving students with the most severe disabilities.

Despite several reviews of the literature, as well as numerous articles published about the needs of this population, there is a major dearth of research in this area, with none in the field of music therapy targeting the use of music to address motor skills or ambulation. An initial case study with two children with B-SVI showed that RAS seemed to be a viable intervention to improve gait (Molloy-Daugherty, 2000a). During the case study, each student improved the length of time that it took for him/her to walk down a straight hallway from the door of the building to the music classroom. The findings were encouraging and held clinical significance, yet lacked generalizability due to study design. The study's design was such that, despite encouraging findings, it did not reveal the precise agent of change secondary to several confounding variables. These included the presence and potential influence of the auditory cue (walking song) providing an auditory trajectory for the travel path; sung words during the presentation of the auditory cue that were inconsistent across sessions of data collection as they provided specific and changing cues to the destination; pre-existing and well-established relationships between therapist and students, which could function as a motivating factor for participation; and, lastly, inconsistencies across sessions in regards to the students' behavior (Molloy-Daugherty, 2010a).

One positive outcome from this study was the observation that both students required additional development of pre-walking skills such as heel strikes, reciprocal arm swing, sensory integration, and overall strength and endurance. When these skills were targeted in a collaborative environment between music therapists, researchers, and physical therapists, outcomes were highly promising (Molloy-Daugherty, 2010b). Yet, it was unclear as to what precisely in this treatment environment facilitated the positive outcomes.

The clinical success of RAS (Molloy-Daugherty, 2010a) indicates that rhythm may be a mediator for improved rhythmic timing during walking. Rhythm is the therapeutic premise of RAS. Therefore, rhythm is the musical element of interest in the present scientific inquiry. Rhythmic auditory-motor entrainment of gait has been studied in healthy adults (Thaut, McIntosh, Prassas, & Rice, 1992), stroke patients (Prassas, Thaut, McIntosh, & Rice, 1997;

Thaut, McIntosh, Prassas, & Rice, 1993; Thaut, McIntosh, & Rice, 1997), Parkinson's disease patients (McIntosh et al., 1997; Thaut et al, 1996), and children with cerebral palsy (Thaut et al., 1998). These studies tested the mediating impact of rhythm on gait. Immediate entrainment effects were reported, with no required training. In addition, it was found that in people with normal gait the use of rhythm smoothed out their movement patterns as shown with EMG (Thaut et al., 1992).

It is being proposed that rhythm, which easily affects motor circuitry through the shared neural networks of central pattern generators responsible for patterned movements such as walking, could possibly also mediate walking patterns in individuals who are B-SVI. The well-established theory of rhythmic auditory-motor entrainment of gait patterns must be expanded to include people with B-SVI for four reasons. First, it is known that walking, a biologically rhythmic, unconscious, and patterned movement, is neurologically based and internally organized within the central nervous system. Second, the neural networks of CPGS for unconscious patterned walking and for unconscious rhythmic entrainment are shared networks. Third, the model of rhythmic auditory-motor entrainment and its impact on gait has not been systematically tested in this population. Last, if the above connections are established, this will allow for sound clinical intervention models to be implemented and tested for clinical efficacy. The application of a clinical treatment protocol such as Rhythmic Auditory Stimulation (RAS) would be supported by such research, and could be substantiated by the proposed study.

Research Hypothesis

The goal of this study was to investigate the influence of rhythmic cuing on the observational stride parameters of adults who are B-SVI. It was a preliminary study because the scientific model of rhythmic auditory-motor entrainment had yet to be applied to the proposed population. In order for the researcher's ultimate goal to be attained, that of creating a clinical research protocol to target motor outcomes for children who are B-SVI and have additional disabilities, the scientific study of rhythm as a mediating stimulus for functional change must first be discovered. Therefore, the proposed research questions were:

1. Does an external isochronous rhythm cue provided by a metronome and set at the tempo of a person's normal walking speed improve the temporal stride parameters of cadence, velocity, and stride length for adults who are blind or severely visually impaired?

2. Does the external isochronous rhythm cue, increased in speed by 5% from a person's self-paced fast walk, also improve these parameters?

CHAPTER 3

METHODS

This study was a preliminary investigation of the impact of rhythm on observational gait parameters for adults with blindness or severe visual impairment (B-SVI). The study was conducted in a functional and controlled setting. It was a within-subjects repeated measures entrainment design with each subject functioning as his or her own control. *Entrainment* is the act of two independent rhythmic sources synchronizing with each other through an interaction between the two (Clayton, Sager, & Will, 2004). This entrainment design tried to detect synchronization of each subject's gait with an external isochronous rhythmic cue provided by a metronome. *Isochronous* refers to the metronome's repetitive stimulus as equal in duration, thus creating stable and equal time intervals in between metronome clicks (Thaut, 2005). The university's internal review board for the social sciences approved this study.

Study Design

The study was designed to detect whether or not a metronome cue would immediately improve the gait parameters of individuals in the sample group in a similar way that has been found in other healthy and clinical populations (McIntosh et al, 1997; Thaut et al, 1992). The research questions target each of these two aspects of rhythmic auditory-motor entrainment.

Two research questions were formulated:

1. Does an external isochronous rhythm cue provided by a metronome and set at the tempo of a person's normal walking speed improve the temporal stride parameters of cadence, velocity, and stride length for adults who are blind or severely visually impaired?

2. Does the external isochronous rhythm cue, increased in speed by 5% from a person's self-paced fast walk, also improve these parameters?

Five testing conditions occurred in the same order for each subject. The initial walk was a baseline condition to assess the subject's cadence. A count of how many steps per minute a subject walked was measured without an external cue (i.e., uncued walk). The baseline condition revealed the subject's limit cycle, which is the pace at which a person optimally moves, also called a person's preferred step cadence (Thaut, 2005). The subject's limit cycle or preferred cadence determined at what number to set the metronome click for the second condition, cued walking.

For the second, cued walk, the metronome click at the person's limit cycle is thought to immediately mediate the internal mechanisms driving the movement parameters that comprise gait, optimizing their work throughout the entire movement period from step to step (Thaut, 2005). The purpose of the second walk with the metronome was to answer the first research question by measuring the dependent variables of cadence, velocity, and stride length.

The third condition was a subsequent uncued walk, but this time the subjects were asked to walk at a speed that was considered to be his or her "fast" walk. This condition allowed the subjects to generate another baseline walking condition that differed from their first. The study design thus allowed for two opportunities to test the theory of rhythmic auditory-motor entrainment based upon subject-driven baseline measures.

The fourth condition utilized the metronome clicking at a cadence tempo that was 5% faster than the uncued cadence detected and calculated in the previous, third condition. The use of a metronome at an incremental faster tempo (5% faster than the subject's perceived "fast" speed) further tested the scientific theory of rhythmic auditory-motor entrainment in regards to the subconscious calibration of internal sensorimotor processes to match an external stimulus (Patel et al., 2005; Stephan et al., 2002; Tecchio et al., 2000). The fourth condition provided the opportunity to answer the second research question: if a person walks his or her own fast walk, and then walks with a metronome clicking which is 5% faster than his or her fast cadence, does the person (a) perceive this, (b) does his or her internal timekeeper respond to this deliberate manipulation, and (c) does the motor output (the dependent variables of cadence, velocity, and stride length) change in response to this manipulation? The rhythmic auditory-motor entrainment theory contends that a person's internal timekeepers detect, mediate, and entrain to this sort of change, without practice or cognitive requirements to do so (Patel et al., 2005; Stephan et al., 2002; Tecchio et al., 2000).

The final, fifth condition was identical to the first baseline condition, a normal walk with no metronome cue. The fifth walk provided a comparison between the first and last baseline condition, and also an evaluation of whether there was carryover of entrainment effects from the cued conditions. The final condition occurred as part of a standard repeated measures study design, and also for possible post-study discussion of any potential carryover effects due to study participation.

The study design utilized a simple cue from a metronome. The use of an isochronous cue provided by a metronome is important for three reasons. First, the theory of rhythmic entrainment is based upon rhythm alone, and does not require music in order for synchronization to take place. Hence the researcher isolated the musical element of rhythm as a timing cue for movement while extracting it from additional musical elements such as melody, harmony, or timbre. Second, the use of an isolated rhythmic cue provided a clear and precise stimulus for the B-SVI subjects. Third, previous research suggested that a metronome better supported typical walking speeds than a musical cue, whereas very slow walking speeds (i.e., patients in stroke rehabilitation) may be better supported with a musical cue which contains more and richer temporal information (Aschersleben & Prinz, 1995; Parncutt, 1994; Thaut, Rathburn, & Miller, 1997).

The independent variables were uncued versus cued walking (no metronome versus metronome), as well as tempo (normal versus self-perceived "fast" walk). The dependent variables included cadence (the number of steps per minute), velocity (the number of meters per minute), and stride length (the length traversed by the individual from one heel strike to the next, on the same foot).

Setting

The study was conducted in the main educational and administrative building on the campus of the Texas School for the Blind and Visually Impaired (TSBVI), located in Austin, Texas. This facility was selected due to its location for accessibility and convenient recruitment of potential study subjects. TSBVI is centrally located in a large metropolitan area tailored to pedestrian travel, as well as the use of public transportation.

Street intersections are equipped with crossing signals specific to vision impairment, and public bus stops are located on all sides of the campus. The physical location of this accessible 40-acre campus provided a setting that was easily accessible by pedestrians, as well as consumers of the city taxi and bus systems.

Second, TSBVI both serves and employs individuals who met the inclusion criteria for this study. The school offers transition and exit programs for high school graduates ages 18-22 years. Several instructors, assistants, and support staff are also B-SVI. Many people who were either attending or working at the school qualified to participate.

Third, the Criss Cole Rehabilitation Center (CCRC), a facility within the Texas Department of Assistive and Rehabilitative Services (DARS) Division for Blind Services, is adjacent to the campus of TSBVI. CRCC is a comprehensive adult vocational rehabilitation service organization. It is a residential campus and provides training in core skills such as O&M, braille, daily living skills, career development, technology, adjusting to blindness, and advanced career guidance. The clientele, as well as the physical location of CRCC, allowed for ease of participation in the study.

The study was conducted in one of three different hallways of the main building on the campus of the Texas School for the Blind and Visually Impaired. The hallways provided a testing space of a minimum optimal length of 30 meters and were clear of obstacles that could interfere with the procedure. Thirty meters indicated the outer start and finish point for the walking trials. Within the 30-meter space, five meters after the start line and before the finish line provided a zone for initiation and termination of the walking trials. The 20 meters inside the 30-meter testing space provided the target for all data collection. The testing space allowed for the walking trials to be conducted in one straight path, with no need for a subject to turn around during the trial. Omitting a turn eliminated this additional mobility task and isolated the measurement of the dependent variables.

Materials

The following materials and tools were utilized during the study. A portable electronic stopwatch (Radio Shack®) was utilized to time all of the walking trials. A quartz metronome (Quik Time®), which was battery operated and similar in size to a deck of playing cards, was inserted into a pouch on a lanyard and worn around each person's neck. Two battery-powered digital video cameras, the Kodak Model Zi8 Digital Pocket Video Camera HD 1080p, and the Cisco Flip Video Ultra HD 8 GB, model U32120B, were used for all videotaping during the study. A tripod was required to stabilize one of the video cameras. Two software applications (apps), designed to measure heart rate, were downloaded to an iPhone 4s model MC922LL/A. The Azumio Heart Rate Monitor and the Cardiograph Personal Heart Rate Meter measured heart rates throughout the study.

Both the Cardiograph Personal Heart Rate Meter and the Azumio Heart Rate Monitor apps worked in a similar fashion. The technology is similar to that of a pulse oximiter, which detects oxygen levels through the fingertip. To detect heart rate, the placing of one's finger on the iPhone camera lens allows the camera to detect the pulse in the fingertip. Both the Cardiograph and the Azumio are marketed for recreational and fitness purposes only, but were selected due to their ability to store measures and their less invasive nature than the researcher taking the participant's pulse at the wrist. Both apps exhibited sensitivities to finger temperature, finger placement, and finger pressure. Hence, if one app seemed to have difficulty in detecting a participant's pulse, the researcher switched to the other app. For each subject, the same app was used consistently for all testing conditions. The researcher used the Cardiograph app with 26 participants, and used the Azumio with 20 participants.

Additional study materials included data collection sheets, a narrative of instructions, number coding system, informed consent documents in print and braille, a signature guide, two nylon camping-style folding chairs, and blue and green masking tape for marking start, finish, and data collections lines on the hallway floor. A software application (app) on the iPhone called Calculator was utilized for calculating cadence, maximum heart rate, and recovery heart rate throughout the study.

Each subject received a stipend of $20 in cash when they completed the study. Due to the subjects' potential need for public transportation, a small stipend to account for this cost was warranted. The researcher received a grant through the women's council graduate assistance fund at the sponsoring university to fund subject remuneration.

Subject Solicitation

Subjects were a convenience sample of volunteers recruited from community-based organizations providing services to consumers who were blind or severely visually impaired. The researcher constructed an oral and printed solicitation script (see Appendix B). Directors of the local area facilities that provide services to potential subjects were contacted and appointments took place to explain the study and obtain initial administrative permission for subject solicitation at each facility. The facility contacts included the superintendent of the Texas School for the Blind and Visually Impaired (TSBVI), the director of TSBVI's academic program for students 18-22 years of age, the school's dormitory case managers for potential participants, and the director of the Criss Cole Rehabilitation Center (CCRC). Initial meetings with administrators consisted of both verbal explanations as well as print copies of the solicitation script.

Upon each director's approval of the researcher's solicitation at the facility, the researcher arranged times to conduct additional oral presentations to potential subjects. At these meetings, the researcher read the solicitation script (Appendix B). These oral presentations were conducted for three dormitories at TSBVI, and took place in each dormitory's shared living space. A total of 15 students attended one of these 30-minute presentations. Braille and large print informed consent documents were available so that potential subjects could read them and ask questions. Students who expressed interest in participating exchanged contact information with the researcher, in the form of an email address and/or cell phone number.

An oral presentation at the CCRC was delivered to a scheduled weekly facility-wide meeting to 65 potential subjects. An initial brief explanation of the study was provided, which was five minutes in length. Upon adjournment, informed consent documents in braille and large print, as well as researcher contact cards in braille and large print, were provided to individuals who approached the researcher and verbally expressed interest while they were exiting. Additional copies were placed at the receptionist desk leading to the consumers' living areas.

Twelve potential subjects were solicited through general word of mouth from the researcher through facility staff members to potential subjects. For example, in the initial meetings with directors at TSBVI, the researcher was apprised of individual staff members, volunteers, or former students who may meet inclusion criteria. Eight individuals who were staff members at TSBVI, and two community members who volunteered at the school, were contacted in this manner. Additionally, two study participants each recommended one spouse or friend for the study, and provided the researcher with contact information for these three additional people.

Once the initial presentations had been conducted, secondary contact via email, phone, or text messaging transpired between the researcher and potential interested subjects. Additional discussion and subsequent solicitation occurred at this time to determine if the interested subject met inclusion criteria. To participate, one had to be a consenting adult between 18 and 70 years of age, have English as his or her primary language, have blindness or severe visual impairment such that a long cane is used for travel purposes, and have a normal range of hearing. Individuals were excluded from study participation if any one of the above inclusion criteria were not met.

If the subject seemed to meet the study's inclusion criteria, then appointment times were scheduled, and a reminder phone call, email, or text message delivered the day before the scheduled appointment. Appointment times were one hour in length, scheduled during evening (5:00 p.m. – 9:00 p.m.) and weekend hours (8:00 a.m. – 6:00 p.m.), and occurred during the time period between March 4 and March 28, 2013. This scheduling allowed for minimal disruption to the utilized facility's normal operating and business hours.

Procedure

Prior to appointment times, the researcher prepared the testing area by applying masking tape to the floor at the subject starting line (0 meter mark), first data collection line (5 meter mark, indicating where the researcher begins data collection), data collection finish line (25 meter mark, indicating where the researcher ends data collection), and the subject's finish line (30 meter mark). The researcher also placed a chair at the 0-meter mark and the 30-meter mark for the subject to use during heart rate checks. Last, the researcher arranged the video camera and tripod to be in place for the study.

Subjects were instructed to meet the researcher at the main entrance of TSBVI. Upon entering the main building, subject and researcher traveled to the hallway where the procedure would be conducted. Two of the three hallways were located on the second floor, and the third hallway was located on the main floor. The subject sat down in the provided chair. The researcher read the informed consent document aloud, along with an additional narrative about what would transpire during the study procedure (see Appendix C). Braille, regular size print, and large print were offered so that participants could read alongside the researcher. Upon completion of reading the informed consent document and narrative, each participant signed a print copy of the informed consent document. If needed, the participant utilized a signature guide provided by the researcher. This is a small tool shaped like a credit card containing a rectangular window in the middle that creates a physical boundary area for a person with B-SVI to sign his or her name. After obtaining informed consent signatures, the researcher asked if there were any questions. The researcher offered a copy of the signed consent form to participants, as well as a braille copy, for their records. The researcher assigned a unique numerical identifier to each subject for data collection, analysis, and reporting purposes. Once questions were addressed the researcher started the digital video camera and the study commenced.

It was expected that some participants would be students or staff members of TSBVI, and potentially very familiar with the hallways of the main building. In contrast, individuals from CCRC or the community at large might be first time visitors to the campus. Each person was asked about his or her familiarity with the testing space and responses were given a numerical code for analysis purposes. A score of 0 indicated that the individual was visiting the building and the hallway for the very first time. A score of 1 indicated that the person had visited the campus/hallway no more than three times. A score of 2 meant that the individual had travelled the hallway a few times as either a former student or new volunteer or teacher. A score of 3 indicated that the person was a frequent user of the hallway, as often as several times per day.

The researcher addressed the potential differences in hallway familiarity by instructing each participant to do an initial walk down and back in the testing space before the data collection on the five walking trials began. This initial walk allowed for a non-visual preview to occur for all subjects. The hallway familiarity rating scale allowed the researcher to potentially group subjects by their reported level of hallway familiarity, in case this were to be a factor influencing participants' walking participation. For example, a group of subjects who have used the hallway on a daily basis could potentially have a different outcome than a group of individuals who were completely unfamiliar with the hallway. Environmental familiarity is a common issue within the B-SVI population, as it has been documented that people who are B-SVI tend to have better walking parameters when they are in familiar versus unfamiliar environments (Clark-Carter et al., 1986; Dawson, 1981; Nakamura, 1997; Ray et al., 2007).

After the initial walk the participant sat back down and the researcher demonstrated how the metronome would sound during the experiment by turning it on and allowing it to play for 10 seconds. Demographic questions were asked of each subject. Data were recorded including the following: gender, age, age of onset of vision loss, type/diagnosis of vision loss, amount of usable vision, and the age of when the subject started walking, if known. Last, the researcher asked, "how would you describe your own walking pattern?" The interview allowed for the collection of demographic data, and also allowed time for the subject to rest prior to beginning the data collection.

Following the demographic interview the subject's resting heart rate (RHR) was recorded. This physiological measure was monitored and recorded throughout the procedure, prior to each walking condition. To measure RHR, the experimenter utilized one of two iPhone apps called the Cardiograph Personal Heart Rate Meter and the Azumio Heart Rate Monitor. The subject held the researcher's iPhone and placed a fingertip on the camera lens. The app detected and recorded the person's heart rate, during a time period of 10-30 seconds. A person's heart rate is said to have "recovered" from a light activity such as walking if the value is less than 50% of the person's maximum target heart rate. A maximum target heart rate is calculated by subtracting the person's age from 220 (American Heart Association, 2012). This measure used the subject's age to calculate their maximum heart rate and recovery heart rate. The monitoring of heart rates ensured that participation in the experiment remained comparable to “light activity” (American Heart Association, 2012). Documentation of recovery heart rates ensured that participants were not overexerted during the study procedures. It also ensured that each person was recovered from any fatigue between each walking trial.

The step-wise procedure for the gait portion of the study was followed. Changes in the conditions are indicated in bold font.

Condition 1: Uncued Normal Walk

1. **The researcher placed the metronome around the neck of the subject.**
2. The researcher turned on the hand-held video camera and began video taping the subject.
3. The researcher instructed, “Please stand at the starting line.”
4. The subject stood and located the starting line with assistance if needed.
5. The researcher instructed, “Please walk down the hallway at your own pace which feels comfortable to you when I say go, and you will stop when you reach the finish line.”
6. The researcher said, “Ready, go.”
7. The subject walked down the hallway.
8. When the first five-meter tape marker was reached, the researcher turned on the stopwatch to time the subject, and began to count steps.
9. After 20 meters and when the subject reached the third tape line, the researcher stopped the stopwatch and stopped counting steps.
10. The subject continued walking for the remaining 5 meters.
11. The researcher told the subject to stop when he reached the final tape finish line.

12. The researcher turned off the hand-held video camera.
13. The researcher instructed, “Please sit down in the chair next to the finish line”.
14. The subject sat down, with the researcher providing verbal assistance if needed for the subject to locate the chair.
15. The researcher recorded the stopwatch time and the counted number of steps for the 20-meter length.
16. The researcher calculated and recorded the subject’s cadence (number of steps per minute).
17. The researcher measured and recorded the subject’s heart rate.
18. If the obtained heart rate value was less than 50% of the subject’s maximum heart rate, then the research protocol continued. If it was not, the subject rested for two minutes and a heart rate was re-calculated until the obtained value was less than 50% of subject’s maximum heart rate.

Condition 2: Cued Normal Walk

19. The researcher turned on the hand-held video camera to videotape the subject.
20. The researcher instructed, “Please stand at the starting line.”
21. The subject stood and located the starting line with assistance if needed.
22. **The researcher asked the subject to hand over the metronome that was hanging in a lanyard pouch around the subject’s neck.**
23. **The subject gave the metronome to the researcher.**
24. **The researcher instructed, “Please walk down the hallway to the beat of the metronome when I say go, and you will stop when you reach the finish line.”**

25. **The researcher turned on the metronome, with the ticks set at the value obtained in step 16, which is the subject's natural and normal walking speed.**
26. **The researcher returned the metronome to the subject and instructed him to return the metronome to the pouch lanyard hanging from the subject's neck.**
27. **The researcher said, "Walk to the beat, ready, go."**
28. The subject walked down the hallway.
29. When the first five-meter tape marker was reached, the researcher turned on the stopwatch to time the subject, and began to count steps.
30. After 20 meters and when the subject reached the third tape line, the researcher stopped the stopwatch and stopped counting steps.
31. The subject continued walking for the remaining 5 meters.
32. The researcher told the subject to stop when he reached the final tape finish line.
33. The researcher turned off the hand-held video camera.
34. The researcher instructed, "Please sit down in the chair next to the finish line".
35. The subject sat down, with the researcher providing verbal assistance if needed for the subject to locate the chair.
36. **The researcher asked the subject to hand over the metronome; when the subject did this, the researcher turned the metronome off.**
37. The researcher recorded the stopwatch time and the counted number of steps for the 20-meter length.
38. The researcher measured and recorded the subject's heart rate.
39. If the obtained heart rate value was less than 50% of the subject's maximum heart rate, then the research protocol continued. If it was not, the subject rested for two

minutes and a heart rate was re-calculated until the obtained value was less than 50% of subject’s maximum heart rate.

Condition 3: Fast Uncued Walk

40. The researcher turned on the hand-held video camera and began video taping the subject.
41. The researcher instructed, “Please stand at the starting line.”
42. The subject stood and located the starting line with assistance if needed.
43. **The researcher instructed, “Please walk down the hallway at your fast pace which feels comfortable to you when I say go, and you will stop when you reach the finish line.”**
44. The researcher said, “Ready, go.”
45. The subject walked down the hallway.
46. When the first five-meter tape marker was reached, the researcher turned on the stopwatch to time the subject, and began to count steps.
47. After 20 meters and when the subject reached the third tape line, the researcher stopped the stopwatch and stopped counting steps.
48. The subject continued walking for the remaining 5 meters.
49. The researcher told the subject to stop when he reached the final tape finish line.
50. The researcher turned off the hand-held video camera.
51. The researcher instructed, “Please sit down in the chair next to the finish line”.
52. The subject sat down, with the researcher providing verbal assistance if needed for the subject to locate the chair.

53. The researcher recorded the stopwatch time and the counted number of steps for the 20-meter length.

54. The researcher calculated and recorded the subject's cadence (number of steps per minute) for her "fast" walk.

55. The researcher calculated a value that was 5% more than the cadence value obtained in step #52.

56. The researcher measured and recorded the subject's heart rate.

57. If the obtained heart rate value was less than 50% of the subject's maximum heart rate, then the research protocol continued. If it was not, the subject rested for two minutes and a heart rate was re-calculated until the obtained value was less than 50% of subject's maximum heart rate.

Condition 4: Fast Cued Walk; 5% Faster than Cadence in Condition #3

58. The researcher turned on the hand-held video camera to videotape the subject.

59. The researcher instructed, "Please stand at the starting line."

60. The subject stood and located the starting line with assistance if needed.

61. The researcher asked the subject to hand over the metronome that was hanging in a lanyard pouch around the subject's neck.

62. The subject gave the metronome to the researcher.

63. The researcher instructed, "Please walk down the hallway to the beat of the metronome when I say go, and you will stop when you reach the finish line."

64. The researcher turned on the metronome, and adjusted the ticks to the value obtained in step 54, the subject's fast walking speed with 5% added to it.

65. The researcher returned the metronome to the subject and instructed him to return the metronome to the pouch lanyard hanging from the subject's neck.

66. The researcher said, "Walk to the beat, ready, go."

67. The subject walked down the hallway.

68. When the first five-meter tape marker was reached, the researcher turned on the stopwatch to time the subject, and began to count steps.

69. After 20 meters and when the subject reached the third tape line, the researcher stopped the stopwatch and stopped counting steps.

70. The subject continued walking for the remaining 5 meters.

71. The researcher told the subject to stop when he reached the final tape finish line.

72. The researcher turned off the hand-held video camera.

73. The researcher instructed, "Please sit down in the chair next to the finish line".

74. The subject sat down, with the researcher providing verbal assistance if needed for the subject to locate the chair.

75. The researcher asked the subject to hand over the metronome and lanyard pouch; when the subject did this, the researcher turned the metronome off and stored the metronome and lanyard pouch for future use.

76. The researcher recorded the stopwatch time and the counted number of steps for the 20-meter length.

77. The researcher measured and recorded the subject's heart rate.

78. If the obtained heart rate value was less than 50% of the subject's maximum heart rate, then the research protocol continued. If it was not, the subject rested for two

minutes and a heart rate was re-calculated until the obtained value was less than 50% of subject's maximum heart rate.

Condition 5: Final, Normal Uncued Walk

79. The researcher turned on the hand-held video camera and began video taping the subject.
80. The researcher instructed, "Please stand at the starting line."
81. The subject stood and located the starting line with assistance if needed.
82. **The researcher instructed, "Please walk down the hallway at your own pace which feels comfortable to you when I say go, and you will stop when you reach the finish line."**
83. The researcher said, "Ready, go."
84. The subject walked down the hallway.
85. When the first five-meter tape marker was reached, the researcher turned on the stopwatch to time the subject, and began to count steps.
86. After 20 meters and when the subject reached the third tape line, the researcher stopped the stopwatch and stopped counting steps.
87. The subject continued walking for the remaining 5 meters.
88. The researcher told the subject to stop when he reached the final tape finish line.
89. The researcher turned off the hand-held video camera.
90. The researcher instructed, "Please sit down in the chair next to the finish line".
91. The subject sat down, with the researcher providing verbal assistance if needed for the subject to locate the chair.

92. The researcher recorded the stopwatch time and the counted number of steps for the 20-meter length.
93. The researcher measured and recorded the subject's heart rate.
94. If the obtained heart rate value was less than 50% of the subject's maximum heart rate, then the research protocol continued. If it was not, the subject rested for two minutes and a heart rate was re-calculated until the obtained value was less than 50% of subject's maximum heart rate.
95. **The researcher asked of the subject, "How would you describe your walking pattern with the metronome? Do you have any comments or questions?"**
96. **The researcher wrote down answers and comments.**
97. **The researcher compensated the subject by giving him twenty-dollars in cash, thanked him for participating, and escorted the participant to the front entrance of the main building.**

Data Collection

The researcher designed and utilized the Data Collection form illustrated in Figure 1. Demographic information, as well as qualitative information such as verbal comments made by the participant during the study, was recorded on this form. Demographic data was organized, grouped, and assigned a nominal value for statistical purposes to allow for comparisons between different demographic groups.

Figure 1

Data Collection Form, Page 1

Data Collection Code # Date: Time:

1. Walk down/back in hall. 2. Demo metronome.	Gender	Age	Age at vision loss onset	Age when started walking
Type of vision loss				
Amount of residual vision				
"How would you describe your walking pattern?"				
Level of hallway familiarity (circle answer) 0 = first time; 1=very few times in this hallway, 2=several times in this hallway 3=frequent user				

Resting Heart Rate (RHR) Using Cardiograph or Azumio (circle) =	Max Heart Rate (MHR) 220 – subject's age	Recovery Heart Rate (VHR) Less than 50% of MHR

1. UNCUED NORMAL WALK: first baseline	Time (sec)	# steps	Cadence (steps per minute) 60 ÷ time = ______ x steps = $\boxed{C =}$

Notes:

Figure 1 Continued

Data Collection Form, Page 2

VHR 1	VHR 2	VHR 3

2. cued normal walk	Time (sec)	# steps

VHR 1	VHR 2	VHR 3

3. Uncued “fast” walk	Time (sec)	# steps	Cadence (steps per minute) 60 ÷ time = _______ x #steps = ______ x .05 = _______ C + 5% = $\boxed{}$

VHR 1	VHR 2	VHR 3

4. cued “fast” walk	Time (sec)	# steps

VHR 1	VHR 2	VHR 3

5. uncued normal walk	Time (sec)	# steps

VHR 1	VHR 2	VHR 3

How would you describe your walk with the metronome? Do you have any questions/comments?	

First, data collected about each subject's gender was assigned a 1 for female and a 2 for male. Second, the age at when vision loss occurred was grouped into age ranges according to overall lifespan development. People who reported to be blind from birth were identified with a zero. Those who lost their vision in infancy, after birth and up to age 1 year were identified with a number 1. Subjects who experienced sight loss in early childhood from the time period after one's first birthday up to age five years were assigned number 2. A number 3 was assigned to those who lost their vision in childhood, between the time period after their 5th birthday to age 18 years, and those who lost their vision in adulthood, after their 18th birthday were assigned a 4. The age range assignment would allow for potential further analysis of data comparing groups of individuals who experienced vision loss at birth with groups who lost their sight in adulthood. Past research has discussed the possible connection between the age when someone lost vision and their walking characteristics (Dawson, 1981; Nakamura, 1997; Ray et al., 2007).

The next grouping of demographic data occurred with the reported types of vision loss. Diagnoses were grouped together with a code number 1 if they were acute incidents. A code number of 2 indicated a progressive illness or disorder spanning a time period of longer than one year. Code number 3 indicated a congenital condition, and code number 4 represented a combination of two or more of the other categories.

The last grouping necessary for the demographic information was for ranges of residual vision amongst the subjects. For this categorization, the researcher referred to the United States Association of Blind Athletes (USABA). For athletic participation and competition, athletes with blindness must be categorized according to how much residual vision is present, in order to ensure fair competition. The USABA follows the classification system of the International Blind Sports Federation (IBSA) guidelines. The researcher of the present study coded the participants accordingly. A code number 1 was for IBSA Visual Classification B1, meaning individuals have no light perception, or some light perception but no ability to detect the shape of a hand in one's visual field at any distance. A code number 2 referred to the IBSA visual classification of B2, meaning individuals have light perception and can recognize the shape of a hand, but also have enough vision to have a visual acuity of 20/600 and/or a visual field of up to 5 degrees, in his or her best eye, with the best practical eye correction. A code number of 3 correlated with IBSA visual classification of B3. Individuals have at worst, a visual acuity of 20/600 and/or a visual field of 5 degrees, and at best, a visual acuity of 20/200 and/or a visual field of less than 20 degrees, in the best eye with the best practical eye correction. Categorizing subjects according to amount of residual vision allowed for comparisons between groups of subjects who had no light perception with groups who had a level of sight loss approaching the definition of legal blindness, which is 20/200 or a visual field of 20 degrees in the best eye with best possible correction (United States Association of Blind Athletes, 2013). Previous research has shown that walking characteristics may differ amongst people who have no residual vision versus ones who have a substantial amount of residual vision (Bouchard & Tétreault, 1999, Larsson & Frändin, 2006).

In addition to using a data collection form, the researcher videotaped all of the walking trials. One video camera captured all of the study procedures conducted in the testing space at a broad and general level, as the camera was stationary on a tripod and videotaped the entire hallway from the start end during each trial. The other video camera was hand-held and was used to record all of the walking data as the researcher followed the participant on each walking trial. Two videotapes supplied a level of dependability in the event of equipment difficulties. The videotapes also allowed for an inter-rater reliability check.

At the beginning of each walking trial, the stationary video camera was turned on. When the participant began a walking trial at the start line, the researcher turned the hand-held video camera on. When the participant reached the masking tape indicating the 5-meter mark, the researcher began the stopwatch and also began counting the participant's steps. To achieve the measures of time and number of steps, the researcher walked behind the participant. When the participant reached the next masking tape line five meters before the finish line, the researcher ceased the counting of steps and stopped the stopwatch. When the participant reached the finish line of the entire 30-meter walking space, the researcher turned off the hand-held video camera. After the initial hallway familiarization walk, the second walk, the fourth walk, and the final walk, the stationary video camera was turned off. It was subsequently turned on prior to the familiarization walk, the first walk, the third walk, and the final walk.

The stopwatch time and number of steps was immediately recorded on the participant's data collection form. The stopwatch time and number of steps was raw data that was utilized immediately during the study procedures to impact subsequent measures during the study procedures. This data was inserted into a formula to determine the person's cadence, or steps per minute. A cadence calculation was necessary in order to program the metronome at the participant's resonant frequency. This cadence calculation determined the setting of the metronome during the second and the fourth walking condition. The cadence was calculated with the formula (60 ÷ number of seconds) ×

number of steps and was completed by the researcher using the calculator software application on the iPhone. For the second walking trial, the metronome ticked at the calculated cadence measure from the first, baseline, uncued normal walk.

For the fourth walking trial, the metronome ticked at the calculated measure from the third, uncued, fast walk, plus an additional 5%. Hence the fourth walking trial's metronome click was 5% faster than the person's uncued fast cadence calculated from the third walking trial. This figure was calculated by the formula (60 ÷ number of seconds) × number of steps; this fast cadence value was multiplied by .05; that amount was added to the first calculated fast cadence value.

All recorded data was input into an SPSS Statistics computer program for analysis. The raw data of time, steps, and calculated cadences in the first and third walking conditions were input directly into SPSS. Subsequent measures on the dependent variables of cadence in walking trials 2, 4, and 5 ((60 ÷ time) × steps), all measures of velocity ((60 ÷ time) × 20 meters), and all measures of stride length (velocity ÷ (cadence ⁄ 2)) were calculated by SPSS by programmed formulas utilizing the direct input raw data.

CHAPTER 4

RESULTS

This study was designed to detect whether or not an isochronous rhythmic cue improved the gait parameters of people who were blind or severely visually impaired (B-SVI) and used a long cane for walking. The study was based upon the theory of rhythmic auditory-motor entrainment, which is the immediate organized motor response to incoming rhythmic auditory stimuli, physically expressed in the observable gait parameters of cadence, velocity, and stride length. The following research questions were asked:

1. Does an external isochronous rhythm cue provided by a metronome and set at the tempo of a person's normal walking speed improve the temporal stride parameters of cadence, velocity, and stride length for adults who are blind or severely visually impaired?

2. Does the external isochronous rhythm cue, increased in speed by 5% from a person's self-paced fast walk, also improve these parameters?

This study was a within-subjects repeated measures design. Since the experiment involved a repeated measure of the subject's walk down the same hallway, there is an inherent practice effect that exists when one does the same task repeatedly. The within-subjects design allows for comparisons across subjects, rather than across groups. Human gait, a biologically rhythmic behavior, varies amongst individuals (Chambers & Sutherland, 2002; Logan et al., 2010; Pearson, Busse, van Deursen, & Wiles, 2004). Hence, a research model in which subjects are compared to themselves was warranted.

Subject Demographics

Initial solicitations targeted a total of 94 potential subjects. Twenty-one people were TSBVI students, 9 were TSBVI staff, 54 were CCRC consumers, 4 were CCRC staff, and 6 were from the community at large. Of this initial group, 2 TSBVI students and 1 TSBVI staff had schedule conflicts preventing participation. Four TSBVI students verbally stated interest in participation and asked for email contact with the researcher, yet did not respond to these subsequent inquiries. One member from the community who was referred by another subject did not return phone calls from the researcher. The remaining 58 individuals attended the weekly meeting at CCRC to receive the initial solicitation. Of those people, 23 initiated contact, via telephone, text, or email, with the researcher regarding their interest in participating.

Two individuals who inquired about participation did not meet inclusion criteria. One TSBVI student was 17 years old and hence did not meet the age requirement. One person from CCRC contacted the researcher in order to participate; however, the person did not have independent travel skills sufficient to locate the testing site at TSBVI, hence he could not participate.

Fifty-one subjects completed study participation and received remuneration of $20 for this completion. Prior to statistical analysis, the data collected for five subjects was removed from the analysis and all data was disposed of, due to various reasons. One subject from TSBVI arrived at the study without a cane and borrowed one from the researcher. The borrowed cane was not of the appropriate length, and the subject reported cane use only in unfamiliar environments at night. One community member became spatially disoriented during the procedure and stopped walking during two of the trials. One subject from CCRC appeared to meet inclusion criteria, yet during the study it was determined by this researcher that the subject's mobility skills, as well as cane skills, were insufficient for the study and that inclusion criteria was not met. Lastly, data collected from two subjects, both TSBVI staff, was inaccurate due to researcher errors in calculating cadences during the testing procedures. In summary, the data of 46 subjects were analyzed for this study.

Of the 46 subjects who were included in the analysis, 22 subjects (48%) were female and 24 (52%) were male. The age range was 18 to 70 years, with a mean age of 34 years, a median age of 32.5 years and a mode of 19 years (n = 7). Subjects originated from a variety of sources including the Texas School for the Blind and Visually Impaired (TSBVI; n=17), the Criss Cole Rehabilitation Center (CCRC; n=25), and the community at large (n=4). Three community members were volunteers at TSBVI, and one was a substitute teacher. Seventy three percent of subjects were consumers of services, originating from TSBVI or CCRC as recipients of services for people who are B-SVI. Demographic information is displayed in Table 1.

Gait patterns of individuals with congenital blindness have been found to be different than gait patterns in people who lost their sight in adulthood as the result of an acute incident. Similarly, people who were born with sight, yet lost their vision over several years due to Retinitis Pigmentosa (RP), may have different gait parameters than someone born with no light perception. A person with good residual vision may walk faster or have a bigger stride than someone who has no vision due to an acute incident in adulthood (Clark-Carter et al., 1986, Dawson, 1981, Johnson et al., 1998, Nakamura, 1997, Nakata et al., 1990).

For these reasons, it was important to categorize the demographic data into ranges for statistical purposes, so that possible comparisons could be made between subgroups. Demographic variables such as the age when a person's vision loss occurred, their amount of residual vision, or how their vision loss occurred (whether the vision loss was congenital, slowly developing over several years, or sudden and acute) are pre-existing factors that can change the gait of a person with B-SVI. In addition, the familiarity with the testing space could have an impact on how a person travels. These groupings are illustrated in Table 1, and show that 46% of subjects were blind from birth, and 67% had vision loss due to congenital and/or progressive conditions. Fifty-six percent of the subjects had no light perception, or light perception so small that one cannot identify the shape of a hand at any distance. Last, 52% of the subjects were walking in the testing space for the first time.

Table 2 provides a detailed summary of the categorization of participants' vision diagnosis conditions. Acute conditions consist of trauma due to accidents or illness, as well as events such as a detachment of the retina occurring over a time period of less than one year. Other examples of acute incidents included traumatic brain injury, complications from surgeries, strokes, and undiagnosed diabetes. A total of 11 subjects reported vision loss as a result of an acute incident or illness.

Progressive conditions are marked by a gradual worsening of vision over a long period of time. The most frequently reported condition in this category was Retinitis Pigmentosa (RP) (n = 10), which is an inherited, degenerative eye disorder characterized by a progressive sight loss often leading to severe visual impairment or total blindness. Two subjects reported having Ushers Syndrome Type II, a specific type of RP that is paired with loss of hearing. Sixteen subjects reported progressive conditions resulting in sight loss.

Congenital conditions are those present at birth; six subjects reported Retinopathy of Prematurity (ROP) and four reported Optic Nerve Hypoplasia (ONH). ROP is seen in premature infants who have received intensive neonatal care and is often linked to oxygen toxicity, whereas ONH is the underdevelopment of the optic nerve resulting in far fewer optic nerve fibers than present in a sighted person. Fifteen subjects reported congenital conditions.

The last category of diagnoses represents a combination of two or more of the above categories, or two acute incidents over the span of many years. Each subject in this category had more than one occurrence of an event leading to sight loss, and those events occurred over the span of several years. Four subjects reported vision loss that fit this category.

Table 1

Summary of Participant Demographics

Category	Participant Origin	*n*	%
01	TSBVI student ages 18-22 years	13	28
02	TSBVI staff member	4	9
03	CCRC consumer	21	45
04	CCRC staff	4	9
05	Community member	4	9
	Age Range for Vision Loss Occurrence		
0	Birth	21	46
2	Early childhood (birth to 5 years)	6	13
3	Childhood (ages 6 years to 17 years)	10	21
4	Adulthood (ages 18 years and older)	9	20
	Type of Vision Loss		
1	Acute onset (i.e., trauma)	11	24
2	Progressive loss (i.e., Retinitis Pigmentosa)	16	34
3	Congenital (i.e., Retinopathy of Prematurity)	15	33
4	Combination of any/all of the above	4	9
	IBSA Visual Classification		
1	Class B1	26	56
2	Class B2	10	22
3	Class B3	10	22
	Level of Hallway Familiarity		
0	First time in the testing hallway	24	52
1	Very few times in testing hallway	3	7
2	Occasional use of testing hallway	8	17
3	Frequent/daily use of testing hallway	11	24
Total		N = 46	100%

Table 2

Categorization of Participants' Vision Loss Conditions

Category	Description	*n*
1	Acute onset (sudden or over less than 1 year)	11
	• Traumatic Brain Injury	1
	• Retinal detatchment	2
	• Trauma during bone marrow transplant	1
	• Stroke during surgery for detatched retina	1
	• Seizures/stroke during sickle cell crisis	1
	• Bilateral optic nerve atrophy due to trauma	1
	• Glaucoma and uvitis	1
	• Detatched retinas due to undiagnosed diabetes	1
	• Leber's Optic Atrophy	1
	• Retinal blastoma	1
2	Progressive Loss (over longer than 1 year period of time)	16
	• Retinitis Pigmentosa	10
	• Ushers Type II	2
	• Glaucoma, cataracts, aphakia	1
	• Juvenile macular degeneration, nystagmus	1
	• Progressive Myoptic Digression	1
	• Keratoconus	1
3	Congenital conditions	15
	• Retinopathy of Prematurity (ROP)	6
	• Optic Nerve Hypoplasia	4
	• Congenital glaucoma	3
	• Coloboma	1
	• Leber's Congenital Amurosis	1
4	Any combination of the above	4
	• ROP, glaucoma, detatched retinas (60 years apart)	1
	• Cataracts, complications from surgery (12 years apart)	1
	• Retinal blastoma (2 occurrences, 25 years apart)	1
	• Congenital glaucoma, cataracts (16 years apart)	1
Total		N = 46

Statistical Analyses

Descriptive statistics were calculated for the dependent variables of cadence, velocity, and stride length in both the uncued and the cued walking conditions. Each uncued and cued walking condition had a normal tempo and a fast tempo condition. Table 3 illustrates the mean and standard deviation for each of the gait parameters in the normal tempo condition, and Table 4 displays the data for the fast tempo condition. Figure 2 visually illustrates a comparison of the means for all dependent variables.

Table 3

Means, Standard Deviations for Normal Walk

Parameter	Uncued		Cued	
	Mean	Std. Deviation	Mean	Std. Deviation
Cadence	111.17	10.91	113.72	11.56
Velocity	69.53	11.09	72.23	11.89
Stride Length	1.25	.18	1.28	.20

Table 4

Means, Standard Deviations for Fast Walk

Parameter	Uncued		Cued	
	Mean	Std. Deviation	Mean	Std. Deviation
Cadence	131.22	12.8	134.63	16.22
Velocity	93.53	17.09	93.88	17.19
Stride Length	1.43	.24	1.40	.23

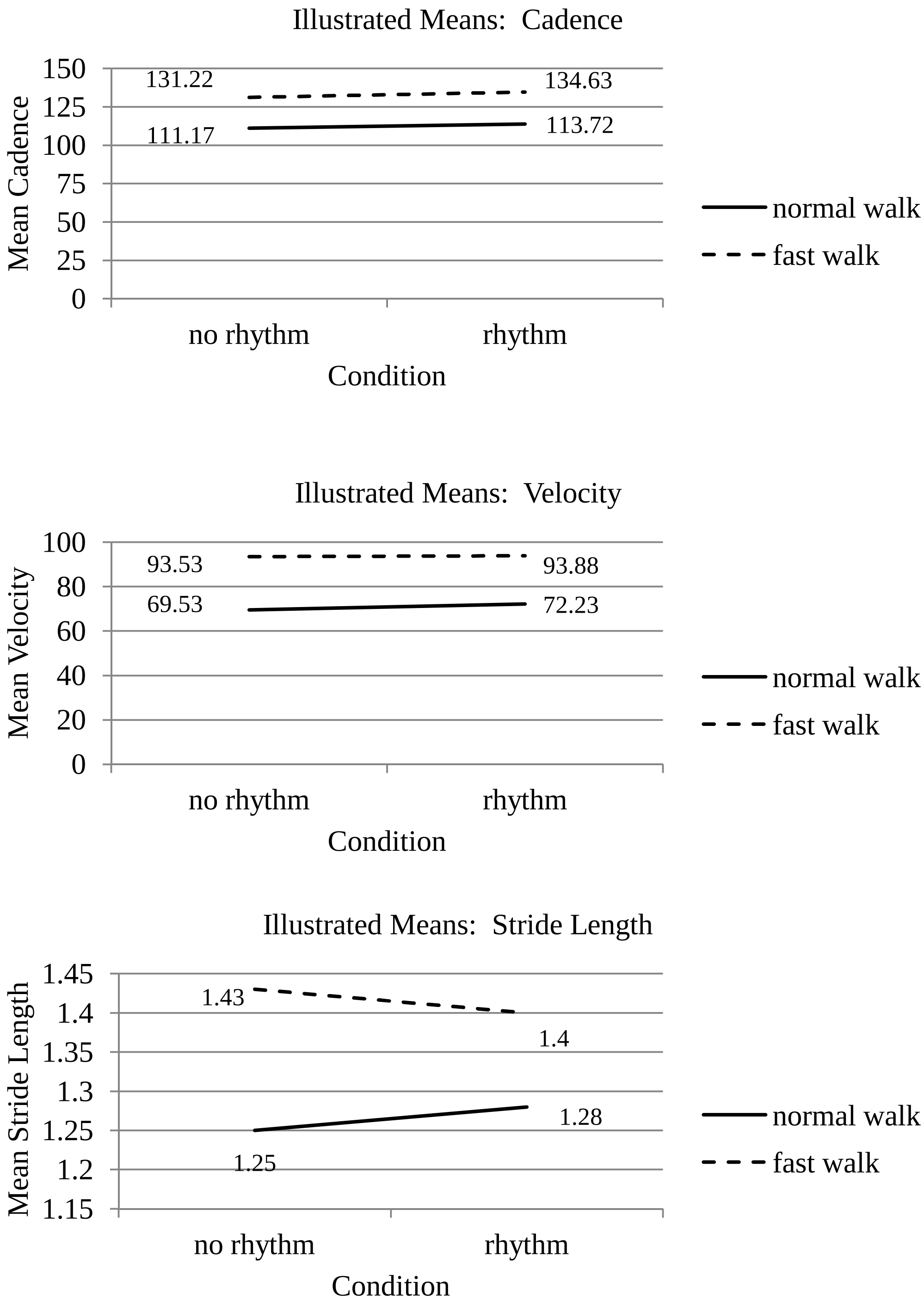

Figure 2. *Illustration of means for all dependent variables*

Figure 2 illustrates that mean cadences increased between the uncued walk and the cued walk, in both the normal and the fast tempii. Mean velocities followed a somewhat similar pattern, yet the velocity change from the uncued to the cued trial at the fast tempo was of a smaller magnitude as the change in the normal tempo walking condition. Velocities in both walking tempii increased, just less so at the faster tempo condition than in the normal tempo condition. Visually, this presented as lines that are not parallel to each other, as with cadence. Means for stride length show an opposite trend than with cadence and velocity. Whereas the stride length increased in the normal tempo condition between uncued and cued metronome conditions, the stride length actually decreased in the fast tempo condition between uncued and cued metronome conditions.

A within-subjects two-way factorial ANOVA (metronome × tempo) with repeated measures was conducted in order to detect changes in participants' gait when comparing the presence or absence of the isochronous metronome cue in both a normal tempo condition and in a fast tempo condition. Main effects of a rhythmic cue were sought for each dependent variable of the gait parameters of cadence, velocity, and stride length at both the normal and fast walk conditions. The statistical assumption of sphericity is relevant when three or more factor levels are present (Field, 2012). In the statistical design for the current study, however, sphericity was not breached, as only 2 levels of the factor of metronome (uncued or cued) and 2 levels of tempo (normal walk or fast walk) were present.

A main effect was found for the independent variable of the metronome,

F (3, 43) = 5.064, p = .004. There was a significant main effect within subjects in comparing walking without the metronome and walking with the metronome. A main effect was also found for the independent variable of tempo, F (3, 43) = 90.175, p = .000. There was a significant main effect within subjects when comparing walking at one's normal walking speed with walking at one's own perceived "fast" speed. Lastly, a significant main interaction was detected between the independent variables of metronome and tempo, F (3, 43) = 4.026, p = .013.

The study procedure asked all subjects to walk at their own "fast" pace for the third walking trial. As a result, the third and fourth walking trials were deliberately faster than the first and second walking trials. The tempo manipulation is the primary function of this independent variable, supporting the test of whether or not subjects changed their gait to match the manipulated tempo. Hence, the study design itself directly affected the statistical outcome, as evidenced in the main effect on the independent variable of tempo. The main effect supports the notion that the subjects walked significantly faster in the fast walk conditions of walking trials 3 and 4, in short, because the subjects were asked to do so.

Subsequent univariate analyses detected statistically significant effects on individual dependent variables. For the independent variable of rhythm, there was a significant effect on the dependent variable of cadence, F (1, 45) = 11.257, p = .002, between the conditions of walking without a metronome cue and walking with a metronome cue. Statistical significance was discovered in subsequent univariate analyses of the independent variable of tempo on all three dependent variables, including cadence, F (1, 45) = 218.838, p = .000, velocity, F (1, 45) = 219.370, p = .000, and stride length, *F* (1, 45) = 105.974, *p* = .000. The main effects of tempo on all stride parameters are expected due to the study's design. Finally, a statistically significant interaction effect was found between the independent variables of metronome and tempo on the dependent variable of stride length, *F* (1, 45) = 9.254, *p* = .004.

Figure 2 visually illustrates the overall main effects and interaction detected in the statistical analysis. The main effect for the metronome is evident in the nearly parallel relationship between the normal and fast tempo conditions for cadence. The illustrated means for velocity follow a somewhat similar trend but are not parallel as in cadence; the increase in velocity is less in the fast tempo condition than in the normal tempo condition. Mean stride length actually decreased from the normal tempo to the fast tempo condition, visually illustrated in the absence of a parallel relationship between the normal and fast tempo conditions. This absence of the parallel relationship is a visual representation of the detected main interaction effects between metronome, tempo, and stride length.

Table 5 provides a visual comparison of mean stride parameters for the first and last walks of the study. Both walks were uncued trials at a normal gait speed, functioning as an initial and a final baseline. Within subjects, all gait parameters increased when comparing the study's final walk with the first walk. In general, subjects walked an average of 7.3 steps per minute faster in the final walking trial. They traveled an average of 8.83 meters per minute faster, and stride lengths increased by an average of 0.08 meters.

Table 5

Means, Standard Deviations for First and Last Uncued Walk

Parameter	Uncued Walk 1		Uncued Walk 5	
	Mean	Std. Deviation	Mean	Std. Deviation
Cadence	111.17	10.91	118.46	12.49
Velocity	69.53	11.09	78.36	11.23
Stride Length	1.25	.18	1.33	.18

Research Question 1

The first question sought to determine if using a metronome cue at a person's normal walking speed improved their gait parameters. This question was answered by walking trials 1 and 2, the normal tempo conditions. A statistically significant main effect was discovered for the independent variable of the metronome. Further investigation revealed that this effect was noted specifically in the dependent variable of cadence. In Table 3, the mean uncued cadence was 111.17 steps per minute. The mean cued cadence increased to 113.72 steps per minute. Participants' cadence, on average, increased with the presence of a metronome cue. In other words, when subjects walked with a rhythmic cue set at his or her own uncued cadence determined in walk 1, they tended to take, on average, 2.5 more steps per minute.

A subsequent univariate analysis of variance found a significant effect of the metronome on the dependent variable of cadence, but not on velocity or stride length. However, the effect of the metronome on velocity approached statistical significance at p = .072. The normal tempo trials yielded mean velocities of 69.53 meters per minute in the uncued walk, and 72.23 meters per minute in the cued walk. This increase indicates that when walking with the metronome cue, velocity increased, on average, by 2.7 meters per minute. Stride length measures did not differ significantly, though the cued stride length (1.28 meters) was larger than the uncued stride length (1.25 meters).

Research Question 2

The second question sought to determine if, when the metronome was subsequently set to a pace slightly faster (5% faster) than the person's self-perceived "fast" walking pace, did the presence of that rhythm cue again improve gait parameters, but in the changed walking condition? The second research question was answered by walking trials 3 and 4, the fast tempo conditions.

As previously stated, an overall statistically significant main effect was detected for the independent variable of the metronome. The main effect was global, spanning across all walking trials. Walking trials 1 and 2 addressed the first research question, targeting a person's normal walking speed. Walking trials 3 and 4 address the second research question, targeting a deliberate change in tempo to a "fast" walk condition.

Walk 3 was an uncued trial where each participant walked at his or her self-perceived "fast" walk. Cadence was calculated, and subsequently increased by 5%. For example, one participant walked with an uncued fast cadence of 142 steps per minute; this cadence with a 5% increase is a manipulated value of 150 steps per minute. Hence, the metronome cue for the participant's cued walk was set at 150 beats per minute, rather than 142 beats per minute.

Table 4 compares the mean uncued fast cadence of 131.22 steps per minute with the mean cued fast cadence of 134.63 steps per minute. Since the mean cued cadence is higher than the mean uncued cadence, the presence of the metronome appeared to increase the cadence measure by, on average, 3.41 steps per minute. Participants took a mean 3.41 more steps per minute when they walked with the metronome cue.

As shown in Table 4, the mean uncued velocity was 93.53 meters per minute whereas mean cued velocity was 93.88 meters per minute. The increase in velocity was extremely small at .35 meters per minute. The mean uncued stride length was 1.42 meters; the cued stride length was 1.40 meters. Thus, a summary of these findings concludes that when subjects participated in the cued walk that was 5% faster than their self-paced uncued fast walk, they had an overall increase in cadence which was statistically significant, a very slight overall increase in velocity, and an overall decrease in stride length.

A more thorough interpretation of the results, the clinical implications, and recommendations for future research will be offered through the discussion.

CHAPTER 5

DISCUSSION

The purpose of this study was to conduct a preliminary investigation into the impact of an external rhythmic cue on the gait parameters of cadence, velocity, and stride length in adults who are blind or severely visually impaired, and who use a long cane for travel. The within-subjects, repeated measures design took into account the two independent variables that were manipulated: metronome (uncued walk versus cued walk) and tempo (normal walking speed versus fast walking speed). The study sought to identify main effects of the metronome on the dependent measures of cadence, velocity, and stride length, across both a normal tempo condition and a deliberately manipulated fast tempo condition. A discovery of main effects in a preliminary study such as this would support continued research as well as clinical protocol development regarding rhythmic auditory-motor entrainment of motor patterns with individuals who are B-SVI.

An overall main effect of the independent variable of metronome was detected. Stride parameters changed significantly when comparing those completed without a rhythm cue to those that were conducted with a rhythm cue. Second, an overall main interaction was detected between the two independent variables of metronome and tempo. Last, main effects were detected for the independent variable of tempo; however, these effects were expected due to the study design.

Research Question 1

Does an external isochronous rhythm cue provided by a metronome and set at the tempo of a person's normal walking speed improve the temporal stride parameters of cadence, velocity, and stride length for adults who are blind or severely visually impaired?

Walking conditions 1 and 2 were conducted at each subject's normal walking speed, and hence they address Research Question 1. When subjects walked with a metronome cue at their regular pace, all of their gait parameters increased. Overall, subjects took more, bigger steps, and they walked faster. The increase in their number of steps taken, represented by the cadence measure, was found to be statistically significant. The presence of an external rhythm cue, clicking at each subject's limit cycle, seemed to have an effect on all measured stride parameters of cadence, velocity, and stride length. All measures increased in the comparison of walk 1 and walk 2.

The first research question specifically asks if stride parameters *improved* with the presence of a metronome cue. The precise answer to this research question depends on the context in which the results are interpreted. Statistical analyses indicated that all measures increased. As previously stated, a range for cadence measures for sighted adults ranges between 111-121 steps per minute; a velocity range is between 79-82 meters per minute; a range of stride length is 1.32-1.48 meters (Rancho Los Amigos National Rehabilitation Center, 2001). In the present study, the mean uncued cadence was 111.17 steps per minute; mean uncued velocity was 69.53 meters per minute; mean stride length was 1.25 meters. A preliminary comparison between the study's data and the cited normative data would indicate that, whereas the subjects' mean cadence was comparable to the sighted normative data, velocity and stride length were decreased. In short, the sample population in this study walked more slowly and took smaller steps than a sample population of sighted adults.

The cued condition yielded increases of all gait measures for the sample population in this study, with a mean cadence of 113.72 steps per minute, mean velocity of 72.23 meters per minute, and mean stride length of 1.28 meters. The mean cadence is still within a similar range as the sighted comparison sample; velocity and stride length increased, yet were still behind the sighted adult sample. Therefore, while the sample from the present study still did not walk as fast or take as big of steps as the sighted comparison sample, the subjects increased on these gait parameters overall. Hence, the presence of a rhythmic cue did indeed appear to improve stride parameters overall, because they increased to a level approaching normative data from sighted adults.

In spite of this, a determination of whether an increase defines improvement should be a clinical determination to be made on an individual patient basis. For example, a patient with a very slow gait, who exhibited increases in gait measures such as ones detected in the present study, would appear to have experienced improvement with the presence of the external rhythmic cue. Conversely, the findings of this study would be contraindicated for a patient with a very fast gait and whose clinical need may be to slow down rather than speed up (exhibited by one subject in the present study).

In summary, it appears that stride parameters improved in the study of the first research question. The presence of the external rhythmic cue did appear to improve stride parameters, and cadence in particular. This improvement is seen in the comparison of means between the uncued and the cued walking conditions. It is possible that while the means show increases, which could be interpreted as improvements, they must be interpreted with some caution and with respect to clinical needs of individual subjects.

Research Question 2

Does the presence of the external isochronous rhythm cue, increased in speed by 5% from a person's self-paced fast walk, also improve these stride parameters?

Research Question 2, supported by walking conditions 3 and 4, sought to detect if the subjects changed their motor behavior (walking) to match an external rhythmic stimulus that was deliberately manipulated. Walking conditions 3 and 4 were conducted at tempi that were deliberately manipulated to contrast with walking conditions 1 and 2, as well as to contrast with each other. Condition 3 represented each subject's own "fast" walking speed; condition 4 was a 5% increase from the value calculated in trial 3.

Question 2, and of walking conditions 3 and 4, was relevant in order to determine if an effect of an external rhythmic cue on walking patterns for adults with B-SVI is intentional and not just by chance alone. Stride parameter improvements in a normal walking task (between walking trials 1 and 2) or in a fast walking task (between walking tasks 3 and 4) is possible evidence. Stride parameter improvements in both a normal walking task and a fast walking task is stronger evidence. Stride parameter improvements in both a normal walking task and a fast walking task in which the cadence was deliberately manipulated could provide the most robust evidence.

In the evaluation of an answer to Research Question 2, subjects took more steps (shown by an increase in mean cadence), they walked only slightly faster (shown in a slight increase in mean velocity), but they actually took smaller steps (shown as a decreased mean stride length). A deliberately manipulated, rhythmically cued, fast walking condition for the subjects seemed to yield more steps that were smaller, but with only a small increase in velocity. Hence, all stride parameters did change, but not all change was statistically significant. The decrease rather than increase in stride length was unexpected.

The second research question specifically asks if stride parameters *improved* with the presence of a metronome cue that was deliberately manipulated. The answer to Research Question 2 is inconclusive. It could be inferred that the presence of the external rhythmic cue in the fast walking conditions did appear to affect stride parameters. The effect was not as pronounced as it was in the normal tempo conditions, and was different than in the normal walking conditions regarding the change in stride length.

To summarize the interpretation of the study's findings, it can be reiterated that there is an apparent effect of the presence of an external rhythmic cue on the walking parameters of adults who are B-SVI. It seems that in the normal walking speed condition in particular, stride parameters improved when comparing walking trials with and without a rhythmic cue, and that these improvements were approaching sighted normative data. However, improvements of clinical relevance should be noted on more of an individual basis, as these comparisons are of means and do not reflect individual circumstances.

Other Effects

One effect noted in this study is that which is inherent in practice effects due to repeated measures. In comparing the means of the first and final baseline walking trials in Table 5 (on page 77), all gait parameters increased from the initial to the final walking trial. The increases of all stride parameters can be attributed to two possible reasons. First, the walking trials were repeated measures so there is an opportunity for the development of practice effects. Second, previous research has indicated that a carryover effect of rhythmic entrainment may exist (Hausdorff et al., 2007; McIntosh, Rice, Hurt, & Thaut, 1998). The study design attempted to account for such effects by asking the subjects to sit and rest until they returned to their baseline resting heart rate. Clinically, the increase in stride parameters of this subject sample is favorable if either or both of the above are true. If the present study's subjects, who were solicited to participate as a population sample but not a clinical sample, exhibited stride parameters that were decreased at the beginning of the study, then any increase that could be interpreted as improvement is a positive outcome from study participation.

Another possible effect to note is that of rhythmic auditory-entrainment. While the metronome seemed to impact stride parameters with this sample, it is plausible to infer that the metronome had an immediate impact on the rhythmic auditory-motor entrainment of gait patterns. The initial findings are promising because the rhythmic cue in this study was not presented as a clinical treatment; it was deliberately added to the environment as an independent variable, with no training required on the part of the subjects. In this case, rhythm demonstrated a potential immediate effect, and in this respect, supports the theory of rhythmic auditory-motor entrainment.

Limitations

The limitation of the present study is that while many promising and significant findings were found, they must be interpreted as preliminary. In order to more fully understand the mechanism of rhythmic auditory-motor entrainment of gait patterns in the sample population, new research questions must be posed, and more temporal data must be collected. First, the research questions specifically used the word "improve," which infers a clinical perspective rather than scientific understanding. Second, the dependent variable measures were obtained by a method referred to as Observational Gait Analysis, a well-established gait assessment method that is used with clinical populations that involves counting steps, timing the patient, and using this data to calculate measures of cadence, velocity and stride length (Rancho Los Amigos National Rehabilitation Center, 2001). It is intended to be a performance measure and is particularly ideal for making clinical treatment decisions regarding gait speed (Pearson et al., 2004).

Observation of stride parameters is indicated for clinical use, and while it was effective at detecting initial effects, different data must be collected in future research studies to better capture the temporal relationship between the absence or presence of the rhythm cue and the dynamic and temporal nature of gait. Measurements collected using digitally recorded stride analysis technology would provide a comprehensive analysis of the temporal events transpiring throughout a subject's entire stride cycle, and stride cycle interaction with the temporal presence of the rhythmic cue.

The results of this study suggest that, for people who are B-SVI, an external rhythm cue does indeed impact gait parameters, and this impact lends initial support to the theory of rhythmic auditory-motor entrainment as a plausible one on which to conduct further research. While the immediate clinical impact has been well documented in the present study, a more complete scientific understanding of the mechanism of rhythmic auditory-motor entrainment as applied to this population is still needed.

Recommendations

The most important recommendation from this study is the justification for continued research into the mediating impact of rhythm on walking for people who are B-SVI. A different study design with different questions being asked could more thoroughly determine the role of rhythmic auditory-motor entrainment with this population. First, a different method of measurement must be utilized. Observational gait parameters are a good and reliable measure for clinical questions. Regarding entrainment, however, the temporal interplay between a person's walking and the presentation of a rhythmic cue must be completed in a more robust manner. Utilizing stride analysis equipment that is available in gait research laboratories would be the ideal method. Footswitch data, collected by inserting sensors into the shoes of participants, provide a wealth of temporal gait information regarding cadence, velocity, steps, veer, what part of the foot touches the floor first, and how much weight bearing occurs on each leg. EMG data collected from leg muscles provides detailed information about muscle activation patterns in relation to the temporal events taking place during a stride cycle. Both forms of measurement provide substantially more quantitative and qualitative data. Fortunately, research models exist which can be replicated (McIntosh et al., 1997; Prassas et al., 1997).

Walking itself is a dynamic and temporal event. Each step taken has a certain amount of inherent variability. It is simply not humanly possible to walk in a manner where each step is precisely identical to the one before it. Thinking of gait in this fashion directs the inquiry to a scientific model regarding the addition of a rhythmic cue to this dynamic, temporal event. The appeal of using rhythm to entrain motor patterns is in the immediate ability to motorically stimulate a person to be "on the beat." Entrainment optimizes the internal sensorimotor processes to produce the most efficient output. Rhythmic auditory-motor entrainment would reduce the variability in the sensorimotor processes that make up human gait. Since there is inherent variability in each step of a person's walking pattern, a rhythmic cue could potentially reduce that variability from step to step.

The recommendations to be made regarding study design can be summarized as follows. Since it is probable, based upon the current study, that rhythm impacts gait parameters for people who are B-SVI, the next research question to be asked is whether or not an isochronous rhythm cue provided by a metronome reduces the variability of gait in people who are B-SVI, as measured by computerized stride analysis equipment. The study design should not be a repeated measures design; rather, the use of computerized stride analysis data would allow for precise temporal measures to be gathered and analyzed, in order to determine precisely what is happening in the absence or presence of the rhythm cue. Rather than comparing performances with repeated measures, this design would allow for actual analysis of the temporal nature of gait and its interaction with the rhythmic cue. This sort of measurement would detect any changes in gait variability and allow for robust comparisons to be made.

A second recommendation targets the number of walking trials utilized in the study's design. Consideration should also be made for optimal performance zones based on the number of walking trials for subjects. In the present study, subjects participated in 5 walking trials, and each trial was 30 meters, or approximately 98 feet. Upon further review of additional published observational gait parameter research, it was discovered that subjects may experience a ceiling effect that can happen with too many walking trials, further suggesting that walking variability in general increases after three walking trials in a research environment (Pearson et al., 2004).

In a future research design, walking requirements could be modified as follows. Walking Trial 1 would be the baseline walk where cadence is calculated. Walking Trial 2 would be the first cued walking trial; the metronome would be set at the limit cycle established in Trial 1. Walking Trial 3 would be another cued walking trial. The metronome would be adjusted from the value in Trial 2 to a value that is 5% higher. Since the manipulation would be on the participant's original limit cycle, it would likely be in a more appropriate range, yet different than the cue in Trial 2. These adjustments would lower the walking trials from 5 to 3, the recommendation by Pearson et al. (2004). This would be accomplished by the removal of the uncued walking measures present in the current study, walking trials 3 and 5. If the first recommendation has been made as previously stated, these trials would not be present anyway because they are part of a repeated measures model, not a scientific variability model as recommended. The design change models those who have conducted similar studies and who have used gait analysis measurement equipment (de l'Etoile, 2007; Hurt et al., 1998; LaGasse, 2013; Thaut et al., 1998; Thaut et al., 1992).

The last recommendation regards an auditory preview of the rhythmic stimulus. One subject from the present study offered a suggestion to allow a set amount of time for the metronome to play prior to starting the walking trial. For example, if the metronome is to be set at 110 beats per minute, the researcher would turn it on at this tempo and allow it to play for a predetermined length of time, such as 10 seconds, before instructing the subject to walk. The subject stated that an auditory preview may be beneficial to people who are B-SVI. Hence, it should be further explored as a consideration for future research designs.

Future Research

A next step in future research implicates the present data set in a preliminary look at the subjects' step variability in relation to the timing of each rhythmic cue in the study procedures. Using the collected video data, each walking trial could be temporally analyzed to detect the step variance of each participant in all walking conditions. A step would be coded at the moment each heel strike occurred; temporal data from step to step would be calculated to obtain a measure of each step's variance in each walking trial. Step variance would be grouped by uncued and cued conditions. It could be hypothesized that the step variance during the cued condition is less than the step variance in the uncued condition. If indeed the step variance differed significantly, it may lend sound support for the theory of rhythmic auditory-motor entrainment.

A large amount of quantitative as well as qualitative data was collected for this research study that could be further analyzed for future research or scholarly purposes. First, the data could be interpreted in regard to the various subgroups according to age of vision loss or amount of residual vision. Second, the research findings could be compared to pre-existing normative data sets. Third, the recording of subject qualitative statements could be analyzed and/or paired with individual subject performance during the study.

The next step in future research stresses the importance of this initial study in regards to future studies being conducted in this area. A preliminary study is effective if the process has allowed the researcher to develop and fine-tune a sound methodology to be used in a future, larger scale study (Robb, 2013). Several aspects of the present study were determined to be effective and should be considered in future research designs. First, the sample population has unique travel and mobility needs and rely on walking or public transportation. For these reasons, the study's physical location in reference to the ease at which potential participants can locate and access it, as well as financial reimbursement for potential travel expenses, is essential. Second, thorough planning of how all information is disseminated to the participants is critical. This includes solicitation, informed consent, written instructions, and narratives. Materials must be adapted for braille and large print readers. Third, the delivery and placement of the metronome cue is important. In the present study, it was worn around the neck of each participant, which kept it close to the ear. It is important to note that headphones are not advisable; this sample population relies on auditory cues in the environment for safety and mobility purposes. Last, many previous walking studies are constructed in a 10-meter testing space, and often, participants are required to turn around and walk back and forth in this area. However, in the present study it was essential to have one straight 30-meter space that did not require the participant to turn. This removed any additional mobility task that could interfere with study procedures, and should be an integral part of a future study of this nature.

In conclusion, the function of the present study as an initial investigation was successful. It stands as an appropriate model for future research targeting people who are B-SVI. The study establishes the need for the next research questions to be asked, and for the next research study regarding rhythmic auditory-motor entrainment of gait for people with B-SVI to be conducted.

Conclusion

The present study sought to determine whether or not a rhythmic cue improved the stride parameters of adults with blindness or severe visual impairment. It is apparent that a rhythm cue increased stride parameters overall, and that this happened immediately and without any sort of formal training. The study's findings are promising, yet additional research should be conducted to determine if rhythmic auditory-motor entrainment actually reduces the variance in gait patterns of adults who are B-SVI. This study's preliminary outcomes suggest that more research is warranted with the mentioned recommendations being incorporated.

The present study's most basic premise is to help further along the field of music therapy research in its understanding of human music perception, human systems (in this case, walking), the critical connection between the two, and the strengthening of the research-based theoretical frameworks that are necessary to ground music therapy clinical work. The field of music therapy needs established clinical protocols that are based in a sound theoretical framework. Critical connections must be established and replicated which illustrate the following premises. Music is a viable therapeutic mechanism for people with B-SVI because of its ease of access to our motor system through shared networks. These shared auditory-motor networks are not dependent upon vision. All people are wired to walk in a similar way, regardless of their eyesight or lack thereof. Rhythmic auditory-motor entrainment of motor patterns is a viable theoretical framework on which to build music therapy protocols for this population. A trajectory for a path of scholarly research is established upon completion of this preliminary study. Additional research must be conducted with the present data set and beyond.

APPENDIX A

FACILITY PERMISSION LETTER

TSBVI

William Daugherty, Superintendent
Texas School for the Blind and Visually Impaired

1100 W. 45th Street
Austin, Texas 78756
www.tsbvi.edu

Voice: (512) 454-8631
Toll-free: (800) TSB-KARE

A center for educational services for all blind and visually impaired students in Texas

September 24, 2012

Chris Winders, Director of Research Compliance
University of Missouri - Kansas City
5319 Rockhill Road
Kansas City, MO 64110

Dear Mr. Winders:

Della Molloy-Daugherty, Ph.D. candidate in the Department of Music Education and Music Therapy, the Conservatory of Music, has requested to use our facility to conduct her dissertation research project entitled *Rhythmic Auditory-Motor Entrainment of Gait Parameters in Adults with Blindness or Severe Visual Impairment.* The Principal Investigator/supervisor is Deanna Hanson-Abromeit, Ph.D., Assistant Professor of Music Therapy in UMKC's Conservatory of Music.

This letter gives written permission for Ms. Molloy-Daugherty to use our facility as requested. Please feel free to contact me if you have any concerns or questions.

Sincerely,

Mr. William E. Daugherty
Superintendent
The Texas School for the Blind and Visually Impaired
1300 West 45th Street
Austin, TX 78756
(512) 206-9134
BillDaugherty@tsbvi.edu

APPENDIX B

PARTICIPANT SOLICITATION SCRIPT

My name is Della Molloy-Daugherty. I am a graduate student in the Department of Music Education and Music Therapy, in the Conservatory of Music and Dance, at the University of Missouri-Kansas City, and I am doing a research project to finish a doctoral degree in music therapy.

I want to understand how a rhythmic cue from a metronome can affect walking patterns of people who are blind or severely visually impaired. I am not testing any sort of a treatment, but I am just looking at how the rhythm affects walking in general. People have special rhythmic connections in their brains that are very sensitive to outside sources of rhythm. One way we can measure change in this sensitivity is by watching a person's walking patterns. Other research has looked at rhythm and walking on groups of people, such as healthy sighted adults, adults with brain injuries, stroke, or Parkinson's disease. I am trying to research that sensitivity in adults with blindness or severe vision impairment, because this has not yet been done.

In order for me to complete this project, I am asking for your participation in my study. This study has been approved by the University of Missouri-Kansas City Social Science Institutional Review Board, and will be supervised by my dissertation advisor, Deanna Hanson-Abromeit. While it is in no way connected to the Texas School for the Blind and Visually Impaired, TSBVI is allowing me to use their facility as a testing site.

In order to participate, you must be a legally consenting adult between the age of 18 and 70 years, you must be a long cane user, you must have English as your first language, you must have no known hearing difficulties, and you must be able to meet me at the front door of TSBVI.

The study will take about one hour of your time. You would make an appointment with me to meet me at TSBVI during evening or weekend hours. You will participate in a series of walking trials. There are 7 trials and each trial is 30 meters or about 98 feet. You will wear a small metronome that is about the size of a deck of playing cards. Between walks, we will check your heart rate by using a smart phone app called the Cardiograph Personal Hart Rate Meter. This will help us be sure that we maintain a level of safe, light activity. You will be walking at your regular, natural pace.

I am offering a small stipend of $20 to thank you for your time.

If you are interested in participating, please visit with me individually so that we can be sure you are a candidate. We will then go through the study in more detail, if you are still interested you will give permission to be in the study and we will make an appointment for you to take part.

Thank you very much for your consideration! Are there any questions?

APPENDIX C

NARRATIVE SCRIPT

The study you are participating in today will involve walking down a 30-meter length of a hallway by using your long cane. This length is equal to about 98 feet. You will walk this 30-meter length a total of seven times. The walking that we ask you to do will be at a speed that is comfortable for you. There will be rest periods in between each time that you walk. During this rest time, you will sit down and I will take your heart rate to be sure that you are well rested. Some of these walks will be done with a steady beat coming from a metronome that you will walk with. The metronome is a box that makes steady clicks. It is smaller than a deck of playing cards, and will be worn around your neck so that you can hear it easily.

First, we will take your resting heart rate. To do this, we will have you place your finger on the camera lens of an iPhone, and an app called "Cardiograph" will measure your heart rate. Next, we will do some calculations to figure out your maximum heart rate and your recovery heart rate. While you will not be asked to do anything more physically demanding than walk, the resting heart rate is used as a way to be sure that you always stay in a safe zone of physical activity throughout the study.

Next, if you have given permission for us to do so, a digital video camera will be turned on. The purpose of this camera is to videotape all of the walking for the study. We will be counting the steps you take and the videotape will be a way for us to make sure we have counted correctly. It is okay if you decide that you do not want to be video taped. You can still help us in this study without the videotape

The first task you will do is to walk the 30-meter walking distance, down the hall and back to this point, to help you become comfortable with the space and the task. You will walk from the start line to the finish line and back again. After you have walked down the hall and back, we will demonstrate how the metronome will sound during the experiment by placing it around your neck, turning it on, and allowing it to play for 10 seconds. The videotape will be turned off and you will then be asked to sit in the chair and rest.

During this rest period we will ask you some questions such as your age, when you lost your sight, what kind of vision loss you have, how much usable vision you have, and the age when you started walking as a child, if known. These questions are important to the study in case we learn that there are different walking patterns among the study subjects. You will also be asked to describe your own walking pattern. After these questions we will take your heart rate to determine if you have returned to your resting heart rate. If you have, the videotape will be started again and you will be given directions for the walking tasks. If not, you will rest for another two minutes and your resting heart rate will be taken every two minutes until it is less than 50% of your calculated maximum heart rate. After the walking tasks, we will ask you a couple more questions, and then we are finished. You will be paid $20 for your time.

Do you have any questions?

REFERENCES

Adelson, E., & Fraiberg, S. (1974). Gross motor development in infants blind from birth. *Child Development, 45,* 114-126.

American Printing House for the Blind, Department of Field Services. (2013). *Annual report 2012: Distribution of eligible students based on the federal quota census of January 3, 2011 (Fiscal Year 2012).* Retrieved from http://www.aph.org/fedquotpgm/dist12.html

Arias, P., & Cudeiro, J. (2010). Effect of rhythmic auditory stimulation on gait in Parkinsonian patients with and without freezing of gait. *PLoS ONE 5*(3): e9675. doi: 10.1371/journal.pone.0009675

Aschersleben, G., & Prinz, W. (1995). Synchronizing actions with events: The role of sensory information. *Perception and Psychophysics, 57,* 305-317.

Batra, M., Sharma, V., Batra, V., Malik, G., & Pandey, R. (2011). Postural reactions: An elementary unit for development of motor control. *Disability, CBR and Inclusive Development, 22,* 134-137. doi: 10.5463/DCID.v22i2.30

Bigelow, A. E. (1992). Locomotion and search behavior in blind infants. *Infant Behavior and Development, 15,* 179-189.

Bouchard, D., & Tétreault, S. (2000). The motor development of sighted children and children with moderate low vision aged 8-13. *Journal of Visual Impairment and Blindness, 94,* 564-573.

Brambring, M. (2001). Motor activity in children who are blind or partially sighted. *Visual Impairment Research, 3,* 41-51.

Brambring, M. (2006). Divergent development of gross motor skills in children who are blind or sighted. *Journal of Visual Impairment and Blindness, 100,* 620-634.

Celeste, M. (2002). A survey of motor development for infants and young children with visual impairments. *Journal of Visual Impairment and Blindness, 96*, 169-174.

Chambers, H. G., & Sutherland, D. H. (2002). A practical guide to gait analysis. *Journal of the American Academy of Orthopaedic Surgeons, 10*, 222-231.

Cheung, K. K. W., Au, K. Y., Lam, W. W. S., & Jones, A. Y. M. (2008). Effects of a structured exercise program on functional balance in visually impaired elderly living in a residential setting. *Hong Kong Physiotherapy Journal, 26*, 45-50.

Chin, D. L. (1988). Dance movement instruction: Effects on spatial awareness in visually impaired elementary students. *Journal of Visual Impairment and Blindness, 82*,188-192.

Clark-Carter, D. D., Heyes, A. D., & Howarth, C. I. (1986). The effect of non-visual preview upon the walking speed of visually impaired people. *Ergonomics, 29*, 1575-1581.

Clayton, M., Sager, R., & Will, U. (2005). In time with the music: The concept of entrainment and its significance for ethnomusicology. *European Meetings in Ethnomusicology*, *11*, 3–142.

Codding, P. A. (1988). Music in the education/rehabilitation of visually disabled and multihandicapped persons: A review of literature from 1946-1987. In Charles E. Furman (Ed.), *Effectiveness of music therapy procedures: Documentation of research and clinical practice.* (pp. 107-134). Washington, DC: The National Association for Music Therapy.

Codding, P. A. (1996). Music therapy literature and clinical applications for blind and severely visually impaired persons: 1940-1996. In *Effectiveness of music therapy procedures: Documentation of research and clinical practice.* (2nd ed.) (pp. 129-168). Washington, DC: The American Association for Music Therapy.

Codding, P. A. (2000). Music therapy literature and clinical applications for blind and severely visually impaired persons: 1940-2000. In The American Association for Music Therapy Publication Committee (Ed.), *Effectiveness of music therapy procedures: Documentation of research and clinical practice.* (3rd ed.) (pp. 159-198). Washington, DC: The American Association for Music Therapy.

Cohen, H. S. (1999). *Neuroscience for rehabilitation.* (2nd Ed.). Philadelphia: Lippincott Williams & Wilkins.

Cooper, H. (1998). *Synthesizing research: A guide for literature reviews* (3rd Ed.). Thousand Oaks, CA: Sage Publications, Inc.

Corn, A. L., & Bailey, G. L. (1991). Profile of music programs at residential schools for blind and visually impaired students. *Journal of Visual Impairment and Blindness, 86,* 379-382.

Dale, N., & Sonksen, P. (2002). Developmental outcome, including setback, in young children with severe visual impairment. *Developmental Medicine and Child Neurology, 44,* 613-622.

Darrow, A. A., & Novak, J. (2007). The effect of vision and hearing loss on listeners' perception of referential meaning in music. *Journal of Music Therapy, 44,* 57-73.

Dawson, M. L. (1981). A biomechanical analysis of gait patterns of the visually impaired. *American Corrective Therapy Journal, 35*, 66-71.

de l'Etoile, S. K. (2007). The effect of rhythmic auditory stimulation on the gait parameters of patients with incomplete spinal cord injury: An exploratory pilot study. *International Journal of Rehabilitation Research, 31*, 155-157.

Elisa, F., Josée, L., Oreste, F. G., Claudia, A., Antonella, L, Sabrina, S., & Giovanni, L. (2002). Gross motor development and reach on sound as critical tools for the development for the blind child. *Brain and Development, 24,* 269-275.

Elliott, D. B., Patla, A. E., Flanagan, J. G., Spaulding, S., Rietdyk, S., Strong, G., & Brown, S. (1995). The Waterloo vision and mobility study: Postural control strategies in subjects with ARM. *Ophthalmic and Physiological Optics, 15,* 553-559.

Ferrell, K. A., Trief, E., Dietz, S. J., Bonner, M. A., Cruz, D., Ford, E., & Stratton, J. M. (1990). Visually impaired infants research consortium (VIIRC): First-year results. *Journal of Visual Impairment and Blindness, 84*, 404-410.

Field, A. (2012). Repeated measures ANOVA. In *Discovering statistics* (4^{th} Ed.) (pp. 1-22). Retrieved from www.discoveringstatistics.com/

Field-Fote, E. C. (2000). Spinal cord control of movement: Implications for locomotor rehabilitation following spinal cord injury. *Physical Therapy, 80,* 477-484.

Ford, S. E. (1999). The effect of music on the self-injurious behavior of an adult female with severe developmental disabilities. *Journal of Music Therapy, 36*, 293-313.

Grahn, J. A., Henry, M. J., & McAuley, J. D. (2011). fMRI investigation of cross-modal interactions in beat perception: Audition primes vision, but not vice versa. *Neuroimage, 54,* 1231-1243.

Greenwald, M. A. (1978). The effectiveness of distorted music versus interrupted music to decrease self-stimulatory behaviors in profoundly retarded adolescents. *Journal of Music therapy, 15,* 58-66.

Grillner, S. (1975). Locomotion in vertebrates: Central mechanisms and reflex interaction. *Physiological Reviews, 55,* 247-304.

Hallenmans, A., Beccu, S., Van Loock, K., Ortibus, E., Truijen, S., & Aerts, P. (2009a). Visual deprivation leads to gait adaptations that are age- and context-specific. I. Step-time parameters. *Gait and Posture, 30,* 55-59.

Hallenmans, A., Beccu, S., Van Loock, K., Ortibus, E., Truijen, S., & Aerts, P. (2009b). Visual deprivation leads to gait adaptations that are age- and context-specific. II. Kinematic parameters. *Gait and Posture, 30,* 307-311.

Hallemans, A., Ortibus, E., Truijen, S., & Meire, F. (2011). Development of independent locomotion in children with a severe visual impairment. *Research in Developmental Disabilities, 32,* 2069-2074.

Harley, R.K., Wood, T.A., & Merbler, J.B. (1980). An orientation and mobility program for multiply impaired blind children. *Exceptional Children, 46*, 326-331.

Harris, S. R., & Thompson, M. (1983). Water as a learning environment for facilitating gross motor skills in deaf-blind children. *Physical and Occupational Therapy in Pediatrics, 3*, 75-82.

Hausdorff, J. M., Lowenthal, J., Herman, T., Gruendlinger, L., Peretz, C., & Giladi, N. (2007). Rhythmic auditory stimulation modulates gait variability in Parkinson's disease. *European Journal of Neuroscience, 26,* 2369-2375.

Hayden, R., Clair, A. A., & Johnson, G. (2009). The effect of rhythmic auditory stimulation (RAS) on physical therapy outcomes for patients in gait training following stroke: A feasibility study. *International Journal of Neuroscience, 119,* 2183-2195.

Herlein, D. G. (1975). Music reading for the sightless: Braille notation. *Music Educators Journal*, *62*(1), 42-45.

Hill, J., Brantner, J., & Spreat, S. (1989). The effect of contingent music on the in-seat behavior of a blind young woman with profound mental retardation. *Education and Treatment of Youth, 12*, 165-173.

Hollyfield, R. L., & Trimble, J. L. (1985). Measuring gait-related blind mobility performance. *Journal of Rehabilitation Research and Development, 22,* 66-74.

Horvat, M., Ray, C., Ramsey, V. K., Miszko, T., Keeney, R., & Blasch, B. B. (2003). Compensatory analysis and strategies for balance in individuals with visual impairments. *Journal of Visual Impairment and Blindness, 97*, 695-703.

Huebner, K. M. (2003). Visual impairment. In Holbrook, M. C. & Koenig, A. J. (Eds.), *Foundations of education (vol. 1): History and theory of teaching children and youths with visual impairments* (2nd Ed.) (pp. 55-76). New York: AFB Press.

Hurt, C. P., Rice, R. R., McIntosh, G. C., & Thaut, M. H. (1998). Rhythmic auditory stimulation in gait training for patients with traumatic brain injury. *Journal of Music Therapy, 35*, 228-241.

Jazi, S. D., Purrajabi, F., Movahedi, A., Jalali, S. (2012). Effect of selected balance exercises on the dynamic balance of children with visual impairments. *Journal of Visual Impairment and Blindness, 106,* 466-474.

Johnson, J. T., Johnson, B. F., Blasch, B. B., & De l'Aune, W. (1998). Gait and long cane kinematics: A comparison of sighted and visually impaired subjects. *Journal of Orthopaedic and Sports Physical Therapy, 27,* 162-166.

Kern, P., & Wolery, M. (2001). Participation of a preschooler with visual impairments on the playground: Effects of musical adaptations and staff development. *Journal of Music Therapy, 38*, 149-164.

Kersten, F. (1981). Music as therapy for the visually impaired. *Music Educators Journal, 67*(7), 63-65.

Kolb, B., & Whishaw, I. Q. (2003). Organization of the motor system. In Atkinson, R. C., Lindzey, G., & Thompson, R. F. (Eds.), *Fundamentals of human neuropsychology* (5th Ed.) (pp. 197-220). New York: Worth Publishers.

Kolb, B., & Whishaw, I. Q. (2003). The occipital lobes. In Atkinson, R. C., Lindzey, G., & Thompson, R. F. (Eds.), *Fundamentals of human neuropsychology* (5th Ed.) (pp. 318-344). New York: Worth Publishers.

LaGasse, A. B. (2013, April). *Basic neuroscience of music therapy in rehabilitation*. Paper presented at the American Music Therapy Association Southwest/Midwest Regional Music Therapy Conference, San Antonio, TX.

LaGasse, A. B. (2013). Influence of an external rhythm on oral motor control in children and adults. *Journal of Music Therapy, 50,* 6-24.

Lam, R. C., & Wang, C. (1982). Integrating blind and sighted through music. *Music Educators Journal, 68*(8), 44-45.

Larsson, L., & Frändin, K. (2006). Body awareness and dance-based training for persons with acquired blindness—effects on balance and gait speed. *Visual Impairment Research, 8,* 25-40.

Levtzion-Korach, O., Tennenbaum, A., Schnitzer, R., & Ornoy, A. (2000). Early motor development of blind children. *Journal of Paediatrics and Child Health, 36,* 226-229.

Logan, D., Kiemel, T., Dominici, N., Cappellini, G., Ivanenko, Y., Lacquaniti, F., & Jeka, J. J. (2010). The many roles of vision during walking. *Experimental Brain Research, 206*, 337-350.

MacGowan, H. E. (1983). *The kinematic analysis of the walking gait of congenitally blind and sighted children: Ages 6-10 years.* (Unpublished dissertation). University of Minnesota, Minneapolis, MN.

Madsen, C. K., & Darrow, A. A. (1989). The relationship between music aptitude and sound conceptualization of the visually impaired. *Journal of Music Therapy, 26*, 71-78.

Mason, S. J., Legge, G. E., & Kallie, C. S. (2005). Variability in the length and frequency of steps of sighted and visually impaired walkers. *Journal of Visual Impairment and Blindness, 99,* 741-754.

McIntosh, G. C., Brown, S. H., Rice, R. R., & Thaut, M. H. (1997). Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry, 62,* 22-26.

McIntosh, G. C., Rice, R. R., Hurt, C. P., & Thaut, M. H. (1998). Long-term training effects of rhythmic auditory stimulation on gait in patients with Parkinson's disease. *Movement Disorders*, *13,* 212.

Merriam, A. P. (1964). *The anthropology of music.* Chicago: Northwestern University Press.

Molinari, M., Leggio, M. G., de Martin, M., Cerasa, A., & Thaut, M. (2003). Neurobiology of rhythmic motor entrainment. *Annals of the New York Academy of Sciences*, *999*, 313-321.

Molloy-Daugherty, D. M. (2010a). *Rhythmic auditory stimulation on the gait parameters of two children with severe visual impairment and additional disabilities.* Unpublished manuscript, University of Missouri-Kansas City, Kansas City, MO.

Molloy-Daugherty, D. M. (2010b). *Integrating rhythmic auditory stimulation (RAS) into an adapted music education classroom.* Unpublished manuscript, University of Missouri-Kansas City, Kansas City, MO.

Molloy-Daugherty, D. M. (2010c). *A research synthesis of motor skills interventions conducted with children who have vision loss.* Unpublished manuscript, University of Missouri-Kansas City, Kansas City, MO.

Molloy-Daugherty, D. M. (2012). Treatment planning for clients with visual impairments. In Gadberry, A. (Ed.), *Treatment planning for music therapy cases.* Denton, TX: Sarsen Publishing.

Murphy, F. M., & O'Driscoll, M. (1989). Observations on the motor development of visually impaired children: Interpretations from video recordings. *Physiotherapy, 75,* 505-508.

Nakamura, T. (1997). Quantitative analysis of gait in the visually impaired. *Disability and Rehabilitation, 19,* 194-197.

Nakata, H., Nakamura, T., Kakizawa, T., & Rahardja, D. (1990). Adapted gait of the blind. In Doll-Tepper, Dahms, Doll, & von Selzam (Eds.), *Adapted physical activity, an interdisciplinary approach: Proceedings of the 7th international symposium* (pp. 357-361). Berlin: Springer-Verlag.

Pal'tsev, Y. I., & El'ner, A. M. (1967). Change in the functional state of the segmental apparatus of the spinal cord under the influence of sound stimuli and its role in voluntary movement. *Biophysics, 12,* 1219-1226.

Parncutt, R. (1994). A perceptual model of pulse salience and metrical accent in musical rhythms. *Music Perception, 11,* 409-464.

Patel, A. D., Iversen, J. R., Chen, Y., & Repp, B. H. (2005). The influence of metricality and modality on synchronization with a beat. *Experimental Brain Research, 163,* 226-238.

Pearson, O. R., Busse, M. E., van Deursen, R. W. M., & Wiles, C. M. (2004). Quantification of walking mobility in neurological disorders. *QJM: An International Journal of Medicine, 97,* 463-475.

Penhune, V. B., Zatorre, R. J., & Evans, A. C. (1998). Cerebellar contributions to motor timing: A PET study of auditory and visual rhythm reproduction. *Journal of Cognitive Neuroscience, 10,* 752-765.

Pereira, L. M. (1990). Spatial concepts and balance performance: Motor learning in blind and visually impaired children. *Journal of Visual Impairment and Blindness, 84*, 109-111.

Pilcher, M. (1964). Resources for teaching music to the blind. *Music Educators Journal, 51*(2), 67-68.

Pogrund, R. L., & Fazzi, D. L. (2002). *Early focus*: *Working with young children who are blind and visually impaired and their families* (2nd Ed). New York: AFB Press.

Portfors-Yeomans, C. V., & Riach, C. L. (1995). Frequency characteristics of postural control of children with and without visual impairment. *Developmental Medicine and Child Neurology, 37,* 456-463.

Prassas, S., Thaut, M., McIntosh, G., & Rice, R. (1997). Effect of auditory rhythmic cuing on gait kinematic parameters of stroke patients. *Gait and Posture, 6,* 218-223.

Ramsey, V. K., Blasch, B. B., & Kita, A. (2003). Effects of mobility training on gait and balance. *Journal of Visual Impairment and Blindness, 97*, 720-726.

Ramsey, V. K., Blasch, B. B., Kita, A., & Johnson, B. F. (1999). A biomechanical evaluation of visually impaired persons' gait and long-cane kinematics. *Journal of Rehabilitation Research and Development, 36,* 323-332.

Rancho Los Amigos National Rehabilitation Center (2001). *Observational gait analysis handbook.* Downey, CA: Los Amigos Research and Education Institute, Inc.

Randel, D. M. (1978). Rhythm. In *Harvard concise dictionary of music.* Cambridge: The Belknap Press of Harvard University Press.

Ray, C., Horvat, M., Williams, M., & Blasch, B. (2007). Kinetic movement analysis in adults with vision loss. *Adapted Physical Activity Quarterly, 24,* 209-217.

Ray, C. T., & Wolf, S. L. (2010). Gender differences and the risk of falls in individuals with profound vision loss. *Journal of Visual Impairments and Blindness, 104,* 311-316.

Repp, B. H. (2003). Rate limits in sensorimotor synchronization with auditory and visual sequences: The synchronization threshold and the benefits and costs of interval subdivision. *Journal of Motor Behavior, 35,* 355-370.

Rhythm. (n.d.). In *Dictionary.com.* Retrieved from http://dictionary.reference.com/browse/rhythm

Rider, R. A., & Candeletti, G. (1982). Influence of motor therapy on children with multisensory disabilities: A preliminary study. *Perceptual and Motor Skills, 55,* 809-810.

Robb, S. L. (2003). Music interventions and group participation skills of preschoolers with visual impairments: Raising questions about music, arousal, and attention. *Journal of Music Therapy, 40,* 266-282.

Robb, S. L. (2013). Editorial: The power of the pilot. *Journal of Music Therapy, 50,* 3-5.

Rosen, S. (1997). Kinesiology and sensorimotor function. In Blasch, B. B., Wiener, W. R., & Welsh, R. L. (Eds.), *Foundations of orientation and mobility* (2nd Ed.) (pp. 170-199). New York: AFB Press.

Ross, S., & Tobin, M. J. (1997). Object permanence, reaching, and locomotion in infants who are blind. *Journal of Visual Impairment and Blindness, 91*, 25-32.

Rossignol, S., & Melvill Jones, G. (1976). Audio-spinal influence in man studied by the H-reflex and its possible role on rhythmic movements synchronized to sound. *Electroencephalography and Clinical Neurophysiology, 41*, 83-92.

Sabin, R. (1952). The Lighthouse School: Music for blind students. *Musical America, 72*(25), 25.

Safranek, M. G., Koshland, G. F., & Raymond, G. (1982). Effect of auditory rhythm on muscle activity. *Physical Therapy, 62*, 161-168.

Schiller, J. S., Lucas, J. W., Peregoy, J. A. (2012). Summary health statistics for U.S. adults: National health interview survey, 2011. *Vital Health Statistics, 10*(256), 7.

Sforza, C., Eid, L., Michielon, G., Fragnito, N., & Ferrario, V. F. (2003). Sensorial afferents, expectations, and craniocervical postural relations in adults who are blind and sighted. *Journal of Visual Impairment and Blindness, 97*, 17-27.

Siegel, I. M., & Murphy, T. T. (1970). *Final report: Postural determinants in the blind:Tthe influence of posture on mobility and orientation.* Jacksonville, IL: Department of Children and Family Services, Illinois Visually Handicapped Institute.

Silberman, R. K. (2003). Children and youths with visual impairments and other exceptionalities. In Holbrook, M. C., & Koenig, A. J. (Eds.), *Foundations of education (vol. 1): History and theory of teaching children and youths with visual impairments* (2nd Ed.) (pp. 173-196). New York: AFB Press.

Silliman, L. M., French, R., & Tynan, D. (1992). Use of sensory reinforcement to increase compliant behavior of a child who is blind and profoundly mentally retarded. *Clinical Kinesiology, 46*(3), 3-9.

Soong, G. P., Lovie-Kitchin, J. E., & Brown, B. (2004). Measurements of preferred walking speed in subjects with central and peripheral vision loss. *Ophthalmic and Physiological Optics, 24,* 291-295.

Steele, A. L., & Crawford, C. (1982). Music therapy for the visually impaired. *Education of the Visually Handicapped, 14,* 56-62.

Stephan, K. M., Thaut, M. H., Wunderlich, G., Schicks, W., Tian, B. Tellmann, L., Schmitz, T., Herzog, H., McIntosh, G. C., Seitz, R. J., & Hömberg, V. (2002). Conscious and subconscious sensorimotor synchronization – prefrontal cortex and the influence of awareness. *Neuroimage, 15,* 345-352.

Stewart, K. A. (1997). *A kinematic analysis of transitional movements of preschool children who are blind or visually impaired.* (Unpublished dissertation). University of Northern Colorado, Greely, CO.

Strickling, C. A. (1998). *Impact of vision loss on motor development: Information for occupational and physical therapists working with students with visual impairments.* Austin, TX: Texas School for the Blind and Visually Impaired.

Strickling, C. A., & Pogrund, R. L. (2002). Motor focus: Promoting movement experiences and motor development. In Pogrund R. L., & Fazzi, D. L. (Eds.), *Early focus: Working with young children who are blind or visually impaired and their families* (pp. 287-325). New York: AFB Press.

Takashita, B. (2010). Developing your child's vision. Retrieved from http://low-vision.org/en/Developing_Your_Childs_Vision

Target heart rates (n.d.). In *American Heart Association.* Retrieved from http://www.heart.org/HEARTORG/GettingHealthy/PhysicalActivity/TargetHeart

Tecchio, F., Salustri, C., Thaut, M. H., Pasqualetti, P., & Rossini, P. M. (2000). Conscious and preconscious adaptation to rhythmic auditory stimuli: A magnetoencephalographic study of human brain responses. *Experimental Brain Research, 135,* 222-230.

Thaut, M. H. (2000). *A scientific model of music in therapy and medicine.* San Antonio: IMR Press.

Thaut, M. H. (2002). Physiological and motor responses to music stimuli. In Unkefer, R. F., & Thaut, M. H. (Eds.), *Music therapy in the treatment of adults with mental disorders* (2nd Ed.) (pp. 33-41). St. Louis: MMB Music, Inc.

Thaut, M. H. (2003). Neural basis of rhythmic timing networks in the human brain. *Annals of the New York Academy of Sciences, 999,* 364-373.

Thaut, M. H. (2005). *Rhythm, music, and the brain: Scientific foundations and clinical applications.* New York: Taylor and Francis Group, LLC.

Thaut, M. H., Hurt, C. P., Dragon, D., & McIntosh, G. C. (1998). Rhythmic entrainment of gait patterns in children with cerebral palsy. *Developmental Medicine and Child Neurology, 40*(78), 15.

Thaut, M. H., Kenyon, G. P., Schauer, M. L., & McIntosh, G. C. (1999). The connection between rhythmicity and brain function: Implications for therapy of movement disorders. *IEEE Engineering in Medicine and Biology, 18*, 101-108.

Thaut, M., Lange, H., Miltner, R., Hurt, C., & Hoemberg, V. (1996). Rhythmic entrainment of gait patterns in Huntington's disease patients. *Society for Neuroscience, 22,* 1851.

Thaut, M. H., McIntosh, G. C., & Rice, R. R. (1997). Rhythmic facilitation of gait training in hemiparetic stroke rehabilitation. *Journal of Neurological Sciences, 151*, 207-212.

Thaut, M. H., McIntosh, G. C., Rice, R. R., Miller, R. A., Rathbun, J., & Brault, J. M. (1996). Rhythmic auditory stimulation in gait training for Parkinson's disease patients. *Movement Disorders, 11*, 193-200.

Thaut, M. H., McIntosh, G. C., Prassas, S. G., & Rice, R. R. (1992). Effect of rhythmic auditory cuing on temporal stride parameters and EMG patterns in normal gait. *Journal of Neurological Rehabilitation, 6,* 185-190.

Thaut, M. H., McIntosh, G. C., Prassas, S. G., & Rice, R. R. (1993). Effect of rhythmic auditory cuing on temporal stride parameters and EMG patterns in hemiparetic gait of stroke patients. *Journal of Neurologic Rehabilitation, 7,* 9-16.

Thaut, M. H., Miller, R. A., & Schauer, L. M. (1998a). Multiple synchronization strategies in rhythmic sensorimotor tasks: phase versus period correction. *Biological Cybernetics, 79,* 241-250.

Thaut, M. H., Rathburn, J., & Miller, R. A. (1997). Music versus metronome timekeeper in a rhythmic motor task. *International Journal of Arts Medicine, 5*, 4-12.

Tröster, H., & Brambring, M. (1993). Early motor development in blind infants. *Journal of Applied Developmental Psychology, 14*, 83-106.

Tröster, H., Hecker, W., & Brambring, M. (1994). Longitudinal study of gross-motor development in blind infants and preschoolers. *Early Child Development and Care, 104,* 61-78.

United States Association of Blind Athletes (2013). *IBSA visual classifications.* Retrieved April 18, 2013 from http://usaba.org/index.php/membership/visual-classifications/

United States Census Bureau American Fact Finder. (2013). *Disability characteristics 2011: American community survey one-year estimates.* Retrieved April 8, 2013 from http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_11_1YR_S1810&prodType=table

Uslan, M., Malone, S., & De l'Aune, W. (1983). Teaching route travel to multiply handicapped adults: An auditory approach. *Journal of Visual Impairment and Blindness, 77*, 18-20.

Vise, N. (1972). *Orientation and mobility in the primary grades taught through the media of rhythms, dance exercises, and body movement exercises.* Nashville: Joint University Libraries.

Wall, R. (2002). Biomechanical substrates of the two-point touch can technique: A review of research. *Journal of Visual Impairment and Blindness, 96,* 86-97.

Wyatt, L., & Ng, G. Y. (1997). The effect of visual impairment on the strength of children's hip and knee extensors. *Journal of Visual Impairment and Blindness, 91*, 40-46.

Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007). When the brain plays music: Auditory-motor interactions in music perception and production. *Neuroscience, 8*, 547-558.

VITA

Della Molloy Daugherty was born October 8, 1969 in Lawrence, Kansas. She graduated from Lawrence High School in May 1987. Ms. Molloy-Daugherty attended the University of Kansas, Lawrence, where she received a Bachelor's in Music Education – emphasis in Music Therapy, in May 1992.

Ms. Molloy-Daugherty passed her national board certification examination and became a Registered Music Therapist – Board Certified (RMT-BC) in January 1993. From January 1993 until May 1994, she worked as a music therapist for Rebound, Incorporated, which was an acute neurological rehabilitation facility within Independence Regional Medical Center, Independence, Missouri.

Ms. Molloy-Daugherty returned to the University of Kansas in August 1994, and worked as a Graduate Teaching Assistant in the Department of Music Education and Music Therapy while she pursued her master's degree. She taught undergraduate and graduate coursework to music therapy students. She also coordinated the clinical training program and the University's music therapy clinic, and graduated with her Master's in Music Education – emphasis in Music Therapy, in May 1997.

Ms. Molloy-Daugherty worked as music therapist for the Kansas State School for the Blind from August 1996 until May 2010. It was during this tenure, in August 2004, that she began the Interdisciplinary Ph.D. program at the University of Missouri-Kansas City.

Upon completion of her degree requirements, Ms. Molloy-Daugherty plans to continue her career by combining research, publication, clinical work, and higher education teaching in the Austin, Texas area.