The effect of rhythmic auditory cueing on goal-directed reaching with changing task difficulty in individuals diagnosed with Cerebral Palsy.

By

Jacqueline Ladwig

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Faculty of Kinesiology and Recreation Management
University of Manitoba
Winnipeg

Abstract

For individuals with Cerebral Palsy (CP), functional reaching is key to independence. Previous research indicates benefits for multisensory input, while presently it is unknown how sensory input occurs during goal-directed movements in CP. This study considered the influence of an auditory stimulus during the planning or execution phases of a goal-directed reach task. Three conditions were presented: No Sound, Sound:Before, and Sound:During. Adult participants (10 CP; 10 TD) reached from a home switch to one of two targets. Reaction time analyses demonstrated a significant main effect for condition, with decreased RT in the SB conditions for both groups. Analysis of variable error revealed significant main effects for group and condition; the CP group executed more consistent movements in both conditions. Analysis of ttPV/movement time revealed a significant interaction, indicating the CP group engaged online control relatively earlier in SB. Overall, the SB condition improved planning, execution, and accuracy of reaching movements for individuals with CP.

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To my students, may you find the courage to step outside of your own comfort zone and expand your horizons in whatever path you choose. To my family and dear friends, thank you for your support, understanding, and encouragement in all of my endeavors.

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Dedication

To my mom and dad; thank you for your unconditional love and support. Your uncompromising dedication to your family and tireless pursuit of a better life for your children is my foundation.

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PREAMBLE

In the world of dance, movements are directed by the external mechanism of music, which appears to be simultaneously driven by an internal rhythm. In this context, the use of music appears to coordinate an internal rhythm that facilitates the performance of complex movements, and attunes a group of dancers to the same metronomic rhythm facilitating movement in ensemble. In movement performance, multi-sensory information is received from our environment, which then informs intricate neuromotor processes, resulting in the harmonious coordination of movement (Bengtsson et al, 2008; Traynor, Galea & Pierrynowski, 2011). This synchronization of rhythm, motor programming, neural processes, and muscle activation is the result of years of practice and processes of motor learning throughout life. Of particular significance are the developmental years from birth through childhood. During this time, interactions with our environment encourage and stimulate the exploration of our world, which in turn directly influence our motor development.

Through the creation of the ExplorAbility program at Canada's Royal Winnipeg Ballet School I have developed a deeper, more meaningful understanding of disability and movement; observing differences in how movement is performed when moving randomly with music versus moving to the rhythmic structure of the music with several different populations, inclusive of both cognitive and physical differences. The diagnosis of primarily spastic cerebral palsy (CP) is of particular interest to me as it poses a pedagogical challenge when teaching structured technical movements. For dancers with CP there seems to be a fine balance between calm, smooth movement and stochastic, explosive movement. This contrast in movement-ability is linked directly to how body schema is developed (Assainte et al., 2013), as well as the amount of neural noise occurring in the neuromotor system during initiation and execution of reaching movements (Meyer et al., 1988; Schmidt et al., 2010). The present study is an opportunity to consider the relationship between multisensory cues (visual and auditory) and movement and disability through a new, more specific, lens.

Previous literature explores the use of a rhythmic stimulus in populations with neurological impairment as a mode of facilitating movement (reach) entrainment over a given duration of time (Thaut, et al., 2002). Much of this work has demonstrated that significant changes do occur in such a setting, however current literature does not define *where* in the movement planning and execution this facilitation might occur. Considering the specific diagnosis of CP, much of the literature available investigates the movement of children, focusing on the developmental stages of learning. In contrast, adult populations pose a unique challenge as movement has been practiced throughout childhood and adolescence within the neurological diagnosis, while physical activity levels may have been limited due to level of impairment and availability of programming. The present study focuses on the impact of rhythm on movement within this specific population, and acknowledges the psychosocial impact of specialized movement programs.

In summary, the present study investigates *where* the rhythmic stimulus might have the greatest impact during a goal-directed reach task in adults diagnosed with CP: the planning stage (Sound:Before) or in the execution of the movement (Sound:During), as compared to their typically developed counterparts. The difficulty of the task increased in the Sound:During condition as it created a dual task paradigm. The following thesis defines and outlines the diagnosis of Cerebral Palsy, reviews existing literature in the areas of goal-directed reach, visual processing, the relationship between audition and reach, and explores the use of auditory stimuli

in neurologically impaired populations. The results of this study are presented and discussed in relationship to the theoretical basis, while considering future implications arising from the experimental process.

INTRODUCTION

Cerebral palsy (CP) is a multi-dimensional heterogeneous neurological diagnosis impacting individuals' ability to be functionally independent over their lifespan. In Canada, it is estimated that there are over 60,000 persons with a form of CP (1/500 births) with approximately one in every three premature babies affected, and many who are undiagnosed (Colledge, 2011). A 2013 meta-analysis found the prevalence of CP worldwide to be 2.11 in every 1000 live births (Oskoui, Coutinho, Dykeman, Jette & Prinsheim, 2013). The authors found a higher rate of diagnosis in preterm births, which decreased with gestational age (Oskoui, Coutinho, Dykeman, Jette & Prinsheim, 2013). The frequency of CP has not decreased despite advances made in prenatal and neonatal care and the improved rate of neonatal survival, therefore the number of infants diagnosed with CP is said to have increased (Eunson, 2012; Straub and Obrzut, 2009).

Inclusive of sensorimotor and perceptual challenges (Straub & Obrzut, 2009), the diagnosis of CP can lead to secondary conditions such as epilepsy and musculoskeletal problems, as well as decreased mobility with age (World Health Organization, 2013; Eunson, 2012; Thorpe, 2009; Rimmer, 2001). Individuals with CP also experience hypertonicity (spasticity), which limits limb control due to postural disturbances, making activities of daily living a challenge (Shumway-Cook & Woollacott, 2007). Liptak (2008) reported a high instance of secondary conditions in adults diagnosed with CP: osteopenia and fracturing, fatigue, deterioration of ambulation, as well as concerns with overall life satisfaction. The authors also report that 20-30% of adults with CP experience limitations in their participation in activities of daily living (Liptak, 2008). In the context of functional ability, many individuals diagnosed with CP are limited in their ability to ambulate safely outside the home and therefore rely on assistive devices and technology to navigate their communities (Rosenbaum et al., 2002). Proficiency and strength of arm movements are particularly important for this population as arm movements are required for ambulation and activities of daily living (ADLs). Independent movement often requires the use of goal-directed (functional) reaching actions; for instance, when picking up a cup, pressing a doorbell, reaching to a shelf, or using a computer keyboard/touch screen for everyday communication.

The present study investigates the impact of auditory cues on functional reach. This research provides a greater understanding of multisensory integration specific to *when* and *how* auditory information may facilitate a change in movement (planning or execution phases of movement) when neurological impairment is present, as compared to typically developed adults. In turn, this knowledge will inform therapeutic prescription for this population specific to the benefits of working on reach in seated positions, as well as the potential importance of incorporating rhythm in traditional therapeutic and alternative program settings.

Definition of CP

Eunson (2012), Rosenbaum, Paneth, Leviton, Goldstein, & Bax (2007), and Shevell & Bodensteiner (2004) state that the term Cerebral Palsy is an umbrella term that recognizes the heterogeneity of the diagnosis where the cause is resultant of a damaging event, or lesioning, to the cerebral cortex, typically occurring during prenatal and/or postnatal stages. Lesions can be caused by brain damage, brain malformation, and disorders of brain function unrelated to malformation (Eunson, 2012). For example, in approximately 2-10% of cases diagnosed with CP intrapartum (birth) asphyxia leading to neonatal encephalopathy, malformations may be genetic in origin or resulting from lesioning occurring during the 1st or 2nd trimester, and disorders of brain function may be a result of cerebrovascular events also occurring in the 1st or 2nd trimester

(Eunson, 2012). Magnetic resonance imaging (MRI) has provided an understanding of the relationship between abnormalities observed in the scans and the physical manifestation of CP (topography and tone), particularly in cases such as malformation, periventricular leukomalacia (PVL), and middle cerebral artery infarction (Eunson, 2012). Typically, CP is classified as non-progressive in reference to the timing and permanence of lesioning (Eunson, 2012; Shevell & Boensteiner 2004). On the other hand, accompanying impairments observed in childhood may continue to develop throughout the lifespan as individuals move through the developmental stages with existing lesioning.

The developmental foundation of a child's motor and functional skills is postural control. This process begins in the immediate postnatal months with direction-specific adjustments (forward and/or backward sway) and continues to develop in four periods of transition throughout the first fourteen months of life (Hadders-Algra, M., 2005). At the root of the CP diagnosis is evidence for impairments of postural and motor development, and activity limitations (Rosenbaum et al., 2007), resulting from abnormal neural function specific to the upper motor neuron (UMN) tracts. UMNs transmit motor signals from the motor cortices to the lower motor neuron tracts via interneurons in the brainstem and spinal cord, facilitating actions such as postural and gross movement, anticipatory postural adjustment and reach, and fractionation of movement (Lundy-Ekman, 2013). Initial evidence of UMN damage is observed in delayed motor milestones, clumsiness, and impairment of gait (Shevell & Bodensteiner, 2004).

The topography of CP encompasses a range of plegias (Eunson, 2012): hemiplegia, diplegia, triplegia, and quadriplegia, and can also be described as symmetrical and asymmetrical. In addition to the varied plegias, physical differences are also observed in muscle tone and are defined as spasticity, dystonia and dyskinesia (inclusive of chorea and athetosis). Muscle tone is described as the amount of resistance to stretch in the resting muscle, often described as hypotonicity (less than normal resistance) and hypertonicity (higher than normal resistance) (Lundy-Ekman, 2013; Shumway-Cook & Woollacott, 2012). By definition, hypertonicity may include spasticity, which is velocity dependent or rigidity, which is velocity independent. Both can lead to musculoskeletal (joint) contractures. Dystonia and dyskinesia are involuntary sustained muscle contractures causing abnormal postures inclusive of athetosis (rhythmic, involuntary contractures) and chorea (non-rhythmic, involuntary movements). Considering the impact on reaching movements, this broad range of plegias, muscle tone, as well as dystonia and dyskinesia, and postural control issues, commonly result in unpredictable movement sequencing and/or limitations in the ability to initiate (reaching) movements.

For individuals with CP, musculoskeletal deformities and tone may also impact the process of developing postural control. In some cases, scoliosis and the degree of the spinal curvature involved may increase over time leading to difficulty with seating and positioning, postural discomfort, and functional independence (Klingbeil, 2004). In adulthood, the resulting development of asymmetric postures in CP can lead to tissue adaptation, increased muscle contracture, and progressive deformities (Rodby-Bousquet et al., 2013). The resulting postural instability directly impacts movement efficiency in both the upper and lower extremities. Seizures are also commonly associated with CP and may result in impaired hand function or language skills (Eunson, 2012). Chronic pain and fatigue may have an effect on the motor ability of the individual, limiting participation and causing increased negative emotions, which may in turn result in decreased satisfaction over the lifetime of the individual (Liptak, 2008; Klingbeil, 2004). Overall, the clinical presentation of CP resides on a developmental continuum dependent on developmental and ageing processes, opportunities for learning, amount of and opportunity for activity, and duration of therapies (Rosenbaum et al., 2007).

In 2006, Steenbergen & Gordon's review of the accepted definition of CP as a motor and postural disorder of development added disorders of motor planning and perceptual impairments to the definition. They suggest that previous therapies that support the execution of movement (joint stability, increased range of motion, limiting deformities) ignore the issue of motor planning and indicate that perhaps issues of motor planning play a larger role in the limitation of physical activity for those with CP. The authors review the concept of anticipatory force planning in a fingertip grasp which determined that individuals with CP were unable to scale fingertip force during movement planning, however with practice they were able to change this process of movement scaling (Gordon & Duff, 1999). Perceptive impairment (PI) in CP can be described as an interruption in the neurological processes used to integrate and interpret internal and external sensory information to plan, control, and execute motor behaviours (Ferrari, Terso, Ferrari, Sghedoni & Chiari, 2010; Bumin & Kayihan, 2001). Though the causes of CP are permanent and non-progressive in nature, providing opportunity for both children and adults living with CP to challenge multi-sensory perception, proprioception, and develop postural awareness can aid in the maintenance of postural control, functional ability, as well as overall fitness (Damiano, 2006; Liptak, 2008).

In Liptak's (2008) literature review of the health and wellness of adults with CP, several comorbidities were found specific to CP as compared to typically developed adults. Among the comorbidities was a gradual decline in functional ambulation, oral motor deficiencies, osteopenia and fracturing, fatigue, chronic pain, progressive musculoskeletal deformity, and resulting contractures of skeletal muscle (dysfunction) (Liptak, 2008; Klingbeil, 2004). Klingbeil (2004) further explained the emergence of comorbidities as resulting from life-long altered postures and movements, immobility, medications, as well as disorders typically associated with the CP diagnosis. It is important to acknowledge that despite the aetiology of the CP diagnosis, the known benefits of physical activity amongst typical adults hold true for this population (Palisano, Snider & Orlin, 2004). The World Health Organization's International Classification of Functioning (ICF), disability and health model describes an interactive relationship between the condition (CP) and activity, delineating the benefits of this relationship in the areas of body structure and function (improved strength, flexibility and agility), participation (the willingness and interest to participate), environmental factors (family unit, home, and school) and personal factors (personal choices and interests) (Rosenbaum & Stewart, 2004). The ICF model provides a common language and approach to disability, functioning, and health, however it falls short in the areas of psychological and social barriers for those living with disability. In addition to the ICF model, the knowledge of potential comorbidities (as noted previously) demonstrates a clear need to increase opportunities for functional physical activity specific to this population.

Much of the research regarding CP and motor function has been specific to children, who are still moving through the developmental stages of life within the diagnosis of CP. Throughout these stages children and adolescents are developing their body schema and motor control for goal–directed tasks in many different venues: at home, school, and play. Body schema is defined as an internal representation of body mechanics, dynamics and orientation in space in relationship to sensory information received from our environment (Assainte, Barlaam, Cignetti & Vaugoyeau, 2013; Schmidt, 1975 & 2003). Assainte et al. (2013) suggest that the representations are used to guide future (physical) interactions and are continually updated based on current sensory information. In the case of CP, damage to the brain occurs perinatally or in the immediate postnatal period, thus the development of initial motor programs and neural pathways are established within an impaired neurological structure. In comparison, children who experience stroke later in childhood establish initial neural processes within a typical neurological structure. Rehabilitation can then be based on those known neuromotor programs and processes, whereas in a child with CP those programs and processes are impaired, and therefore a habilitative approach is required. In summary, children diagnosed with CP perform activities of daily living within the limitations of their motor impairment/s; impacting what activities are accessible to them due to safety concerns/risks and limited truly adaptive programming, as well as participation (Liptak, 2008).

Gross Motor Functional Classification Scale

Gross Motor Functional Classification Scale (GMFCS) ratings are used by clinicians and researchers to capture the functional ability of individuals with CP (Table 1, pp 9). These ratings are based on the actions of sitting and walking, and acknowledge the physical topographies of CP, as well as the (functional) arm strength required for using a walker, hand-held mobility devices, and propelling oneself in a manual wheelchair (Palisano, Rosenbaum, Bartlett, Livingston, 2007; Palisano et al., 1997). In 2007, Palisano et al. expanded and revised the original GMFCS ordinal scale previously established by Palisano et al. (1997) to include specific age groupings for the five levels of the GMFCS. The current GMFCS rating (see Table 1, pp 9) recognizes this synergy and ability to integrate sensory and postural input, ultimately categorizing the functional gross motor ability of the individual (Palisano et al., 2007).

In a more detailed document, the expanded and revised measure also takes into consideration the developmental stages and the changes that may occur during each phase of development and divides the stages into specific age groupings: before 2yrs old, 2 to 4 yrs, 4 to 6 yrs, 6 to 12 yrs, and 12 to 18 yrs. For example, (GMFCS level 3 rating; ages 2 to 18yrs), before the age of 2 an infant may roll and creep forward on the stomach. Between 2 and 4 yrs of age, the same child may roll and creep forward on their stomach on hands and knees without reciprocal leg use. From 4 and 6 yrs of age, the same child may move in and out of a chair using a stable surface to push on/pull up with their arms. The same child between 6-12 yrs of age performs sit to stand and floor to stand transfers with physical assistance. Lastly, at 12-18 yrs of age, the same individual may self-propel using a wheelchair or powered mobility while at school or in the community, and sit to stand/floor to stand transfers require physical assistance (Palisano et al., 2007). In addition to the actions of sitting and walking as posited by Palisano et al. (2007), and accounting for the larger picture of the development of functional ability over the course of childhood and adolescence, we must also consider the significance of the sensory input from our environment.

Table 1

Gross Motor Function Classification Scale

GMFCS Level	**General description of limitation**	**Distinctions between levels**
Level 1	Walks without limitations	
Level 2	Walks with limitations	Limitations walking long distances and balancing; may need mobility device when learning to walk or when traveling long distances in the community; not as capable of running and jumping.
Level 3	Walks using a hand-held mobility device	Requires a mobility device to walk indoors and use wheeled mobility outdoors and in community. Sit on own/limited support, independent in standing transfers.
Level 4	Self-mobility with limitations; may use powered mobility	Function in a supported sitting device, self-mobility is limited, more likely to be transported by manual wheelchair or use powered mobility.
Level 5	Transported in a manual wheelchair	Severe limitation in head and trunk control, extensive assisted technology and physical assistance required.

Based on GMFCS - E & R © Robert Palisano, Peter Rosenbaum, Doreen Bartlett, Michael Livingston, 2007, CanChild Centre for Childhood Disability Research, McMaster University.

During the early years of child development, parents play an active role in the development of a child’s body schema through interactive play and physical (group) activities that incorporate physical, as well as social, literacy. In the management of a child’s diagnosis (of CP), parents also play a crucial role in accessing various therapies (physical, occupational, speech) that impact the overall development of the child. Once transitioning into adulthood, the functional progress made during childhood and adolescence begins to shift yet again, as individuals move from paediatric care to adult centred care (Young, 2007). Young (2007) suggests that the health care system itself is also experiencing a transition as individuals diagnosed with CP are now living longer lives, therefore requiring an increased number of physicians who specialize in CP beyond the pediatric years. This decrease in specialized care, in addition to transitioning to adult centred care, results in fewer individuals accessing rehabilitative services among CP populations. Young et al. (2010) assessed quality of life (QoL) in youth and adults diagnosed with CP (GMFCS levels 1-5) and found that although overall QoL scores were not statistically significant, there was an observable pattern in reported quality of life. The more functionally able group (GMFCS level 1-3) reported a slightly better quality of life in comparison to those at GMFCS level 4-5. Considering the domains assessed, the adult group scored lower in the illness subdomain as compared to youth; the authors feel that this may demonstrate an early decline in clinical status and/or the onset of new comorbities (Young et al., 2010). The difference between scores according to functional ability (GMFCS) suggests a need for activity programming that is adaptable to all functional levels for adult populations with CP in an effort to delay onset of and/or improve management of comorbidities through maintaining a physically active lifestyle. Because of the differences between the development of a child’s body schema, a decreased level of childhood participation, and the high number of potential comorbidities during adulthood coupled with the onset of the aging process, it is difficult to make inferences of adults diagnosed with CP from data specific to children. Therefore, it is crucial that research in the area of CP and multisensory integration also study the adult populations.

Psychosocial Perspective

In addition to the developmental, motor, and perceptual aspects of CP, it is also important to consider the psychosocial impact of supporting the role of motor function and physical activity in the diagnosis of CP. Bandura (1982) defines self-efficacy as the belief in one's ability to pursue life goals and the persistence to work towards achieving those goals despite any physical, emotional, or societal obstacles. Becker & Schaller (1995) considered perceptions of self-efficacy and health attitudes among persons diagnosed with CP. Overall, self-efficacy scores were highest in the health responsibility subscale (e.g. nutrition, health care), while self-efficacy for exercise scores were lowest. In other words, individuals with CP are likely to ensure good nutrition and health care, but were less likely to participate in exercise on a regular basis. The authors suggested that lower self-efficacy specific to exercise may reflect a need for promotion of programs and interventions that facilitate feasible forms of exercise and physical activity, which in turn may also break down societal and assumed barriers for adults with CP.

The Canadian Society for Exercise Physiology and American College of Sports (CSEP) Medicine recommends 30 minutes of moderate-intensity aerobic activity, five days a week to maintain physical health in the general adult population (muscular, skeletal, as well as cardiorespiratory; Tremblay et al., 2011; Garber et al., 2011). The psychological benefits of physical activity are also known to aid in managing depression, anxiety, and improve overall feelings of self-worth and self-efficacy (Usuba, Oddson, Gauthier & Young, 2015; Garber et al., 2011). CSEP has defined the Canadian physical activity guidelines for those living with Multiple Sclerosis, spinal cord injury, and Parkinson's disease, though there are no specific guidelines outlined for those diagnosed with CP (Tremblay et al., 2011; Garber et al., 2011). Usuaba et al., 2015 conducted research with adults diagnosed with CP regarding levels of participation in physical activity (PA) specific to frequency and intensity, and to explore the range of PA in adults with CP according to self-reported GMFCS levels (1-5). The authors reported that 52% of respondents were non-ambulatory (GMFCS IV-V), 13% were classified at GMFCS III, and the remaining 35% at GMFCS I-II; 91% of the CP group reported participating in broad range of PAs at least once a week. Considering GMFCS levels I-III, 27% were physically active as compared to those at GMFCS levels IV-V (non-ambulatory) reported at 11% being active. Barriers to increasing and maintaining levels of PA for the non-ambulatory CP participants were health condition (23%), availability of respite workers/assistants (30%), cost (24%), and accessibility (24%). Though a high percentage of adults with CP reported regular weekly physical activity, there is a clear discrepancy in this percentage when comparing by GMFCS levels (as described in Table 1, pp 9). The physical, perceptual, and social barriers, that limit participation for CP population, and the need to foster self-efficacy in regards to PA, should be taken into consideration when creating programs and the CSEP physical activity guidelines for the CP population.

Sensorimotor Development

During childhood, the exploration of one’s environment facilitates the development of motor function which leads to independent, and in some cases automatic, movement throughout life. A child’s environment plays a key role in this process as functional motor development is intertwined with our ability to integrate multiple sensory inputs from the surrounding environment. Held and Hine (1963) demonstrated this in what is known as the kitten experiment. The authors exposed pairs of kittens to two specific apparatus conditions; one was placed in a passive condition in which physical movement was restricted, and the other in an active condition where physical movement was allowed. Both kittens had full vision and were equally exposed to the patterned walls of the apparatus. Following this procedure, three different visually-guided tests were performed. The authors found that the development of visually-guided behaviour was directly linked to the kitten's ability to actively explore their own environment through self-produced movement (Held and Hine, 1963). The authors also demonstrated the plastic nature of the central nervous system, noting that after the passive group of kittens was exposed to a forty-eight hour period of roaming freely in a lighted room, they showed normal visually guided test results. Here, the authors suggest that exploring our environment through self-produced, voluntary movement is critical for our sensorimotor development.

In the diagnosis of CP, these developmental processes are interrupted before neural pathways are developed during the perinatal period and in the proceeding developmental months. From a movement perspective, the neurological impairment that occurs in CP limits how the individual explores their environment during these early stages using full unilateral and bilateral movements, as well as visual information. Considering the diagnosis of CP and the need to maintain and encourage functional movement, it is then important to examine the active self-initiation of movement on both the affected and non-affected sides of the body. Neurological deficits are the foundation of the diagnosis of CP, limiting full movement, coordination, and strength (as compared to a typically developed individual). Opportunities to encourage and improve bilateral ability, sensory perception and integration (through practice) strengthens neurological processes of motor function, as well as sensory integration and is therefore an important goal in occupational and physical therapy, as well as activity programming.

Functional Reach

Functional, goal-directed reach requires the processing and integration of sensory information from our environment and from our bodies to accomplish many ADLs; reaching to open a door, turning on a light, reaching for a pen or pencil, or to reach for a cup to take a drink, are all functional examples of goal-directed, reaching actions. Accurate and efficient (functional) reaching requires a coordination of the joints of the limb in use and the integration of sensory input, as well as postural adjustments in relationship to the reaching action. For individuals living with CP, the ability to maintain functional reach can determine whether or not they must rely on others to assist them with essential ADLs. For instance, individuals for whom verbal communication is inefficient and/or ineffective will, in many cases, use tablet to communicate. In this case, when an individual loses the ability to reach forward to tap the screen (with an adapted stylus) of the tablet, they lose their sole form of communication with their community and world, making them reliant on others for communication. Working with hemiparetic stroke patients, Thaut et al. (2002) found that the use of a continuous, rhythmic auditory stimulus during reaching movements improved the kinematic stability in timing and trajectory of the reaches by enhancing sensorimotor control of the arm. The task required participants to perform a reciprocal reach task to two vertical targets (perpendicular to the starting position) and to pace their target touches to the metronome. Thaut et al. (2002) found that the mean coordinate distance in wrist trajectories was 7.05 ±3.27mm (with rhythm) as compared to 11.84±7.43mm without rhythm. Coordinate distance was defined as deviations of wrist trajectory occurring in a (2 dimensional) *yz*- plane, averaging position data across a trial (Thaut et al., 2002). Upon visual analysis of wrist velocity curves, the authors found that 16 of the 21 participants demonstrated a clear smoothing of the velocity curve (decrease in number of reversal peaks in the curve) in the rhythmic condition, which Thaut et al. (2002) suggests was evidence of more efficient movement. Thaut et al.'s (2002) work focused on hemiparetic stroke patients, where brain damage has occurred to the developed adult brain. It is important to note that when stroke occurs in adults, motor programs and neural pathways have been established previous to the damaging event; the pre-existing programs can then provide a map from which to rehabilitate functional movement and create new neural pathways specific to functional movement. When considering developmental neurological impairment as in CP, the ability to effectively incorporate sensory information, as well as develop efficient motor programs, is interrupted before early motor programs and resulting movement patterns (during pre/early postnatal stages), therefore inefficiencies in movement are entrained through the lifespan making the learning of efficient movement a habilitative process.

The present study considers whether the incorporation of a rhythmic (auditory) stimulus influences the accuracy of a goal-directed reach task, in relationship to postural control, in adults diagnosed with spastic Cerebral Palsy (CP), as compared to a typically developed (TD) control group. It was expected that in all conditions the CP group would demonstrate overall longer reaction times and a greater number of corrective movements, as well as greater postural adjustments during reach, as compared to the TD group. When the auditory stimulus was presented during movement execution (the Sound:During condition) it was predicted that the CP group would become more efficient in both spatial and temporal measures of reach over the duration of the trials. At the same time, the involvement of the shoulder was predicted to decrease and become more consistent throughout the duration of the trials. In contrast, it was also predicted that the TD group would demonstrate a gradual adaptation to the pace of the auditory stimulus in the Sound:During condition and therefore take more time to complete the reaching movements.

THEORETICAL FRAMEWORK

The current study is guided by the foundational work of Elliott et al. (2010), Colonius & Diederich (2004), and Welch & Warren (1980); specifically, the concepts of sensory processing proposed by Elliott et al. (2010), the TWIN model (temporal window of integration) (Colonius & Diederich, 2004), and the modality appropriateness hypothesis proposed by Welch & Warren, (1980).

Elliott et al. (2010) propose a multiple processing paradigm, which combines relevant concepts from early theories on goal-directed reach, yet further acknowledges the role of sensory input when reaching to a target. Three types of online control are suggested: early online control using the efferent copy (a motor program learned from a previous performance of the same task) to enhance motor control, early and continuous control using visual and proprioceptive information, and late visual control using information comparing the current target and limb positions (Elliott et al., 2010). Feedback and knowledge of results also play important roles in the decrease in movement time (sub-movements) and target error. The authors proposed a two-phase paradigm of reach within which information gained from the sensory (afferent) and motor (efferent) systems form an internal model. Building on the process of online control (comparison to, and concurrent adaptations of, the efferent copy) the internal model facilitates a process of dynamic adaptation and movement correction throughout the phases of reach. This multiple processing paradigm also takes into consideration the stochastic neural noise occurring within the nervous system throughout goal-directed reach. In the diagnosis of CP, neural noise is heightened to the extent of impacting the ability to reach in a smooth and precise motion. In the present thesis, we consider how the incorporation of an auditory stimulus may, or may not, effect change during reach. To this end, it is important to include theoretical models that incorporate sound specifically.

Investigating the measure of saccadic reaction time (RT) in relationship to time, Colonius & Diederich (2004, 2010) and Diederich & Colonius (2015) suggest a temporal window of integration (TWIN) model, which considers an optimal window of time for multisensory integration to occur, as suggested by Shams, Kamitanji & Shimojo (2002). Shams et al. (2002) found a cross-modal interaction, such as the presentation of a visual target and an auditory stimulus together, to be dependent on the temporal characteristics of the stimuli. The interaction was an audio-visual illusion where the presentation of a *singular* flash of light with 1-4 beeps simultaneously, the auditory stimulus (beeps) influenced perception of the number of flashes as being greater than one. Colonius & Diederich (2004) suggest that multisensory integration is dependent on stimulus onset asynchrony (SOA), or the duration of time between two different stimuli, and the likelihood that they fall within the optimal temporal window of 200ms. In addition, if the directions given in the task attenuate focus to specific stimuli, multisensory integration is then facilitated when the non-target stimulus occurs first. The authors also found that the strength and location of a unimodal (auditory or visual) stimulus may modulate the timing of multisensory integration in relation to the optimal temporal window. In an earlier review, Welch and Warren (1980) review intersensory bias literature to explore how information is organized when we encounter a typical intermodal situation and what is perceived as the dominant modality. The authors suggest that when presented with discrepant modalities, the perceptual system attenuates to what is typically perceived as the non-discrepant (normal) modality. The overall perception of a situation is also influenced by the characteristics of the modality, experiences in similar situations, and the perception of a singular event. Welch and

Warren (1980) also support the modality appropriateness model that suggests that certain stimuli are most suited to our perception of specific events (e.g. vision is typically best for spatial location). The authors suggest that in a bi-modal presentation, primary attention is typically directed to the stimulus that is most appropriate to the situation. In contrast, secondary attention is influenced by instruction, experience, and the demands of the task and may influence how attention is directed. When attention is directed to a stimulus not typically used in a particular situation, that stimulus (modality) changes our attentional focus, influencing the perception of stimuli presented in that particular event.

The current study considered how an auditory stimulus impacts the timing of reach to a visual target with neurologically impaired population (CP group) and a typically developed population (TD group). Two unique auditory conditions were presented: immediately before the visual stimuli is presented (SB), and during the presentation of the visual stimuli (SD). Here, the task directions in each condition focus participants' attention to the auditory stimulus first, in both a unimodal (Sound:Before) and bimodal (Sound:During) presentation, as well as a unimodal visual presentation (No Sound). In the present thesis I considered whether or not the auditory stimulus, when presented during the planning or the execution phase of reach, would facilitate the planning (Sound:Before) and/or the execution of reaching movements (Sound:During) for a group with primarily spastic CP, as compared to the TD group.

LITERATURE REVIEW

Goal-Directed Reach

Elliott et al. (2010) proposed a model that describes multiple processes of limb control. The multiple process model builds on Woodworth′s (1899) two component model by incorporating concepts of the motor program (Posner & Keele, 1968), the relationship between force and accuracy (Schmidt et al., 1979), the use of corrective sub-movements (Meyer et al., 1988), while recognizing neural noise and the impact of integration of sensory information on movement planning and execution. Woodworth's (1899) seminal work defined two distinct phases of movement control: the initial impulse phase which brings the limb to the area of the target, and the homing phase (current control) where proprioceptive and visual feedback are used to home in on the target (Elliott et al., 2010). Woodworth established that movement planning and online control play significant roles in the precision required for manual aiming, and suggested that the impulse phase is also ballistic in nature. Elliott et al.'s (2010) review of the two components of goal-directed aiming follows the evolution of Woodworth's theory, and proposes a more complex multiple process model involved in goal-directed aiming. The authors discuss Meyer et al.'s (1988) optimized submovement model, which takes into account the inherent neural noise that occurs in the typically developed individual. Neural noise is a general term which is defined as the level of neural activity occurring at rest; increasing with the initiation, execution, or (in the case of CP) incorporation of random muscle activity due to increased muscle tone; this noise may be also be referred to as being stochastic, or random, in nature. The stochastic nature of this noise affects the distribution of the movement endpoints, resulting in a pattern centred on the target over a series of trials. In addition, the distribution is affected by the amount of force required for the initial movement, resulting in a broader distribution when the movement requires more force as compared to slower movements (Elliott et al., 2010; Lyons, Hansen & Harding, 2006; Schmidt, 1979). Therefore, when task difficulty increases (target size is smaller, speed is higher, amplitude is greater) the spatial variability of the corresponding sub-movements will then increase, resulting in decreased precision and (endpoint) accuracy.

The multiple-process of limb control proposed by Elliott et al. (2010) maintains Woodworth's two components of movement and further adds to the discussion regarding endpoint variability. In contrast to Woodworth's description of the initial phase being ballistic in nature, the authors here propose that the distance-covering (current control) phase of the movement is not entirely ballistic. Building on Schmidt et al.'s, (1979) principles of force-variability, and Meyer and colleagues (1988) perspective on the linear relationship between endpoint variability and movement velocity, Elliott et al. (2010) suggest that the instructions given (task requirements) lead the performer to choose to balance between movement velocity and endpoint variability. In an earlier study, it was found that with practice over the course of four days aiming movements improved including: increased speed, greater accuracy, and decreased energy expenditure, resulting in a more consistent endpoint distribution around the target (Elliott, Hansen, Mendoza &Tremblay, 2004; Elliott, Hansen & Grierson, 2009). The integration of visual information allows the performer to reduce the size and number of sub-movements, and, in turn reduce variability and improve accuracy (Elliott et al., 2009). In the proposed multiple-process model, Elliott et al. (2010) posit that internal models provide an efferent copy of the movement that includes sensory information. The efferent copy (expected output resulting from efferent commands) is described as being similar to a blueprint that is compared to the efferent command (similar to a program) in a feedforward process (Elliott et al., 2010). From the process of comparing the efferent copy and motor commands, current movement performance is then adjusted, guiding and improving movements over time. The internal model also uses explicit (visual) and proprioceptive feedback such as knowledge of performance regarding movement time and error, formed at the time of movement planning (Elliott, 2010). For example, when running a race, there is a pre-existing internal copy of the movements and coordination a runner typically uses when going on a daily run or from previous races. During the race, the runner might pay attention to both time and distance achieved by looking at their watch or by observing distance markers en route. Additional visual input is also received from the terrain, details specific to surface conditions (cement surface or a dirt path) and weather conditions. This visual information is then used to adapt the internal model of running for future runs.

Considering populations with neurological impairment such as CP, the (initial) internal model as described by Elliott et al., (2010) is created during the developmental years within existing neurological impairments that are caused by lesioning during pre/postnatal development. As individuals with CP move through the developmental years this (impaired) internal model is then accessed, adapted, and updated within the impaired system. In comparison, (adult) stroke patients experience a damaging incident which also causes lesioning to the brain. This lesioning occurs after the individual has developed internal models of movement, therefore when moving through the stroke recovery process there is an existing (unimpaired) internal model from which to rehabilitate movement. The distinction between these populations is an important consideration for therapeutic and active settings. For stroke patients, the process is based on pre-existing internal models for movement and therefore is rehabilitative in nature. In CP, the process may be more habilitative due to the impact of existing neural damage, and the resulting process of learning new movements at all stages of life.

Though Elliott and colleagues do discuss special populations, diagnoses with a distinct cognitive aetiology (Down Syndrome, Williams Syndrome, Autism Spectrum Disorder) are the focus rather than diagnoses specific to physical changes due to neurological impairment, such as CP. The authors also suggest that in aging populations greater temporal and spatial variability is observed, and includes more conservative play-it-safe movement strategies, which minimize energy costs associated with overshooting (Elliott et al., 2010). These strategies and sub-movements have been observed in the later (control) phase of the movement and relate to processing online sensory feedback. The description of aiming movement performance by an aging population thus parallel the CP perspective. For those with CP, a play-it-safe approach would be taken for voluntary movement.

In the current study, we must acknowledge that the amount of neural noise in the nervous systems of individuals diagnosed with CP has been altered during early development as a result of the pattern of lesioning on the brain, increasing the stochastic nature of reaching movements, as compared to typically developed individuals. When examining the efficiency of reach within the diagnosis of CP, it is important to consider that the internal model and efferent copy recalled in the planning phase of movement includes an exaggerated level of neural noise as compared to typically developing counterparts. In the case of cerebral palsy (CP), where the limbs of the body are affected by the lesioning in different ways, these differences between the affected and non-affected sides of the body are further magnified in the efferent copy and the integration of sensory information as compared to typically developed individuals. Despite the increased noise, those with CP are predicted to work towards energy efficient strategies over time, as in typically developed adults.

Two Visual Processing Streams

The visual system is intricate in design, and plays an integral role in the process of receiving and integrating visual information. In their extensive studies of visual processing, Goodale and Milner (1992) defined two streams for processing visual information received by the visual cortex, projecting from the primary visual cortex (area V1): 1) the dorsal (action) stream which projects to the posterior parietal cortex; and 2) the ventral (perception) stream which projects to the inferotemporal cortex. The dorsal stream processes information needed for action, whereas the ventral stream processes information needed for perception. Though these two streams are described as separate paths, both are interconnected in a complex and intricate relationship necessary for visually guided movements such as goal-directed reach. For example, consider reaching for a cup of water on the counter; the ventral stream processing facilitates our perception of the distance, colour and size of the cup which may inform the cup selected. At the same time, the dorsal stream processing contributes to the planning and execution of the action of extending the arm in the direction of the cup. Simultaneously, we perceive (ventral stream) the size of the cup so that the width of grasp can be adjusted (dorsal stream) to fit the cup (Goodale, 2011).

Clearly, these visual processing streams play an important role in the guiding of movement and the perception of space/environment, however in everyday life we use multiple senses to move throughout our environment. It is then essential that we consider how information from other senses, such as audition, impact the execution of movement. For instance, we use vision to observe when the light has turned green and audition to know if a car is approaching the intersection too quickly (screeching of tires or honking of a horn) to cross safely. When participating in a dance class, we use vision to manage our use of the space while we are moving and audition to synchronize our movement to the music. To that end, the incorporation of audition into perceptual illusions creates a multisensory illusion and provides the opportunity to consider the role of audition and how vision and audition coordinate in a goal-directed reach task.

Audio-visual illusions: fission and fusion

Visual illusions play a key role in understanding visual processing as they allow us to investigate the interaction between these two visual processing streams in relation to the environment surrounding a specific target (visual afferent information) and the effects on the perception of the target (Westwood, 2010). Andersen, Tiippana, & Shams (2004) explore the processes of multi-sensory integration through the use of congruent and incongruent auditory and visual stimuli in a multi-sensory illusion. The authors define two important characteristics of the multi-sensory illusion: first, the illusory effect in an incongruent condition is stronger than in a congruent condition and secondly, in multisensory integration, one modality is often dominant over the other. In an earlier study, Shams, Kamitani, and Shimojo (2002) investigated cross modal interactions involving visual illusions induced by sound. In their first experiment, Shams et al. (2002) presented a single flash accompanied by a single beep, as well as two or more beeps. They found that the number of perceived flashes observed increased when the number of beeps was greater than one. This sound induced illusory flashing (Shams et al., 2002) suggests that the auditory stimulus influenced the perceived number of flashes. Their second experiment considers the temporal window that the illusion occurs. Here, one flash was presented with one accompanying beep, followed by a second beep presented at varying intervals of time. They found that the illusory interaction between auditory and visual stimuli was strongest between ± 70 and ±115 ms. This further supports the crossmodal interaction between audition and visual perception, and also suggests that this interaction is dependent on the temporal characteristics of the stimuli as proposed in Colonius & Diederich's (2004) Time Window for Integration (TWIN) model (Colonius & Diederich, 2010; Diederich & Colonius, 1987, 2004, 2008a, 2015).

Building on the work of Shams, Kamitani, & Shimojo (2002), Andersen and colleagues (2004) considered audiovisual fusion and fission illusions using flashes and beeps. The two illusions considered are defined as: fission, when more beeps than flashes are presented resulting in the perception that there are *more* flashes than beeps, and fusion, when more flashes than beeps are presented resulting in the perception that there are f*ewer* flashes than beeps. The authors propose four hypotheses. First, the *discontinuity hypothesis* states that a discontinuous modality is stronger than continuous; for example, the two short beeps (discontinuous) presented at the same time as one flash (continuous) altered the perception of the visual stimulus (Shams et al, 2002). Second, the *modality appropriateness hypothesis* where the most appropriate modality for the performance of the task dominates (Welch & Warren, 1980; Glazebrook, Welsh, & Tremblay, 2015); for example, when the task is temporal in nature, audition provides the best information over visual information (Glazebrook, Welsh, & Tremblay, 2015). Third, the *information reliability hypothesis*, where the determining factor is the reliability of the modality, as opposed to the dominant nature of the modality. Lastly, the *directed attention hypothesis* speaks to the strength of one modality attracting more attention in relation to the other modalities; such is the case when attempting to read in a noisy environment (Shams et al., 2002).

Here, the authors used both continuous and discontinuous visual and auditory stimuli of varying dB in two separate experiments.

Overall, the visual fusion illusion was highly significant, however the fusion effects of both auditory and visual conditions were consistently weaker than the fission effects. The authors found a significant visual fusion illusion effect, demonstrating that the discontinuity of the stimulus may not be necessary for a fusion effect to occur, but may increase modality dominance (Andersen et al., 2004). When considering information reliability, the illusory effects in experiment 2 (where the dB level was decreased) demonstrated the influence of the auditory stimuli despite the lower dB level. In both experiments, the counting beeps condition where visual (16.7ms duration) and auditory information (7.0ms) was presented, showed a lack of visual influence on the auditory stimuli as compared to the counting flashes condition, demonstrating that task instructions were a key factor. Here, the incongruence between the stimuli is due to the duration of time for each type of stimuli, as indicated in brackets in the previous sentence. Because the lack of visual influence also occurred during the incongruent presentation of stimuli, the previous finding also supports the directed attention hypothesis. Overall, the authors also found that task instructions impacted subject response by directing subjects' focus toward a specific stimulus: beeps (auditory) or flashes (visual) demonstrating an inconsistent integration of the audio-visual stimuli during the task. For instance, it was found that participants were not influenced by the beeps in the counted flash condition, supporting the directed attention hypothesis where the incongruent stimulus discussed previously did not facilitate an illusory effect. In the current study, task instructions direct the participants' attention to both the a visual and an auditory stimulus in the Sound:During condition, and in the Sound:Before condition the two stimuli are presented separately.

Audio-visual illusion and reach

Tremblay and Nguyen (2010) replicated Andersen et al.'s (2004) previously described fusion and fission illusions using a spatially demanding reach task and considered how performing a reaching action might alter how visual and auditory cues are perceived. It is important to note that both of these illusions (fission and fusion) demonstrated the dominance of audition in a temporally demanding task. When incorporating a reaching task into the auditory condition, Tremblay & Nguyen (2010) found that the fusion illusion at the stimulus midpoint (50ms stimulus onset) was linearly reduced in relation to limb velocity. In other words, when velocity at stimulus midpoint was high (1600 mm/s), the illusory effects of the fusion illusion were not significant. The opposite held true as well, when the velocity at midpoint was low (600mm/s) the illusory effect was found to be significant. The authors suggest that this linear relationship could be associated with reduced processing of non-visual (auditory) cues since the illusory effects of the fusion illusion did not hold high visual signal to noise ratio at higher velocities on the retina between visual samples (Tremblay & Nguyen, 2010). Taking into consideration the spatially demanding nature of the task, the authors posit that the results demonstrate an adaptation of the use of visual input by the central nervous system during online control in relation to the relevancy of the visual stimuli. In other words, the relationship of multisensory processing to the amount of noise occurring in the nervous system played a key role during goal-directed actions. Specifically, at higher movement velocities visual input remains dominant and at lower movement velocities auditory information overrides visual information. Tremblay & Nguyen (2010) concluded that the influence of visual and auditory information is therefore modulated online throughout the reaching movement in relationship to movement velocity and neural noise. For the CP group in the current study, the modulation process may be influenced by the level of neural noise pre-existing in the central nervous system, while the control group may be influenced by the noise introduced with the slower movement pace required. In the present thesis, changes in the amount of neural noise during movement planning and execution can be inferred from the proportion of movement time used for online control, as well as the accuracy and consistency at endpoint.

Goal-directed reach and CP

Ju et al. (2012) investigated multidirectional reach in relationship to posture in children (no age was specified) diagnosed with diplegic cerebral palsy (DCP), as compared to matched controls, in a seated reach task. Here, participants reached to three different hanging targets (ipsilateral, anterior, and contralateral) from a seated, unsupported position, at a pace modulated by a metronome set at 46 bpm. Using pressure mats as well as a six-camera motion capture system, center of pressure (COP), ground reaction force (GRF), and hand position were measured. In DCP, the plegia is defined as being specific to the lower body. The authors clearly demonstrate the effects of the diagnosis on the upper body in DCP through the relationship between posture and reach. It was found that the DCP group used greater mediolateral velocity in anterior and posterior COP in the anterior and ipsilateral reach tasks. When merging the data for medial and lateral reach directions the authors found that the DCP group made different adjustments than the TD group, in that the DCP group used a higher COP velocity in all three reach directions, as compared to the progressive change in velocity used in the TD group. This suggests that although the DCP group is accomplishing the task, the ability plan and scale movement response is limited. Ju et al., (2012) suggest that the adjustments in reach and the high velocity of COP are compensatory strategies taken by the DCP group (involving a transfer of weight and/or wider placement of the feet) to accomplish the task while working to maintain stability. When compared to the TD group, the DCP group demonstrated a non-significant increase in COP anterior-posterior velocity in the ipsilateral reach direction and a significant increase in COP medio-lateral velocity in the contralateral reach direction, supporting the hypothesis that task demand does influence motor output. Not surprisingly, the DCP group also demonstrated a consistently wider foot COP pattern in all tasks as compared to the TD group's ability to adjust foot position according to task demands. Overall the DCP group was less able to make the subtle postural adjustments needed in the varying reach directions, which in turn resulted in compensatory movements such as increased trunk rotation, small trunk adjustments, as well as greater foot braking and pushing force with their feet. Using Pediatric Reach Test (PRT) scores to qualify postural control ability (Ju et al., 2012), it was found that the children with CP had lower scores than the TD children, demonstrating lesser postural control in the CP group as compared to the TD group. PRT scores were positively correlated with the seated reach for anterior and lateral reach; demonstrating that those with CP use a wider pattern of reach in relation to COP. At the same time, the seated reach was negatively correlated to the number of acceleration and deceleration sub-movements used during reach. These correlations demonstrate that the CP group had weak postural control and an increased scale of COP, and accessed a greater number of sub-movements throughout reach (smoothness of hand movements). Overall this relationship was greater in the anterior and ipsilateral reaches, and not as evident in the contralateral reach. As task difficulty changed with direction of reach (anterior, lateral, and medial reach) stability decreased, and in turn the amount of postural adjustment increased.

Ju et al. (2012) have demonstrated that when the level of task difficulty increases in a seated and non-supported reach task, children with DCP use greater compensatory measures to achieve reaching to the target than their TD counterparts. Further to this they also demonstrated that although the diagnosis of diplegia is specific to the lower body, movement deficits related to postural control occur in the upper body as well. The authors suggest that the children in the DCP group understood their physical (postural) limitations and therefore instinctively chose compensatory postural adjustments to perform reaching movements, while being mindful of personal safety (avoiding falls). Similar to the corrections based on Elliott et al.’s (2010) internal model which takes into account afferent, efferent, as well as proprioceptive information, the DCP group also made postural adjustments that optimized reaching efficiency. For example, upon receiving the task instructions, seeing the size of the target and the distance between the target and themselves, the children may choose a safer shift of body weight (wider, less direct shift) when initiating reach, followed by an adjustment of body weight toward the target for a more efficient control of end point (homing in on target) and to facilitate the return action of the arm. Here, the metronome stimulus was used throughout all conditions, and from movement planning through execution of the movement phase. Instructions were not specific as to whether or not to follow the pace of the metronome. Using a similar auditory stimulus, the current study focuses specifically on timing reaching movements to the pace of the auditory stimulus at two different phases of the movement (movement planning and movement execution). This approach allows us to investigate if, and where, the influence of the stimulus is most effective in coordinating and smoothing of movement during either, or both, phases. Movement performance is measured using reaction time (RT), movement time (MT), onset of online control, and endpoint accuracy.

Rhythmic Auditory Stimulus

Investigating alternative methods of movement entrainment for neurological populations with motor impairment, Thaut et al. (2002) explored the use of rhythm as a sensory cue to enhance the neurological mechanisms responsible for controlling voluntary movements. In a goal-directed reach task with hemiparetic stroke patients, Thaut et al. (2002) investigated a seated task using two anteriorly placed, vertically mounted touch sensors. The authors compared 30s of continuous pointing movements between two targets, with and without the incorporation of a rhythmic (metronome) stimulus (cue), with the affected arm. In the rhythmic trials, participants were directed to touch the sensors continuously, on the beat, and could self-select how long they listened to the beat before moving. Measurements were gathered using a three-dimensional camera motion analysis system (SELSPOT). Improvements in stability of temporal parameters were shown at the start of the rhythmic cued task, and were highly correlated throughout the experiment. Most notably, in the auditory rhythm condition the wrist velocity profiles in 16 out of 21 participants showed a reduction in the number of reversal peaks in the velocity curve during the deceleration phase of the movement. In the deceleration phase, the smoothing of wrist trajectory was facilitated by the rhythmic cueing. When examining temporal (rhythmic) synchronization to a continuous stimulus both groups show negative errors due to the anticipation of the beat (25-40ms), however periods of synchronization to the stimulus showed smaller intervals in time deviation. The authors suggest that this is due to the periodic coupling of the rhythmic stimulus and movement frequency (14.4 ± 17.6 ms in real time) which agrees with their data from healthy subjects and demonstrates that coupling did occur between the stimulus and movement frequencies (Thaut, et al., 2002). Kinematic stability in the rhythmic condition was demonstrated by more efficient, or direct, wrist trajectories of the affected arm as well as the number of reversal peaks of the wrist in the *yz*-axis, resulting in the increase of elbow extension angles during reaching. There was also a reduction of spastic inhibition that commonly occurs in hemiparetic stroke patients, which suggests a facilitative effect of rhythm on motor planning and movement execution (Thaut, et al., 2002). Thaut et al. (2002) indicate that these changes in the control of movement timing and trajectory observed in the rhythmic condition suggests that time constraints provided by the rhythmic stimulus added kinematic stability (smoothing of movement patterns and increased efficiency) to the reaching motion of the affected arm, which were not seen in the control condition (no rhythmic stimulus). Further to this, the authors suggest that the use of an auditory rhythmic stimulus with hemiparetic stroke patients may enhance and improve rehabilitation of the affected arm. The authors suggest that the temporal constraint presented in this study, a *continuous* rhythmic auditory stimulus, challenges the brain to optimize movement when moving from target A to B, while simultaneously timing movement to an external stimulus (Thaut et al., 2002). It has been clearly demonstrated that kinematic changes in movement efficiency occur when required to synchronize movement to a continuous rhythmic stimulus (Thaut et al., 2002; Hatfield, Wyatt, and Shea, 2010). In the current study we take this a step further and look specifically at *where* in the process of reaching the rhythmic (auditory) stimulus couples with movement execution for improved kinematic stability.

In the present study, hand preference, target direction, and three different conditions were considered with both the CP and TD groups: No Sound, Sound:Before, Sound:During. Taking into consideration evidence of impairment extending beyond the diagnosed condition of diplegic CP (Ju et al. 2012), and the suggestion that kinematic measures can provide perspectives on movement control in the CP group (Domellof, Rosblad & Ronnqvist, 2009), here both the preferred hand and non-preferred hand are explored as both exhibit differing levels of impairment and plegias within the diagnosis of CP.

Objectives

The overarching objective of this thesis is to determine how movement efficiency and accuracy in a seated, goal-directed reach task are impacted by changes in task difficulty and auditory cueing, specific to adults diagnosed with CP. The *primary objective* is to examine the differences in movement efficiency in two different auditory conditions (Sound:Before, Sound:During), as compared to the control condition (No Sound), comparing both non-impaired (dominant) and impaired (dominant) hand, and as compared between the CP and TD groups. The secondary objective is to examine the differences occurring in postural contribution to reaching as defined by the total shoulder displacement.

Predictions

Taking into account the muscle and joint contractures, as well as muscle tone, in the which directly impact movement control in the diagnosis of CP, it was decided to present the auditory stimulus over a 6s duration of time. It was predicted that participants would follow the metronome in the Sound:During condition and due to the pace of the metronome the TD group would show a gradual slowing of reach as compared to their natural movement pace observed in the No Sound and Sound:Before conditions. In contrast, considering Ju et al. (2012) and Thaut et al.'s (2002) findings which demonstrated improved reach trajectories with a continuous auditory stimuli, the CP group would demonstrate a more efficient, smoother reaching pattern in the the Sound:During condition, as compared to the control and Sound:Before condition. Based on the heterogeneity of the CP group and the inherent differences in movement control, when comparing the two groups it is predicted that the CP group will show greater variability, longer reaction and movement times, and more movement reversals throughout reaching movements in all three conditions. It was also predicted that in the CP group the number of movement reversals would decrease in both sound conditions, with the least number of reversals in the Sound:During condition because there is an external stimulus to follow. Considering postural adjustment, group differences are expected due to the differences in mobility and limitations in range of motion in the CP group. The TD group was expected to demonstrate minimal shoulder movement in the No Sound and Sound:Before conditions due to participants' engaging a natural pace. In the Sound:During condition, TD participants were expected to demonstrate an increased amount of shoulder movement due to the exaggerated slowing of reach. For the CP group, it was expected that the least amount of shoulder movement, and therefore postural adjustment, would occur in the Sound:During condition due to the timing of reach to the stimulus (Ju et al., 2012; Thaut et al., 2002).

METHOD

Participants

Participants 18-45 years of age with the diagnosis of CP, as well as typically developing (TD) individuals, were recruited for this study. A total of 12 TD participants were recruited, however two were excluded in the final matching of groups. Table 2 (below) outlines general group characteristics.

Table 2.

Group characteristics for TD and CP groups. F= female/M=male; RH = right hand/LH= left hand; GMFCS = gross motor function classification score.

Group	**Mean Age**	**Age Range**	**Gender & Handedness**		**GMFCS**
TD (n=10)	24 years	19-37	7 F; 3M	5 RH; 5 LH	n/a
CP (n=10)	30 years	21-44	8 F; 2 M	5 RH; 5 LH	Level 2: 1 Level 3: 2 Level 4: 7

The CP group includes 10 adults (8 female, 2 male; M_{age} = 30) within the GMFCS range of levels 1-4 including individuals who may be able to ambulate independently, with assistance, or require the use of a wheelchair in activities of daily living (Rosenbaum et al., 2007). Inclusion criteria for the CP group were: 1) a diagnosis of CP, GMFCS level 1 to 4, and 2) vision and hearing normal or corrected-to- normal. Exclusion criteria were: 1) any orthopaedic surgeries occurring in the past six months, and 2) any botulinum injections occurring in the past six months. The TD group includes 10 adults (7 female, 3 male; M_{age} = 24.1), matched on handedness, with no neurological or orthopaedic conditions, as well as normal, or corrected-to-normal, vision and hearing. Ethical approval was granted by Education/Nursing Research Ethics Board (ENREB) of the University of Manitoba (see Appendix F, pp 101). Both the preferred and non-preferred hands were considered initially, therefore participants completed the Waterloo Handedness Questionnaire (WHQ) before the experiment began to ensure a clear understanding of handedness. Prior to testing, all participants completed consent forms (see Appendix E, pp 86). For CP participants who have a substitute decision maker, or rely on others for decision-making, the appointed decision maker was asked to complete the informed consent form, and assent was also sought from the participant. Details of the group characteristics can be found in Appendix A, pp 76).

Participants from the University of Manitoba community were recruited through posters placed at various visible locations throughout campus. Participants from the Winnipeg community were recruited through advertisements with local community organizations such as Cerebral Palsy Manitoba, Society of Manitobans with Disabilities, Trailblazers Life Choices, Inc., and the Rady Jewish Community Centre via an electronic version of the recruitment poster.

Apparatus

Participants were seated at a height adjustable table (74.5 cm x 150cm) in either a typical chair, or in their own wheelchair, aligned with the home switch located on the anterior edge of the apparatus surface, and reached to two targets located on the apparatus surface (see Figure 1, pp 37). The table height was set at 72cm. Taking into consideration the differences in timing and muscle contractures within the CP group, and the potential for fatigue during the experimental procedure, the experimenter piloted this study with an individual diagnosed with CP to ensure that the apparatus used is placed at a realistic distance between the home switch and the targets (for an overview of the pilot study see Appendix B, pp 77). It was concluded that placing the targets 36.5cm from the home switch would provide an appropriate functional reach distance for the CP group. During the experimental process it was necessary to adjust this distance for some participants as it was unrealistic to require the pre-determined distance of reach due to acute muscle contractures and structural deformities (see Appendix A, Table 5, pp 76). Two target snap action switches with long lever actuator (LKG Industries) were built into a dense foam tube which was cut in half lengthwise into two smaller, square support surfaces (4.5 cm x 8 cm x 4 cm) with an LED light placed directly beneath each target switch (two in total). Each support surface was then attached to the surface using heavy duty Velcro. Movement accuracy is a concern due to movement control impairment for the CP group (Domellof et al.,2009), therefore the switches were enlarged from a .3cm x 2.5cm lever to a round target 5cm in diameter using simple craft foam and weighted with a coin to facilitate accuracy.

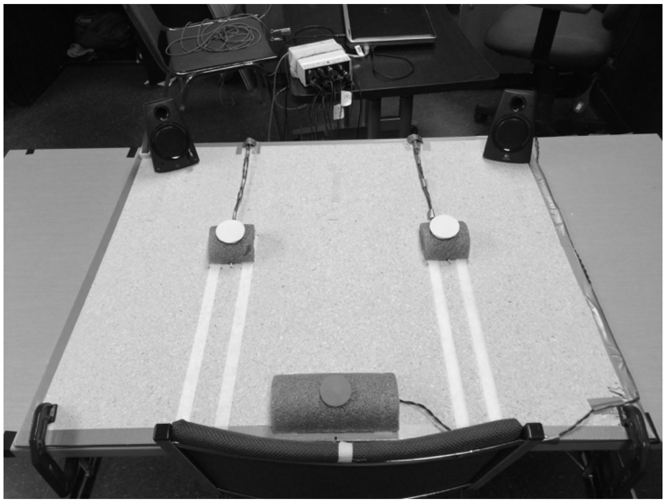

Figure 1. *Superior view of the apparatus setup. The blue home switch is centred between the two yellow target switches (located 35.6cm from anterior edge of the surface). Two black Logitech speakers are placed behind the two target locations.*

To provide a supportive surface for the hand, the home switch (4.2cm) was threaded through a dense foam tube cut in half lengthwise (18cm x 8cm x 4 cm; see Figure 2, below). To ensure stability of the targets and adaptability of target distance without disrupting the apparatus, both the base of the home switch and target switches were attached to the apparatus surface using heavy duty Velcro. The entire surface and apparatus was then secured to a height adjustable table with four clamps. The auditory stimulus was presented using two Logitech audio speakers placed on either side of the apparatus surface facing towards the participant. Volume was set at a consistent level (45%) and any adjustments in volume were recorded by the experimenter during the experimental procedure (none were made).

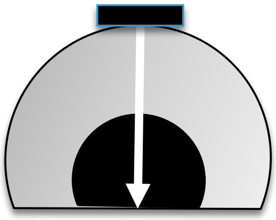

Figure 2. Lateral view of home switch setup. Using approximately one half of a foam tube (18cm x 8cm x 4 cm), a small centre section is removed. The wiring (white arrow) attached to the switch is then thread down through the hole and drawn out the side of the foam tube (see Figure 1). The process was followed for the target switches.

Procedure

Before testing, both groups practiced six reaches with each hand to the ipsilateral and contralateral targets in a sound condition where one tone was presented six seconds after the target light appeared. These practice reaches familiarized the participants with the apparatus and involved seeing the target light and, when using the sound condition, hearing the auditory stimulus during practice reaches. Throughout the practice session, participants were instructed to use a natural reach to the appropriate target switch (as indicated by the target light) and work to press the switch in time with the auditory stimulus (when present). The practice session was programmed using E-Prime software (version 2.0, Psychology Software Tools, Inc.) and incorporated the same sound file used in the experimental procedure. Due to technical issues arising during testing, a no sound practice program was substituted for the original sound practice. If the participant had difficulty in the practice session, additional practice and explanation was facilitated and subsequently noted by the experimenter at that time. At the start of the experimental procedure, participants were instructed to place the hand that was not being tested on their lap (out of view of the Optotrak cameras) and, using the opposite hand, to reach naturally and accurately to the appropriate target as indicated by the target light. During the experimental procedure participants performed twenty trials with each hand (total of forty trials), in each of the three conditions, for a total of 120 trials. Three conditions were programmed in two sequences using Eprime: The first sequence was No Sound, Sound:Before, and Sound:During, and, to protect against order effects, the second sequence was presented in a randomized order, with the caveat that No Sound could not be first. To protect against practice effect and participant fatigue handedness was blocked (10 trials) within each condition, and within each block of trials target direction (ipsilateral and contralateral) was randomized. Participants completed a series of two blocks of ten trials, in each of the three conditions for a total of 60 trials. This series was then repeated again for a total of 120 trials. To prevent fatigue, rest breaks were facilitated when requested by the participant and were built into the procedure when changing conditions. The entire procedure took approximately 30-60 minutes to complete (depending on the number and length of breaks). Throughout the procedure three dimensional position data was recorded using the Optotrak 3-D Investigator motion analysis system (Northern

Digital, Inc.; accuracy to 0.4mm) at a collection rate of 250Hz for later kinematic analyses. Individual stationary target positions were collected post-experiment (target files) which provide the target location specific for each individual and were used for analysis. Target files measured the location of the markers while the participant held a stationary position at the home and target switches. Movement axes were defined with the x-axis in the medio-lateral direction, y-axis in the anterior-posterior direction, and the z-axis in the vertical.

Measurement

In order to capture limb movement using the Optotrak, infrared markers (IREDS) were placed on the participants' right and left arms at the following positions: posterior surface of the distal phalanx of the index finger, posterior surface of the proximal metacarpal interphalangeal joint of the index finger, posterior ulnar styloid, and anterior acromion processes of both arms. Before experimenters attached the IRED markers, participants were asked to roll up and secure any shirtsleeves to ensure the IRED sensors were visible to the Optotrak. The IREDS were attached to the distal phalanx of the index finger and acromion process using Blenderm (3M) surgical tape. Taking into consideration the potential for differences in the dominant hand placement due to spasticity and contractures, a fingerless glove created from Tensogrip © elasticated (tube) stockinette was created. This modified glove allowed the IREDS on the knuckle and wrist to be affixed using Velcro which facilitated adjustment of the IREDs when needed. The modified glove also secured the wires onto the hand as the wires were threaded under the glove to the forearm, preventing any extraneous sensory information from wires moving on or touching the skin. To prevent any additional movement, or blocking, of the IREDs during the experiment, Prowrap™ was used to secure the IRED wiring to the fore and upper arm of the participant.

Programming and Setup

All conditions were programmed using Eprime software (version 2.0, Psychology Software Tools, Inc.). Because both preferred and non-preferred hands were considered during testing, handedness was reported using the (revised) Waterloo Handedness questionnaire (Elias, Bryden, & Bulman-Fleming, 1998). All handedness questionnaires were scored in the following manner: categories of (i) left-always, (ii) left-usually, (iii) equal, (iv) right-usually, and (v) right-always, with scores ranging from -2 to 2 respectfully (Elias, Bryden, & Bulman-Fleming, 1998). Taking into consideration the differences in movement control between the preferred and non-preferred arm in the CP group, data was sampled at 250Hz and collected in time intervals of 6s for all conditions. The initiation of the Optotrak was triggered externally via the E-Prime program and synchronized with the presentation of the visual stimulus that served as the "go signal". In both the Sound:During and Sound:Before conditions the auditory stimulus is a set sequence of three auditory tones of the following duration and hertz (the same sequence is used in all trials using auditory stimulus): 575Hz tone for 200ms (followed by a 1800ms pause), a 575Hz tone for 200ms (followed by an 1800ms pause), and finally a 600Hz tone for 30ms. The auditory stimulus sequences, target lights, switch presses and releases (depending on condition) were coordinated via a custom program designed using E-Prime software (version 2.0, Psychological Tools, Inc).

ANALYSIS

Initial analysis of the raw data (via Optotrak) was processed in a reach analysis program created by Kinsilico Labs (Toronto, Ontario) in MatLab (The Mathworks, Inc). Blank files produced by the Optotrak occurred when switching the Eprime (version 2.0, Psychology Software Tools, Inc.) program for each condition. The blank files were deleted before initial analysis, and any trial errors (e.g. marker error, movement not captured, participant distraction, etc.) were excluded in the pre-processing stage of initial analysis. Trial errors occurred in 6% of the CP group trials, and in none of TD group trials. For the initial analysis, reaching onset for both groups was defined as the first frame where the velocity exceeded 30 mm/s and remained there for 30ms. Reaching offset was defined as the first frame where the velocity fell below 30 mm/s and remained at that criterion for 30ms. The Matlab program excluded 17% of the remaining CP group trials, and .5% of the TD trials. Within the Matlab program data was smoothed to 5 n-points. To remove any outliers the means at position end in the y-axis were calculated for each participant before statistical analysis. The diameter of the target size was added to the means to establish upper limits, and in turn subtracted from the mean to establish the lower limit, any trials which fell outside of the upper and lower limits of the participants' means were then removed. To this end, 35% of the CP trials and 10% of TD trials were removed; the large percentage of the CP groups trials reflects those participants who did not reach to the contralateral target, as well as the level of difficulty in the SD dual-task paradigm.

Statistical analysis was performed using Statistica software v.12 (Statsoft, Inc.). A 2 Group x 2 Condition design with one between subjects measure (group) and one within subjects measure (condition) was used. Dependent variables considered were reaction time, movement time, constant error, variable error, ratio of time to peak velocity to movement time, and overall total distance travelled (of the shoulder). These variables were defined as: reaction time (stimulus to beginning of movement; RT), movement time (onset of movement to offset/movement end; MT), constant error (mean endpoint bias; CE), variable error (standard deviation of endpoint: VE), as well as the ratio of ttPV to MT (amount of time available for online control; ttPV/MT). To measure postural adjustment, the variable considered was the distance traveled by the shoulder during reach. Significance (alpha) was set at $p < .05$. Main effects and interaction involving more than two means were further investigated using Tukey's HSD post-hoc test, $p < 0.05$.

The focus of this study was the change occurring in the auditory conditions as compared to the no sound condition (NS), therefore for the statistical analysis the NS condition was considered the baseline condition and was then subtracted from the SB and SD conditions. In the CP group three participants chose to use their preferred (less impaired) arm throughout testing, due to the level of fatigue experienced when using the non-preferred (more impaired) arm; for these reasons analysis is based solely on the preferred hand. In addition, three CP participants chose to reach only to the ipsilateral target (less impaired side) throughout testing, due to fatigue when using the non-preferred (more impaired) arm; preliminary analysis of RT and MT across targets for the CP group did not reach significance (RT, F (1,14) = .41, p = .531; MT, F (1,14) = 2.67, p= .125), therefore data has been collapsed across targets for all variables, for both groups. Lastly, due to individual levels of impairment (muscle contractures), target distances were adjusted to an achievable (shorter) distance for seven of the ten CP participants (for specific distances see Appendix A, Table 5, pp 76). The impact of target distance on the measure of MT, and because the focus of this study is on the change occurring in the auditory conditions, the NS condition has been considered the baseline measure for each variable. For the analysis of each variable the NS condition was subtracted from values in the SB and SD conditions; in other words, SB = $M_{SB} - M_{NS}$, and SD = $M_{SD} - M_{NS}$.

Performance and Kinematic Measures

The performance and kinematic measures used in this study have been clearly defined by Schmidt and Lee (2011). Reaction time (RT) is defined as the measure of the time between the presentation of the stimulus and the start of movement initiation;. movement time (MT) is the measure of the time between the start of movement (initiation) and movement end. Here, the start of movement occurs at a set threshold of 30mm/s and movement end is defined as a set threshold of 30mm/s. Constant error (CE) provides a measure of accuracy at endpoint as represented by the amount and direction of bias in relationship to the target location. Variable error (VE) measures the amount of variability occurring at movement end. The ratio of time to peak velocity to MT (ttPV/MT) provides an understanding of the relative ratio of time used to reach peak velocity, which in turn is a snapshot of how much time was available for online control after peak velocity is reached; smaller ratios indicate that more time was available for online control.

RESULTS

This study explored the effect of a rhythmic auditory stimulus and changing task difficulty on movement planning and execution in relationship to goal-directed reach; the changes occurring between the auditory condition (SB or SD) and the NS condition are presented below (see pp 43-44 for rationale).

Reaction Time

The main effect of condition on RT was significant, F (1,18) = 37.035, p = .000. Figure 3 (pp 46) illustrates that for both groups a positive change occurred (increase) in RTs in the SD condition, while negative change occurred (decreased) in RTs in the SB condition.

In contrast, no significant difference was found in the main effects of group, F (1,18) = 1.36, p = .258, nor the group by condition interaction, F (1,18) = 3.54, p = .076. Though significance was not reached in the group by condition interaction, there was a trend for the amount of change between the SB and SD conditions to be greater in the CP group.

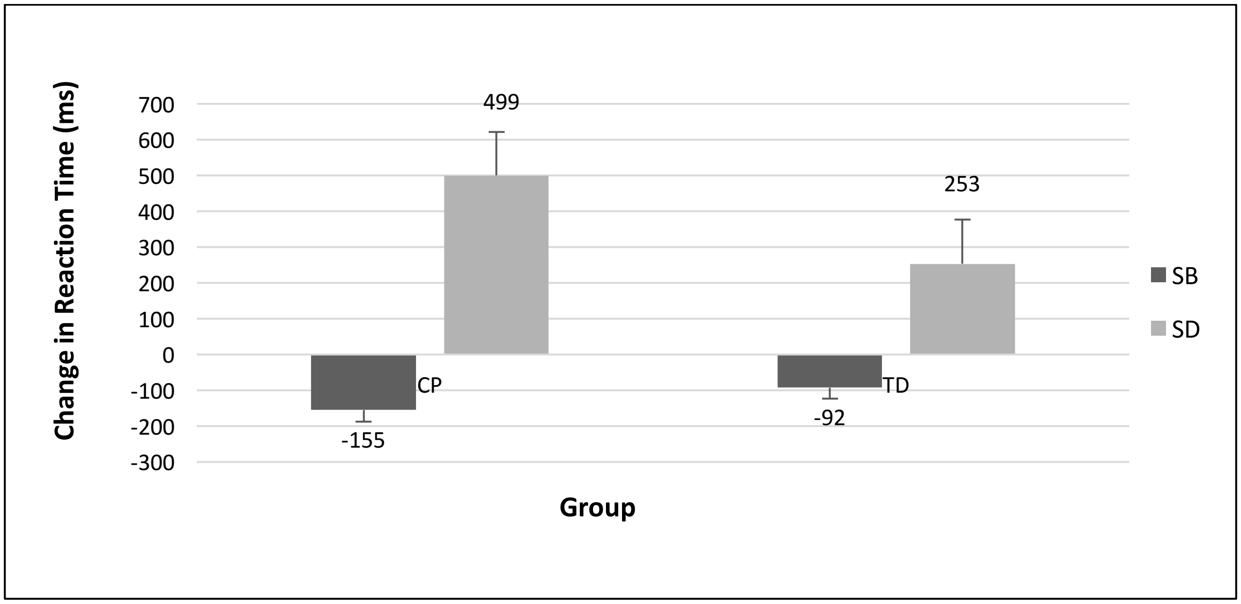

Figure 3. The amount of change in reaction time (RT) occurring in each auditory condition, for both the cerebral palsy (CP) and typically developed (TD) groups; measured in milliseconds. The means presented represent the amount of change occurring between the Sound:Before and Sound:During condition and the No Sound baseline condition. Natural means are presented in Appendix C, Figure 12, pp 79.

Standard Deviation of Reaction Time

A statistically significant difference was found in the variability of RT across conditions, F (1, 18) = 15.50, p= .0009. The SD condition showed a positive change (increase) in variability and a negative change (decrease) in the amount of variability in the SB condition.

In contrast, analysis indicates a non-significant difference in the variability of RT between groups, F (1,18) = 0.452, p = 0.509, as well as in the group by condition interaction, F (1,18) = 3.41, p=.081. Though the interaction did not reach significance, Figure 4 (pp 47) depicts a pattern of change emerging in both groups; in the CP group there is a larger difference in variability of RT between the SB and SD conditions, while in the TD group a smaller range of difference (less variability) is demonstrated.

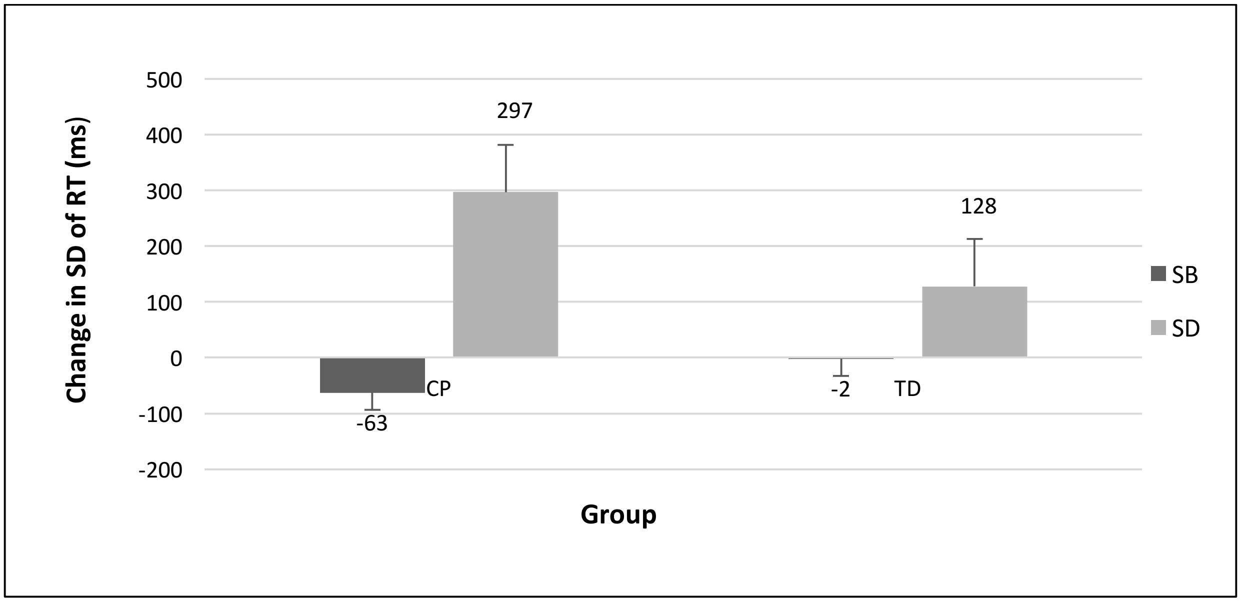

Figure 4. The amount of change in the standard deviation of reaction time (RT) in each auditory condition; for both the cerebral palsy (CP) and typically developed (TD) groups; measured in milliseconds. The means presented represent the amount of change occurring between the Sound:Before and Sound:During condition and the No Sound baseline condition. Natural means are presented in Appendix C, Figure 13, pp 79.

Movement Time

A significant main effect for condition on MT was found, F (1,18) = 90.952, p=.0001. Figure 5 (pp 48) demonstrates that the least change occurred in the SB condition and the largest change occurred in the SD condition. The main effect of group on MT was also found to be statistically significant, F (1,18) = 45.874, p=.0001. The least amount of change in MT occurred in the CP group, while the TD group experienced the largest amount of change in MT (see Figure 5, pp 48).

Finally, the group by condition interaction was statistically significant, F (1,18) = 88.655, p=.0001. In the SD condition demonstrated the greatest positive change (increase) in MT occurred in the TD group as compared to the minimal positive change (increase) in MT in the CP group. In the SB condition the least positive change in MT was observed in the CP group and the largest negative (decrease) change occurred in the TD group. Post hoc analysis of the group by condition interaction using Tukey's HSD indicates that for the CP group there was no significant difference between the SB and SD conditions, however in the TD group a significant difference was found between SB and SD conditions.

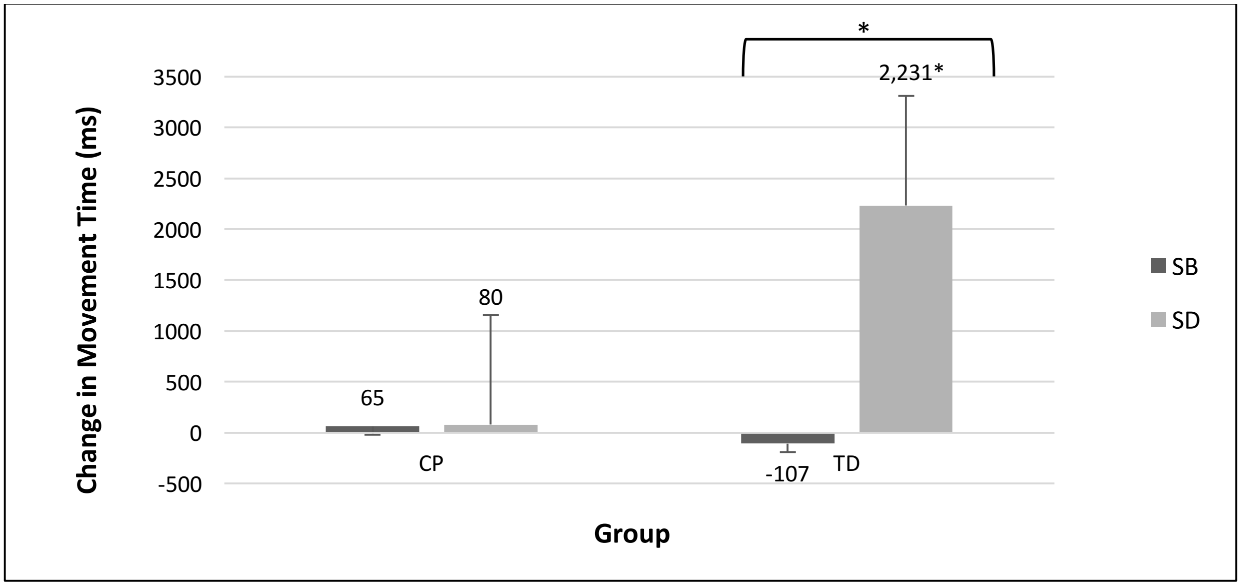

Figure 5. The amount of change in movement time (MT) in each auditory condition, for both the cerebral palsy (CP) and typically developed (TD) groups; measured in milliseconds. The means presented represent the amount of change occurring between the Sound:Before and Sound:During condition and the No Sound baseline condition. Natural means are presented in Appendix C, Figure 14, pp 80.

Ratio of Time to Peak Velocity to Movement Time

For this variable, the main effect of condition was not significant, F (1,18) =1.767, p=.20, nor was the main effect of group, F (1,18) = .762, p= .394. Significance was achieved in the interaction between condition and group, F (1, 18) = 5.948, p = .025. Here, the smallest change in the ratio of ttpv/MT occurred in the TD group in the SB condition and for the CP group the smallest change occurred in the SD condition, as seen in Figure 6 (below).

Further post hoc analysis of the interaction using Tukey's HSD indicated that for the mean change in the ratio of ttpv/MT in the SB condition no difference was found between the CP and TD groups. In the SD condition a significant difference was found between the CP and TD groups. Within the two groups, no differences were found between conditions in the CP group in mean change in the ratio of ttpv/MT, while in the TD group a significant difference was found between the SB and SD conditions.

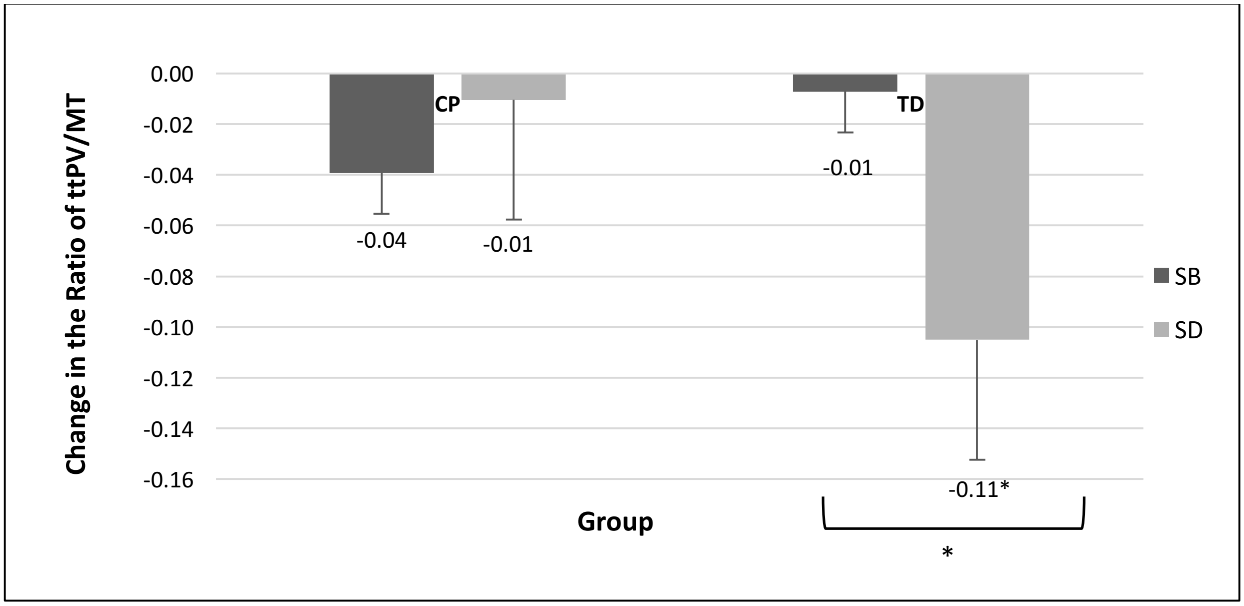

Figure 6 The amount of change in the ratio of time to peak velocity(ttPV) by movement time (MT) in each auditory condition, for both the cerebral palsy (CP) and typically developed (TD) groups. The means presented represent the amount of change occurring between the Sound:Before and Sound:During condition and the No Sound baseline condition. Ratios demonstrate *when* peak velocity was reached, and therefore how much time was available to engage online control processes after peak velocity. Natural means are presented in Appendix C, Figure 15, pp 80.

Constant Error in the Y-axis

Main effect for condition did not reach significance, F (1,18) = 1.716, p= .20. The main effect for group neared, but did not reach, conventional levels of significance F (1,18) = 3.706, p =.070. An emerging trend is noted between the CP and TD groups, in that the CP group demonstrated minimal change in mean differences between conditions, while the TD group data indicates greater undershooting compared to the NS condition (see Figure 7, below). The condition by group interaction did not reach significance, F (1,18) =1.645, p=.215.

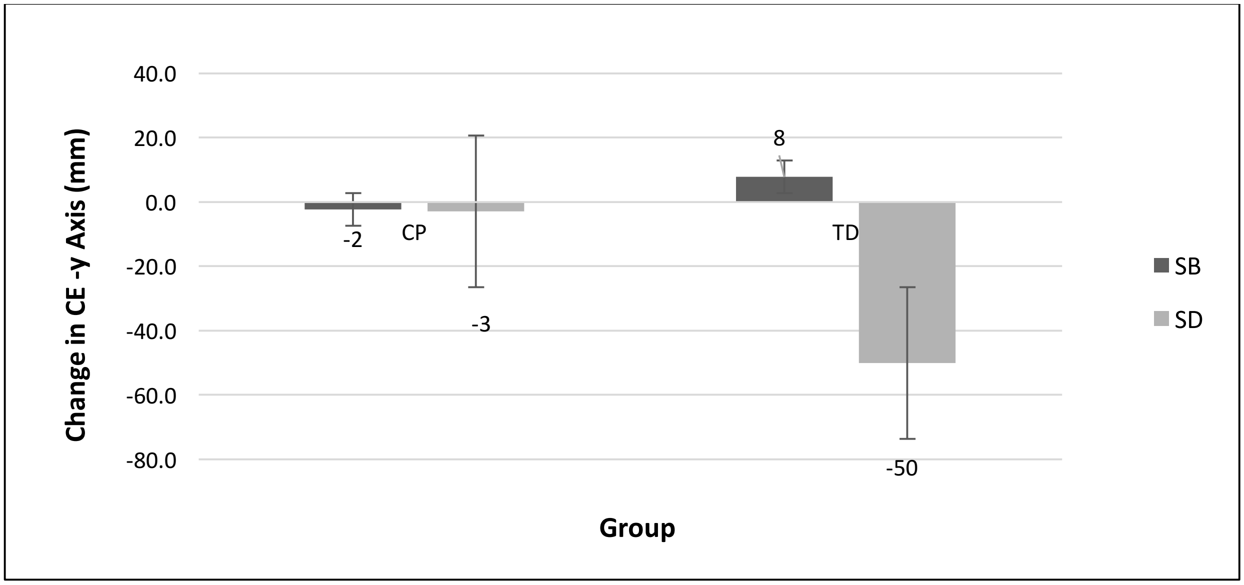

Figure 7. The amount of change in constant error (CE) in the Y-axis in each auditory condition, for both the cerebral palsy (CP) and typically developed (TD) groups; measured in milliseconds. The means presented represent the amount of change occurring between the Sound:Before and Sound:During condition and the No Sound baseline condition.. Natural means are presented in Appendix C, Figure 16, pp 81.

Variable Error in the Y-axis

Here, we consider the standard deviation of the means of position endpoint for each condition, in the Y-axis, in each group, collapsed across targets (VE-y). The main effect of condition was significant, F (1,18) =7.246, p= .0149. Figure 8 (below) demonstrates that the least amount of change in VE-y occurred in the SB condition, while the largest change in VE-y occurred in the SD condition. The main effect for group was also found to be significant, F (1,18) = 7.26, p = .0148. Here, the CP group shows the least amount of change in VE-y, while the TD group shows the overall largest amount of change (increase) in variability (see Figure 8, below). The group by condition interaction did not reach significance, F (1,18) = 2.199, p=.155.

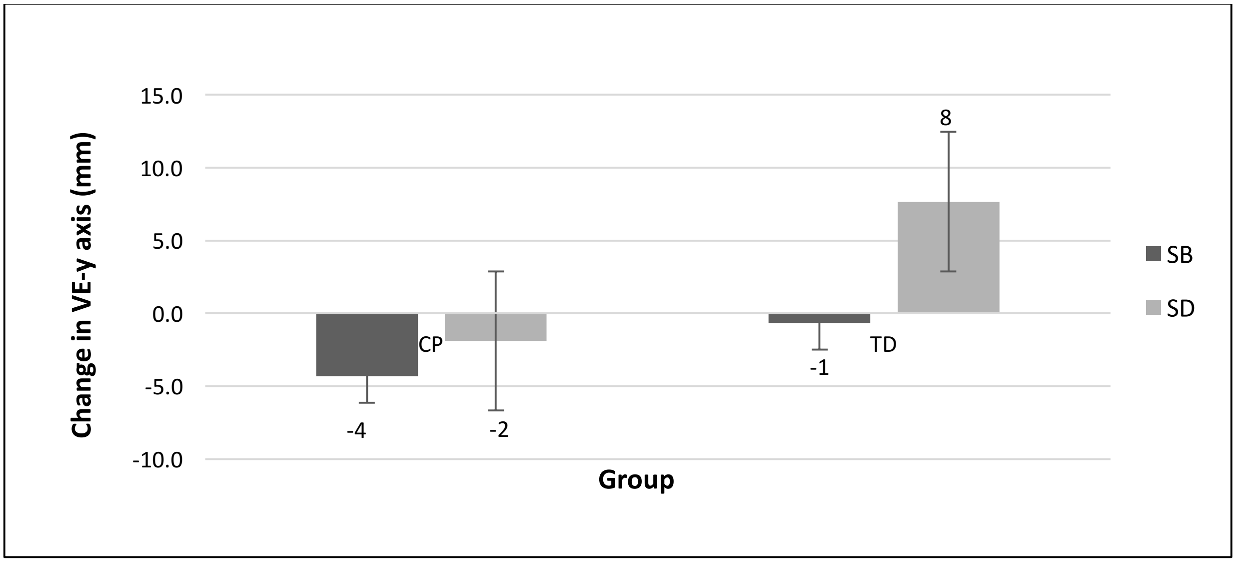

Figure 8. The amount of change in variable error (VE) in the Y-axis in each auditory condition, for both the cerebral palsy (CP) and typically developed (TD) groups; measured in milliseconds. The means presented represent the amount of change occurring between the Sound:Before and Sound:During condition and the No Sound baseline condition. Natural means are presented in Appendix C, Figure 19, pp 82.

Constant Error X-axis

The main effects and interactions in the variables for constant error in the X-axis did not reach significance (see Table 3, below). Natural means are presented in Appendix C, Figure 17, pp 81.

Variable Error X-axis

The main effects and interactions in the variables for variable error in the X-axis did not reach significance (see Table 3, below). Natural means are presented in Appendix C, Figure 18, pp 82.

Movement Peaks Z-axis

The main effects and interactions in the variables for movement peaks in the Z- axis did not reach significance (see Table 3, below). Natural means are presented in Appendix C, Figure 20, pp 83.

Table 3

F and P-values for each category of main effects for the variables of Constant Error X-axis (CE-x), Variable Error X-axis (VE-x), and Movement Peaks Z-axis (MP-z).

Variable	**Effect**	**F (1,18)**	**P (<.05)**
CE-x	Group	1.87	0.189
	Condition	1.09	0.309
	Condition by Group	4.23	0.054
VE-x	Group	1.40	0.253
	Condition	0.03	0.860
	Condition by Group	0.40	0.533
MP-z	Group	0.66	0.426
	Condition	1.62	0.218
	Condition by Group	0.41	0.530

Distance Travelled by the Shoulder

The distance travelled by the shoulder during each reach was used as an indicator of postural contribution to the overall reach. Due to poor visibility of the markers as a result of muscle contractures and compensatory movements used in the CP group, only two participants provided enough kinematic files for statistical analysis for the CP group. Thus, statistical analysis has not been performed for this measure. The two participant files, and the matched TD counterparts, are represented in Figure 9 (below). It is clear that each group has a unique pattern of displacement and that within the CP group there is a large degree of variability in these patterns as well.

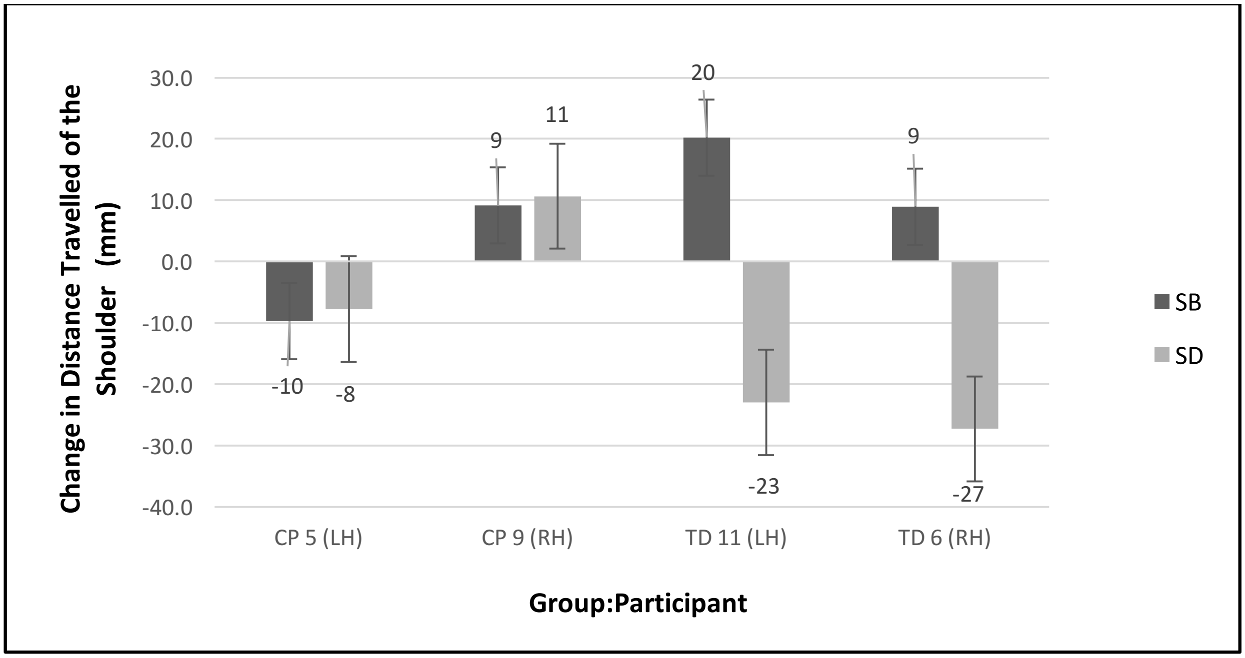

Figure 9. The change in distance travelled by the shoulder during the reaching movement in both auditory conditions; measured in millimeters (mm). The means presented represent the amount of change occurring between the condition (SB or SD) and the baseline (NS). Two participants in the CP and their matched counterparts from the TD group are presented.

DISCUSSION

The overarching objective of this thesis considers the effect of an auditory stimulus and changing task difficulty on the movement planning and execution phases of a goal-directed reaching task with a CP group, as compared to typically developed counterparts. To this end, the results indicate that when an auditory stimulus is presented in the planning phase of the movement (SB), negative change does occur in RT and in variability of RT, online control (ttPV/MT), endpoint variability (CE-y) and accuracy of endpoint (VE-y), thus facilitating a more efficient response and trajectory of reaching. By comparison, when an auditory stimulus was presented in the execution phase (SD) the results demonstrate a delay in response and decreased accuracy overall. Looking solely at the CP group results, the SB condition facilitated more direct and accurate reaching similar to the TD group. When the instructions specified timing the end of the reaching movement *with* the auditory stimulus (SD), the complexity of the task increased as the instruction effectively created a dual task condition where participants were focused on spatial *and* temporal accuracy. This discussion will begin by looking at the impact on movement planning, followed by movement execution, limitations, implications of the results, and finally, future directions.

Movement Planning

Reaction time (RT) is defined as a measure of the time needed to plan and initiate a movement. For the present study, the task was a goal-directed reach to a visual stimulus (a target light) that, in some conditions, was accompanied by auditory information (a series of beeps) presented either before or during the movement. In the analysis of the planning phase of movement *both* the CP and TD groups experienced an improvement in RT when the sound was presented before the movement (SB condition), however the CP group demonstrated the greatest amount of change overall. In the SB condition, RT for the CP group showed greater negative change (decrease) as compared to the TD group, and in the SD condition RT showed a greater negative change (increase) when compared to the TD group.

A number of authors have suggested that when task difficulty increases, the amount of neural noise in the nervous system also increases (Hatfield, Wyatt and Shea, 2010; Elliott et al., 2010, Lyons, Hansen & Hurding, 2006, and Schmidt, 1979). Hatfield, Wyatt and Shea (2010) postulated that auditory feedback impacted the planning phase of movement (in a classic Fitts' task) and effectively lowered the task difficulty by decreasing the amount of neural noise. In the present study, the decrease in RT in the planning phase (SB) suggests that the incorporation of the auditory stimulus facilitated movement planning, resulting in shorter reaction times. Keeping in mind the heterogeneity of the CP group, it is of interest (see Figure 3, pp 46) that the RT differences in the CP group were brought closer to that of the TD group. Hence, movement planning was facilitated; indicative of improved coordination of the neural processes and programs required to execute the movement. This result suggests that the added auditory information during the planning phase effectively reduced noise in the neural system and improved response time and movement initiation for the CP group, despite existing neural impairment.

The change in within participant variability of reaction time (SD of RT) provides a snapshot of how consistent RT is in both conditions and groups. Differences in the movement characteristics inherent between the CP and TD groups were demonstrated by the exaggerated difference in variability of RT between the two groups. That said, the pattern of variability in RT in the CP group was *similar* to that of the TD group, with a negative change (decrease) in the amount of variability in the SB condition occurring for both groups. Furthermore, a *greater* decrease noted in the CP group (see Figure 4, pp 47), in contrast to the slight decrease in the amount of variability in the TD group. For the CP group, this is in stark contrast to the increase in the variability of RT in the SD condition. Again, this change in the amount of variability in RT suggests that the incorporation of the auditory stimulus during the planning phase of the movement facilitates RT, and in turn decreases the amount of variability in RT overall. Thus far, the results support the relationship between the auditory stimulus, the reduction of neural noise, and movement planning in both non-impaired and neurologically impaired (CP) participants.

The ratio of time to peak velocity to MT (ttPV/MT) provides a picture of *when* during the movement peak velocity is reached, and therefore how much time is available for online control for that particular condition and group. Specific to reaching, online control occurs when an individual is able to use visual and proprioceptive information to guide the limb towards the target accurately (Elliott, 2009 and 2010). In a practical sense, larger ratios of ttPV /MT demonstrate later use of visual and proprioceptive information for online control, whereas smaller ratios mean more relative time is available for online control (Elliott, 2001, 2009 and 2010; Hansen, Glazebrook, Anson, Weeks, and Elliott, 2006). Elliott et al. (2010) suggest that during movement planning an internal model (program) is accessed and, in a feedforward process, visual and proprioceptive information is then used to update the internal model during movement execution. Comparing the means of the groups in the SB condition, the CP group demonstrated a *greater* negative change in the mean ratio of ttPV/MT, as compared to the TD group in the same condition. Though the change in the ratio of ttPV/MT in the CP group was not significant (see Figure 6, pp 49), a pattern of interest is emerging for this group. Elliott et al. (2009 and 2010) suggest that the integration of visual information fosters an improvement in movement planning and accuracy. Here, online control in the CP group began slightly earlier in the SB condition and later in the SD condition, whereas the opposite is true in the TD Group. In the CP group the amount of change occurring in the SB condition suggests that hearing the auditory stimulus during movement planning facilitated the earlier integration of sensory information with movement planning in relationship to movement time, in turn facilitating movement coordination, resulting in a greater amount of time for online control after reaching peak velocity.

Endpoint accuracy in the primary axis (CE-y) showed that the amount of bias towards under or overshooting the target in relationship to the baseline measure (NS) decreased when sound was introduced during movement planning (SB) for the TD group. In other words, endpoint accuracy improved when hearing the auditory stimulus in the planning phase of reaching (SB). The CP group also showed a negative change (decrease) in the amount of variability at endpoint in relationship to the baseline measure in both conditions, however the level of variability in this group was quite small by comparison (see Figure 7, pp 50). And, in the SB condition, a greater decrease in the amount of endpoint variability (VE-y) occurred in the CP group, indicating that when participants heard the auditory stimuli before initiating reaching (SB), movement accuracy was facilitated resulting in a more accurate endpoint measure (see Figure 8, pp 51). In 2010, Elliott and colleagues proposed that when visual information is present, typical participants are able to improve endpoint accuracy by reducing the number of sub-movements occurring during movement execution in relationship to a decrease in neural noise.

In the present study, the improvement in accuracy for CP group, in addition to improved response time, suggests that when auditory information is present during movement planning, the feedforward processes of initiating the efferent copy of the movement and engaging online control earlier are facilitated. For those diagnosed with CP, this results in an improved response to stimulus, as well as improved integration of visual information, improving accuracy and movement control at target end.

Movement Execution

In the SD condition a similar pattern of change in reaction time occurred between the two groups (see Figure 3, pp 46). At first glance, it is evident that the additional task instruction of timing the movement to the auditory stimulus in the SD condition influenced RT for both groups, in that RT showed a positive change (slowed) when the auditory stimulus was present during the reaching movement. Here, in the SD condition the target light (visual information) is presented first, and the auditory information is *added* when movement is initiated; in observation, the reaction time of both groups in the SD condition changed in a positive direction, in other words movement initiation was delayed. The influence of task instructions is consistent with Andersen et al.'s (2004) suggestion that the task instructions directed subjects' focus to a specific stimuli when audio and visual stimuli is simultaneously presented. In the current study, the instruction given prior to the SD condition was specific; "you will see the target light first, and when you begin moving you will hear the auditory stimulus. You are to time your movement to this stimulus, pressing the target switch on the third beep." The *first set* of conditions (10 trials of each condition) was consistently presented in the same order (NS, SB, SD) with the *second set* of conditions being randomized. It is possible that the order of the first set of conditions influenced participants' response in the SD condition, in that after completing the SB condition they expected to hear the auditory stimulus first. In turn, participants may have waited for a longer duration before responding to the target light.

It was observed during the experimental process that MT in the SD condition (particularly for the TD group) relates to the imposed temporal constraint; in the SD condition participants were instructed to time their reaches to the auditory stimulus which occurred over a 6 second duration of time, therefore MT in TD group was expected to reflect this duration in the SD condition. The CP group had difficulty timing movement to the auditory stimuli (see Figure 5, pp 48), suggesting that when temporal constraint is added to the reaching task, compensatory actions such as increased movement of the torso at movement initiation were used to achieve the endpoint (Figueiredo, Silva, Avelar, da Fonseca, Boosma, & Mancini, 2015; Ju et al., 2012; Thaut et al., 2002). James, Ziviani, Ware and Boyd, (2015), Ferrari et al., (2010) and Steirs et al. (2002) suggest that the diagnoses of hemiplegic, diplegic and quadriplegic CP may be inclusive of visual-perceptual impairment in addition to motor impairment, and may vary according to the location of brain lesioning and the resulting neural re-organization. The heterogeneity of the diagnosis indicates that these confounding perceptual impairments are varied amongst the CP population. Here, movement execution in the SD condition is guided by visual information of the target and auditory stimulus and may be influenced by perceptual issues in the CP group. In addition, considering the range of plegias and functional levels represented in the CP group, the MT results in the SD condition support the notion that the clinical definitions of levels of function and plegias are indeed an unclear representation of the true physical aspects of the diagnosis. For instance, of those self-reporting to be hemiplegic and GMFC level 4, two participants were able to use both arms effectively for testing, two chose to use the dominant hand due to the level of fatigue as a result of muscle contracture on the impaired side, and one showed extreme slowing of movement. In addition, three participants' stories of their progression from diplegic to triplegia, over the course of their lives supports the need to move from clinical to functional level classification (GMFCS); as heterogeneous as the diagnosis is, the physical aspects of CP appear to evolve over the lifespan, which further supports the need for research across the lifespan.

In the SD condition, when given the instruction to time the end of the reaching movement with the auditory stimulus (6 second duration), the CP group used more time to reach PV, resulting in slightly less time available for online control in the SB condition. In contrast, the TD group initiated reach PV earlier than the CP group in the SD condition, resulting in more time being available for online control (see Figure 6, pp 49). This is in agreement with the observation noted previously that the SD condition required an unnatural slowing of reaching (for the TD group), in turn requiring exaggerated and unnatural movement control early in the movement. Though this creates a perceived imbalance in the results, when comparing the two groups we can see the opposite effect occurring in the CP group. That is, for in the SD condition the CP group used more ballistic compensatory movements over a longer duration of time to move the hand close to the target endpoint, therefore online control began later in the movement. This suggests that the change in task difficulty disrupted participants’ ability to engage in online control early in the movement, therefore less time was available for control to the target endpoint. It is interesting that despite this disruption of online control in the CP group, the results reflect better consistency of endpoint accuracy in the SD condition for the CP group, than in the TD group.

In the TD group, there is a clear positive change (increase) in participants’ bias for undershooting the target in relationship to the primary movement axis (CE-y) in the SD condition (see Figure 7, pp 50). Taking into consideration the additional task of timing the reaching movement to the auditory stimulus, this result is unexpected for the TD group. Because the timing of movement was slow it was expected that more control would be used to achieve the endpoint. It is most likely that the required slowing of movement in the SD condition caused a stopping of the movement early in the trajectory. Because of the timing anomaly for the TD group in this condition, it is likely that this decrement in accuracy at endpoint is due to the participants' ending their movement early rather than the concurrent presentation of the auditory stimulus. Contrary to this phenomenon, and most interestingly, the CP group showed a slight negative change (decrease) in accuracy at endpoint. Although highly variable, this result is less than 1 mm greater than in the SB condition for the CP group.

Despite the confounding factor of the timing instructions given for the SD condition, the CP group demonstrated a trend toward an improvement in the amount of variability at movement endpoint. Though non-significant, this improvement in endpoint accuracy for a group that is neurologically impaired (CP) suggests that, for participants who were able to time their movements to the auditory stimulus, the selected timing of the stimulus was appropriate for the CP participants.

In summary, the results from the SD condition demonstrate that task instructions had two different effects on participants' movements. For the CP group, RT increased (longer) and became more variable when sound was incorporated into the planning phase of movement, and showed improvements in patterns of constant and variable error at endpoint. The results support the current understanding that when neurological impairment is present, individuals engage compensatory movements to achieve movement end successfully with accuracy and within known physical limitations. That said, CP participants experienced less time for online control to endpoint in the SD condition and a trend toward an improvement accuracy at endpoint.

Limitations

In the translation of the results it is important to note observations made during the experimental process. First, early in the experimental process it became clear that the presentation of the auditory stimulus of 6 seconds in the SD condition created an unanticipated challenge for the TD group; requiring participants to slow their reaches to an unnaturally slow pace which resulted in participants stopping short of the target. Second, potential perceptual impairments (as discussed previously) and known physical impairments within the CP group may have influenced performance, particularly in the SD condition, resulting in the CP group using compensatory strategies to accomplish the task.

The Optotrak is limited in that consistent visibility of the IRED markers is required for data collection. This limitation, in combination with the unpredictable movements used by the CP group, resulted in lost data files. Optimal collection of kinematic data may be facilitated by adding an additional Optotrak camera placed parallel to the lateral side of apparatus, and preferred hand of the participant. This would allow for dual capture of data and increase the number of complete data files available for analysis. Because of the inherent spasticity and heterogeneity of movement in the CP group, future studies may also benefit from the incorporation of video recording during the experimental process to facilitate observation by the researchers. This information would allow for clarity in understanding the trajectory used in the CP population post-testing. In addition, in future studies the markers placed on the shoulders could be raised up from the shoulder to improve the visibility of the IREDs when measuring postural change.

Although recruitment of CP participants was successful, the range of functional level and physical topography represents a broad portion of the CP population (GMFCS 2-4). This representation was not equally balanced, and therefore is not a true representation of the CP population as a whole. In an ideal situation, 10 participants would be recruited at each GMFCS level, which in turn would lead to more specific inferences regarding this population. Grouping individuals by level of function (GMFCS I-III and IV-V) with the goal to recruit 10 participants for each grouping may be a more realistic goal (requiring a total of 20 CP participants), and would allow inferences specific to functional level. To protect against practice effects and participant fatigue, handedness was blocked (10 trials) within each condition, and within each block of trials target direction (ipsilateral and contralateral) was randomized. Participants completed a series of two blocks of ten trials (dominant and non-dominant hand), in each of the three conditions for a total of 60 trials. This series was then repeated again for a total of 120 trials. In the first block of 10 trials in each condition, the conditions were presented in the same order for each participant, while the second series was randomized for each participant. The initial concern was participant fatigue and understanding; despite these concerns, the first series of conditions may have created a practice effect. Future work in this area will ensure that order effects are taken into consideration in the experimental design, limiting the influence of order of conditions.

Future Directions

The exaggerated slowing of movement for the TD group in the SD condition indicates the need for a follow-up study which considers the auditory stimuli being presented over a shorter (more natural) duration of time, during reaching, with a typically developed population. Simplifying the instructions given in the SD condition may bring further clarity to any effects currently confounded by task instructions. The potential for practice effects will be taken into consideration in the follow-up experimental design, limiting the influence of order of conditions.

To further determine how audition impacts movement kinematics in the diagnosis of CP, further studies will consider a similar task using a continuous auditory stimulus that does not require timing movement to the stimulus in comparison to a SB condition as used in the present study. At a GMFCS functional level of four individuals may experience acute contractures of the shoulders and arms, and in turn may use their feet, or head to access tablet devices for communication. As these adaptive measures require a high level of movement accuracy, the incorporation of the auditory stimulus to a modified reaching and/or Fitts' task using different parts of the body may also be considered. Lastly, it would be beneficial to consider and measure perceptual impairment for future studies in the area of CP. The potential for visual-perceptual impairment in the CP group suggests that similar work in the future would benefit from assessing this potential using an assessment such as the visual-perceptual battery L94 (Stiers et al., 2001) to gain a clear representation of possible perceptual impairment.

Implications

In addition to the leading causes of morbidity (e.g. cardiovascular disease, cancer, and depression) in adults, the diagnosis of Cerebral Palsy infers an accompanying host of comorbidities including decline in functional ambulation, progressive muscular and skeletal deformities, fatigue and gastrointestinal disease (Liptak, 2008; Klingbeil, 2004). For those living with CP, access to affordable programming that is appropriately adapted, yet is challenging and interesting, is limited (Usaba, Oddson, Gauthier & Young, 2015). Psychosocial barriers to physical activity for this population have been demonstrated in low self-efficacy for pursuing and participating in physical activity and the belief that one is capable of being physically active (Becker & Schaller, 1995; Usaba, Oddson, Gauthier & Young, 2015). This suggests a clear disconnect between our understanding of chronic disease across populations. There are a number of considerations for the CP community, including comorbidities in the diagnosis of CP, the availability of adapted, challenging, and interesting accessible programming, as well as overall low self-efficacy for a physically active lifestyle. Here, the rhythmic paradigm during the planning phase of reaching provides an interesting perspective from which to adapt therapies and programming for this specific population.

The current study considered the influence of a rhythmic (auditory) stimulus on the accuracy of a goal-directed reach task in adults diagnosed with CP. Presenting the auditory stimulus during the planning phase of movement improved overall kinematics, movement execution, and accuracy for both groups, suggesting a decrease in existing neuromotor noise was facilitated. In addition, the dual task paradigm of the SD condition had a negative impact on the reaching movement of the TD group, while demonstrating the CP group's attention to the accuracy of the reaching at movement end. Application of this paradigm might include adapting therapies and programs to include a preparatory count down when executing specific movements. For example, when performing arm strengthening exercises, the practitioner (or the client) may count out loud before the client/participant moves their limb. In a group activity setting incorporating music, individuals with CP could be instructed to slow their movement down and count "1-2-3" with the music before performing specific types of movement. In an occupational therapy setting, individuals could be taught to count "1-2-3" when having to reach to press a button to open a door or to access an elevator.

Conclusion

The findings of this study suggest that the use of sound during movement planning decreases existing neuromotor noise, resulting in improved response times and variability of response times, movement control, as well as accuracy at movement end (target) for the CP group. Supporting rhythmic paradigms used instinctively in therapeutic settings, these findings will foster new approaches to therapies, as well as alternative adaptive programming. This study also provides initial evidence supporting the practice of Conductive Education which combines practitioner led verbal cueing with therapeutic modalities designed for neurologically impaired populations. The application of this rhythmic paradigm in physical activity and therapeutic settings has the potential to facilitate progress in functional movement efficiency for individuals with CP, which in turn will foster greater self-efficacy for participation in physical activity throughout the lifespan.

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APPENDIX A

Table 4

Summary of Group characteristics for TD and CP groups.

Grp	**Sex**	**Handedness**	**WHQ**	**Vision & Hearing**	**GMFCS**
TD n=10	7 F; 3 M	2 M & 3F; right handed	M: 54	1 M & 4F; corrected vision	
M (age):	24.1	1 M & 4F; left handed	M:-16	3 M & 7F; normal hearing	
CP n=10	8 F; 2 M	1 M & 4F; right handed	M: 66	2 M & 3F; corrected vision 1 F; partial (functional) vision 4 F; normal vision	1 M: GMFCS 4/5 1 M & 5F: GMFCS 4
M (age):	30	1 M & 4F; left handed	M:-67	2 M; normal hearing	1 F: GMFCS 2/3 1 F: GMFCS 2 1F; GMFCS 3

Table 5

Adjusted Target Distances for the CP group

CP participant	**Adjusted Target Distance**
1	n/c
2	n/c
3	n/c
4	14 cm
5	25 cm
6	9.9 cm
7	26 cm
8	24 cm
9	11 cm
10	6.3 cm

APPENDIX B

Pilot Study Observations

A pilot study was completed with four TD individuals and one individual with CP. The original procedure was blocked in sets of 20 reaches with each hand, repeated again within each condition (total of 40 reaches per block of trials). In the original setup, the targets were small buttons placed on the anterior edge of a shelf, which was placed at a distance of 45.72cm from the home switch. During the initial pilot (with an individual with CP), it was clear that the apparatus and procedure required a significant amount of physical and mental effort (increasing fatigue) on the part of the participant with CP. In particular, it was noted that a) the targets were placed too far from the home switch, b) the target buttons were too small (decreasing accuracy and increasing level of difficulty for the CP participants), and c) the placement of the target buttons on the anterior edge of the shelf required a significant amount of effort on the part of the participant (working against gravity in deceleration phase to arrive at the button press). After observing this initial performance and the effort required of the participant to execute the tasks, it was determined that the following changes be made to the apparatus: a) remove the shelf apparatus and place the targets on the apparatus surface to allow participants to work with gravity when pressing the button, b) use the same switch setup as used for the home switch (enlarging the target size for increased accuracy), and c) decrease the reach distance by placing the targets at a distance of 35cm from the home switch, making the task more manageable overall for the CP participants.

When assessing the fatigue level of the participant with CP as well as practice effect, the following adjustments were made to the experimental procedure: Handedness has been blocked in sets of 10 trials within each condition, with target direction (ipsilateral and contralateral) randomized. To ensure at least minimum data capture, participants now complete a series of two blocks of ten trials (dominant and non-dominant hand), in each of the three conditions for a total of 60 trials. This series is then repeated for a total of 120 trials. The apparatus and procedure outlined in this document reflect these changes.

APPENDIX C

Natural Means of Performance and Kinematic Measures

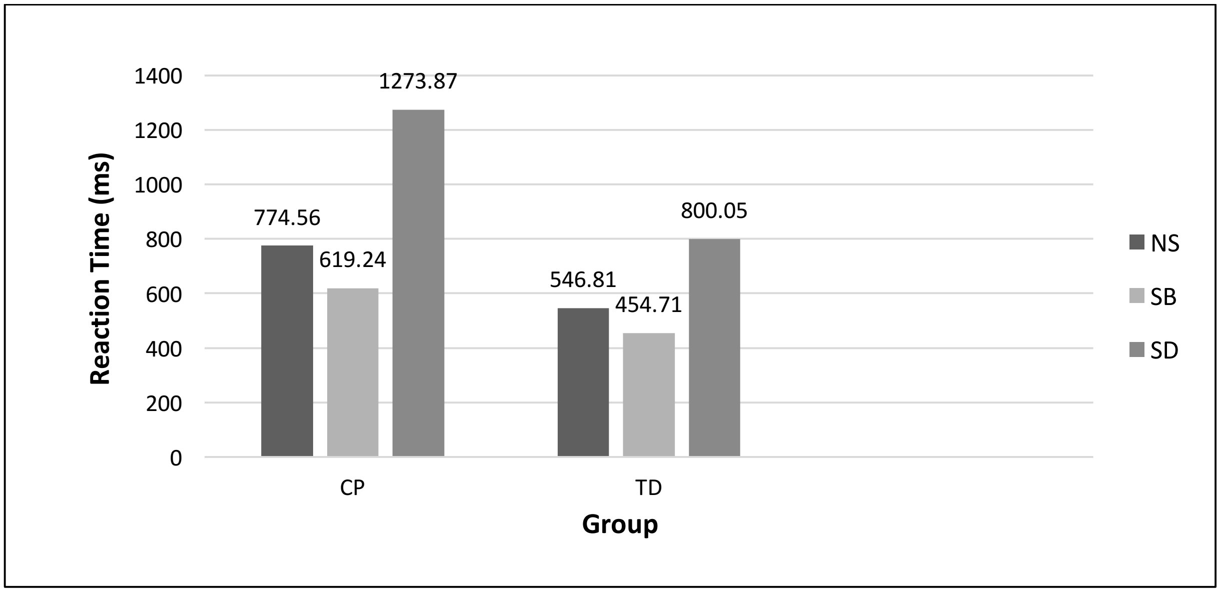

Figure 10. Natural means of RT, measured in milliseconds.

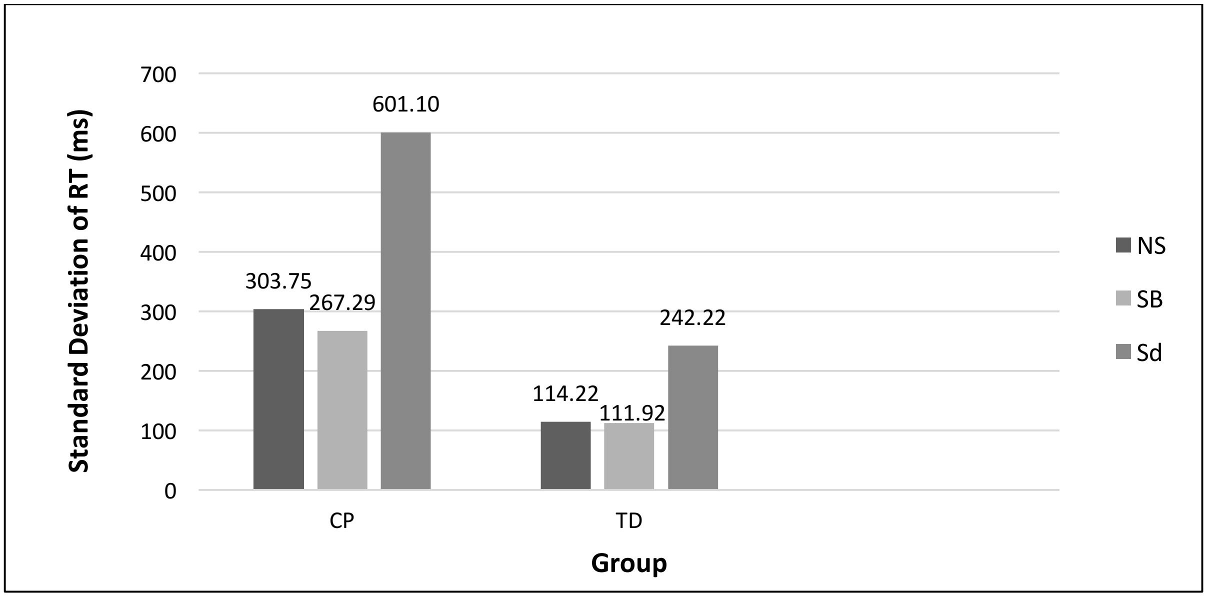

Figure 11. Natural means of the standard deviation of RT, measured in milliseconds.

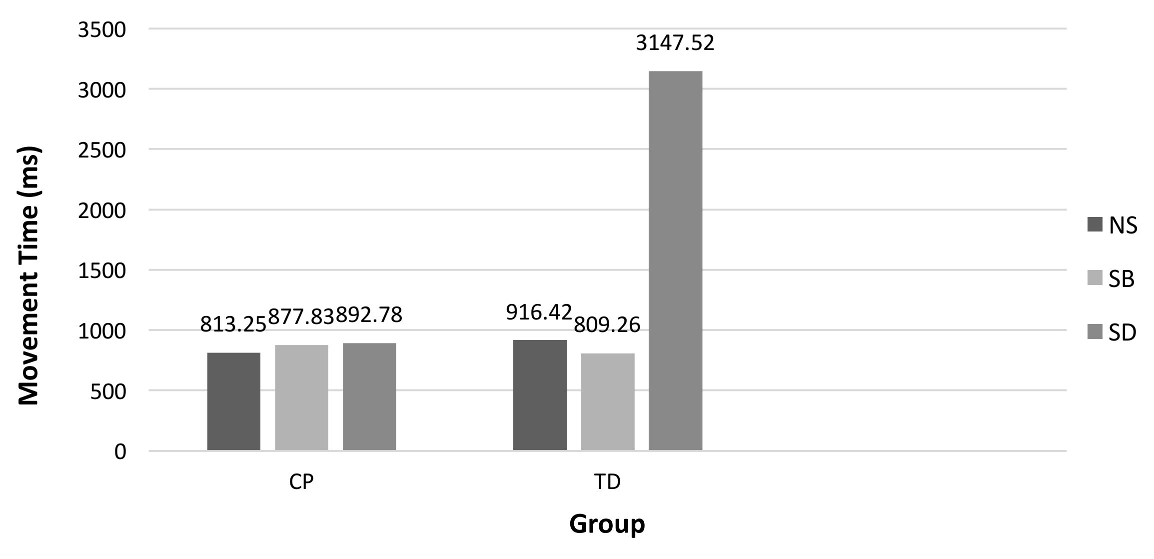

Figure 12. Natural means of MT, measured in milliseconds.

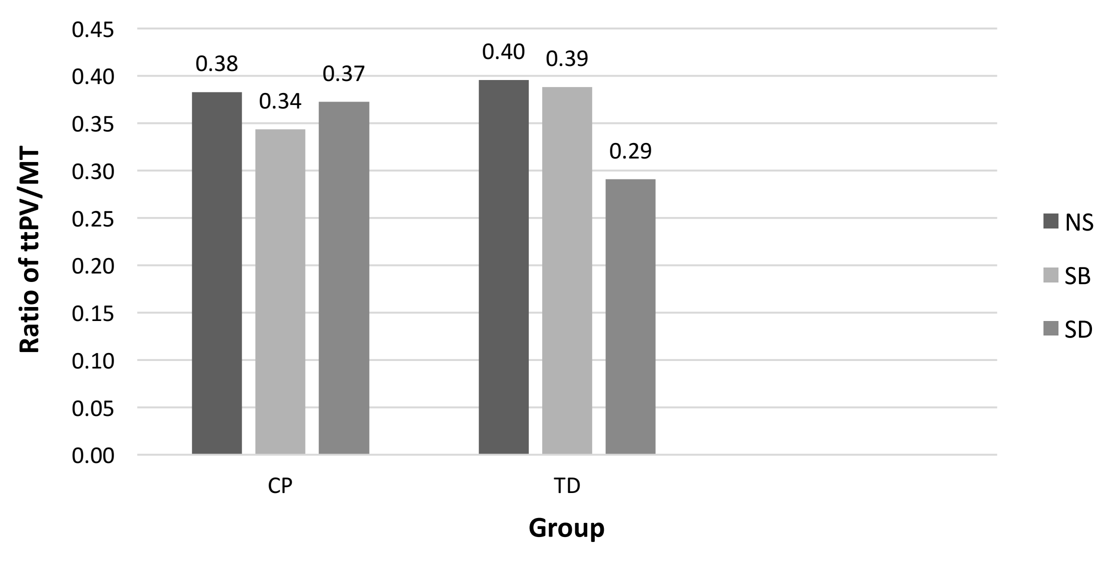

Figure 13. Natural means of the ratio of ttPV/MT.

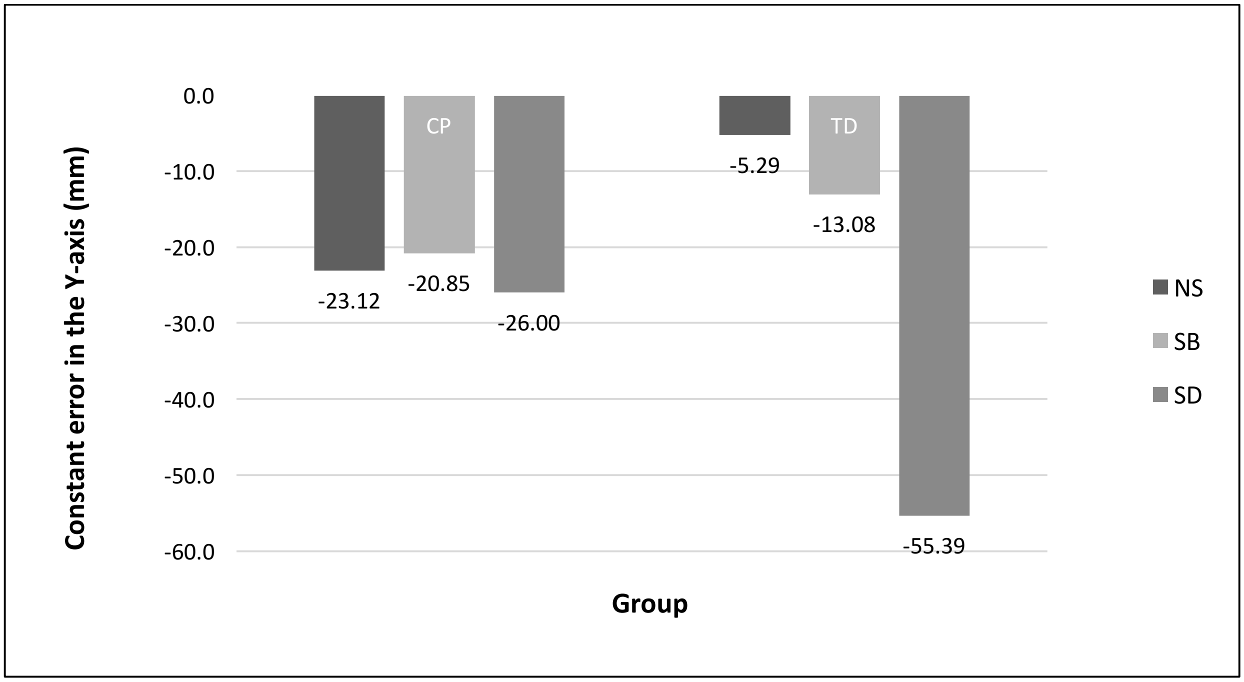

Figure 14. Natural means of constant error in the Y-axis, measured in millimeters.

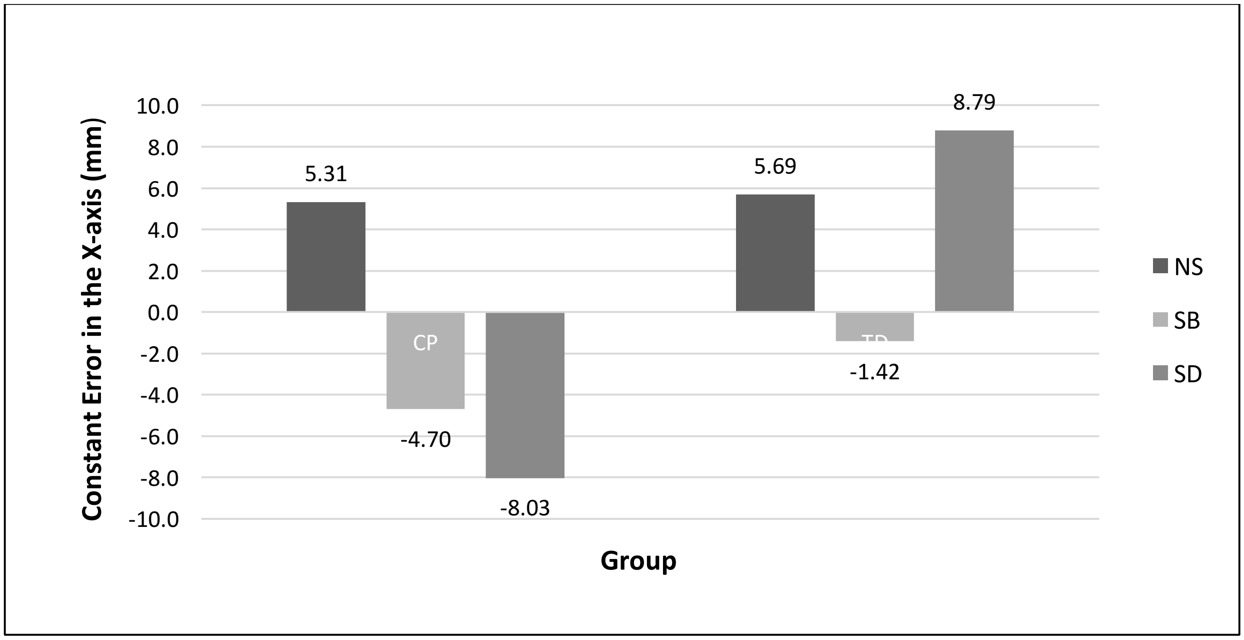

Figure 15. Natural means of constant error in the X-axis, measured in millimeters.

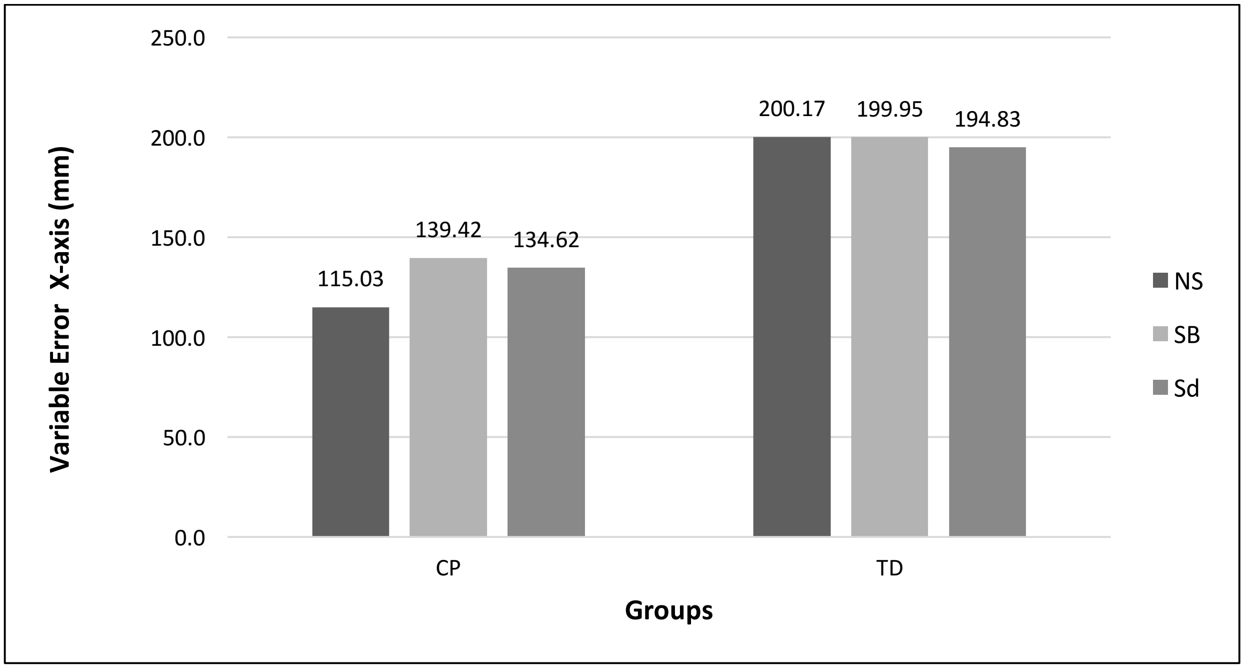

Figure 16. Natural means of variable error in the X-axis, measured in millimeters.

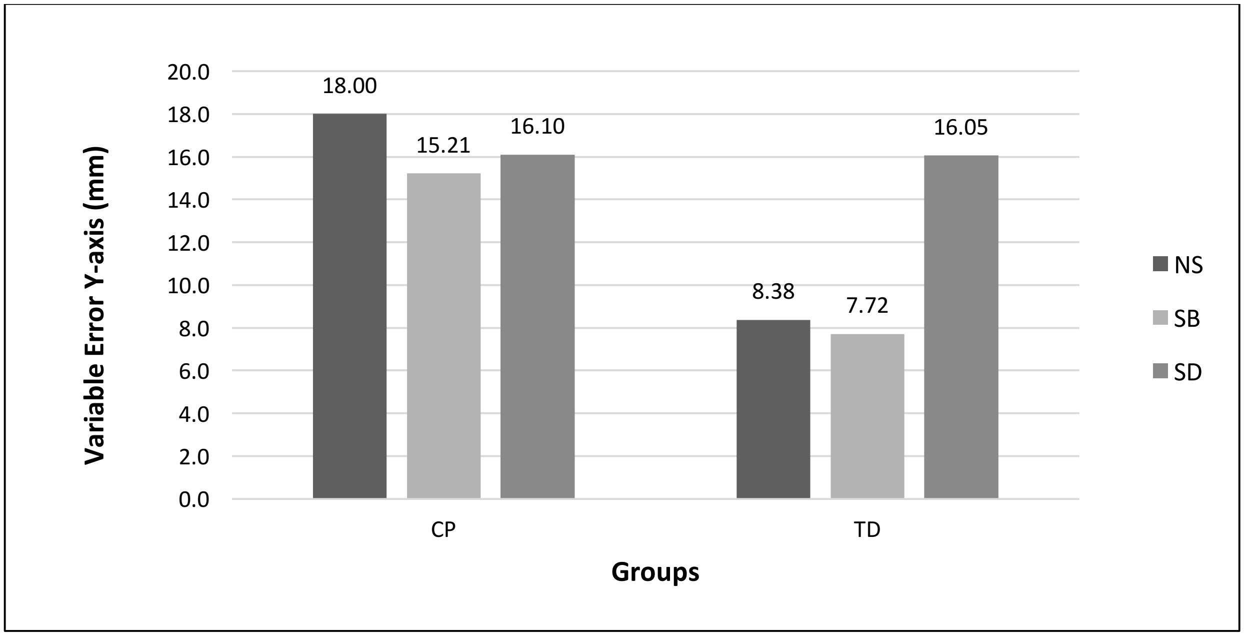

Figure 17. Natural means of variable error in the Y-axis, measured in millimeters.

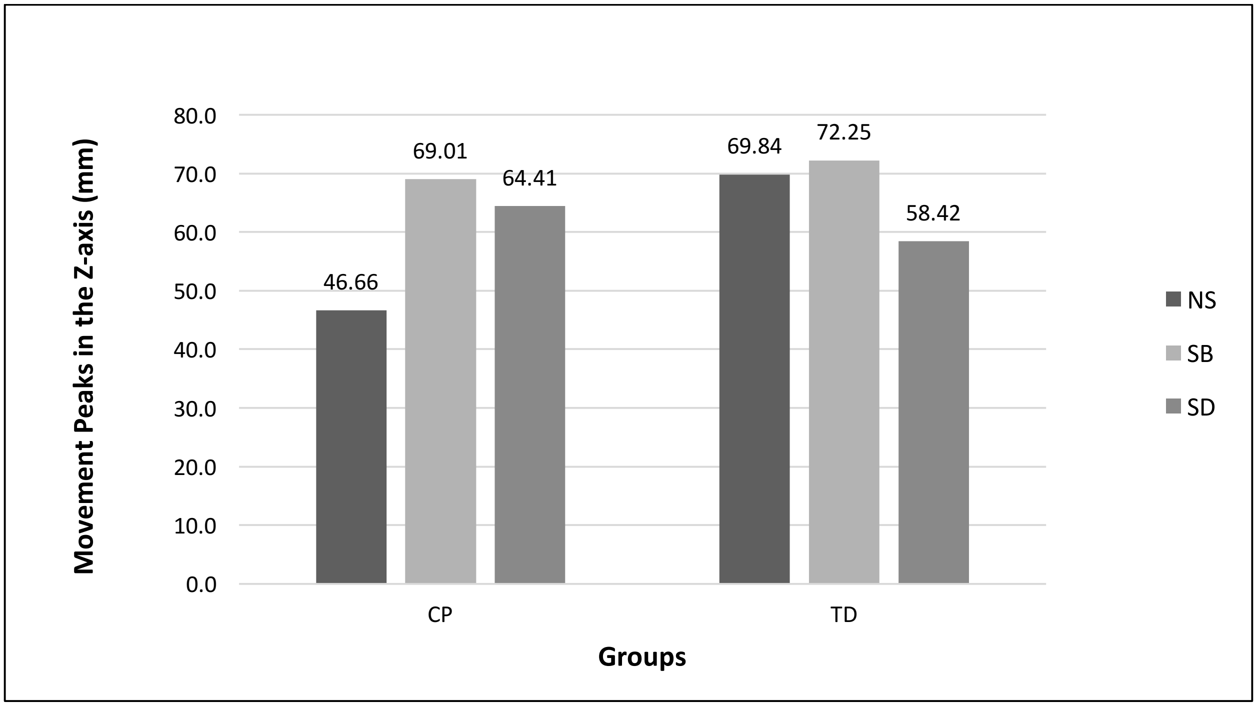

Figure 18. Natural means of the movement peaks in the Z-axis, measured in millimeters.

APPENDIX D

Glossary of Abbreviations

ADLs	Activities of daily living
CE (x or y)	Constant error and corresponding axis
CP	Cerebral Palsy
COP	Centre of pressure
CSEP	Canadian Society for Exercise Physiology and American College of Sports
dB	Decibel
fMRI	Functional magnetic resonance imaging
GMFCS	Gross Motor Functional Classification Scale
Hz	Hertz
ICF	World Health Organization’s International Classification of Functioning
IRED	Infra-red emitting diode
LED	Light emitting diode
MT	Movement time
NS	No sound condition
PA	Physical activity
PVL	Periventricular leukomalacia
QoL	Quality of Life
RT	Reaction time
SB	Sound before condition
SD	Sound during condition

TD	Typically developed
ttPV	Time to peak velocity
UMN	Upper motor neuron tracts
VE (x or y)	Variable error and corresponding axis
WHQ	Waterloo Handedness Questionnaire

APPENDIX E

Informed Consent and Assent Forms

UNIVERSITY OF MANITOBA

FACULTY OF KINESIOLOGY
AND RECREATION
MANAGEMENT

319 Max Bell Centre
University of Manitoba
Winnipeg, MB R3T 2N2
Telephone (204) 474-8773
glazebro@cc.umanitoba.ca

INFORMED CONSENT

The effects of changing task difficulty in a goal-directed reach task in adults diagnosed with HCP

Principal Investigator:	Dr. Cheryl Glazebrook Faculty of Kinesiology & Recreation Management University of Manitoba (204) 474-8773 cheryl.glazebrook@umanitoba.ca
Student Research Assistants:	Jacqueline Ladwig-Davidson, Niyousha Mortaza, Kayla Duna, Ilana Naiman, Bayonle Olakadun Perceptual Motor Behaviour Lab Rm 234, Investors Group Athletic Centre Faculty of Kinesiology & Recreation Management University of Manitoba (204) 480-1487 ladwigj@myumanitoba.ca

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

PURPOSE: We are interested in learning how individuals with and without Cerebral Palsy plan and execute reaching movements of varying complexities, and how their posture may or may not be impacted by the movement.

DESCRIPTION: During the study, you will be asked to make a series of pointing movements to a cup on a shelf. An accelerometer will be used to record your postural changes when performing these tasks and an OPTOTRAK 3-D motion analysis system will be used to record your shoulder, arm, and hand movements of both arms. Prior to this task, you will be asked to fill out a brief demographics questionnaire that inquires about your age, gender, handedness, whether or not your vision and hearing are corrected (glasses, contact lenses, hearing aids), as well as the Waterloo Handedness Questionnaire. The whole procedure will take 30-60 minutes to complete.

RISKS AND BENEFITS: There are no evident risks inherent in the tasks you will perform but some of the tests may become repetitive and you may experience boredom and/or mild muscle fatigue in your arms. While this may be frustrating, the investigator with you will provide breaks throughout and you may request a break at anytime.

Your participation in this study will help us discover ways in which participants with cerebral palsy might use an external rhythm to improve control of arm movement, as well as broaden our understanding and perspective of how multisensory-motor integration changes with task difficulty.

COSTS AND PAYMENTS: There are no fees or charges to participate in this study. If you require transportation to the Perceptual-Motor Behaviour Laboratory at the University of Manitoba via Handi-transit we will reimburse the cost of your fare. You will receive a gift card for Tim Hortons to thank you for donating your time. The amount of the gift card will be proportional to the time duration of the study. Specifically, ten dollars per hour, rounded up to the nearest half hour. For example, if the protocol is 60 minutes then you will receive a $10 gift card.

CONFIDENTIALITY: Your information will be kept confidential. Once you begin the study your name, information, and results will be referred to by a code number. All files containing identifying information will be stored in a locked cabinet separate from data with your code number. Your files will only be accessible by the investigators and will be destroyed by Dr. Glazebrook seven years after the completion of the study (approximately June, 2022). As PI for the project Dr. Glazebrook may be present during testing for the HCP group only in order to assist with the data collection process. All papers containing personal information will be shredded. All electronic files will be deleted. Any CDs or DVDs containing data will be physically destroyed. Only Dr. Cheryl Glazebrook and the student research assistants listed will have access to any lists that contain identifying information.

Results will be presented at academic conferences, invited presentations, and published in peer-reviewed academic journals. In almost all cases only group averages will be presented. In some cases a drawing of an individual movement path will be presented. This data contains no identifiable information and therefore your anonymity will be maintained.

DEBRIEFING: Upon completion of the study the experimenter will describe the research questions being considered. If the participant would like to know the results of the study please indicate 'yes' on the consent form where indicated and the Principal Investigator or the student research assistant will contact you with a summary of the findings in approximately 4 months.

VOLUNTARY CONSENT: If the participant *does not wish to participate* in the study or wishes to withdraw from the study, he/she is free to leave without consequence at any point in time and we thank you for your consideration.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you choose to withdraw from the study you will still receive compensation for the time you have participated. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

Note: Following the principles of the Vulnerable Persons Act participants are encouraged to speak for themselves in regards to consent, with the support of a guardian or Substitute Decision maker. For participants who turn to others such as guardians and Substitute Decision Makers (SDM) for support in making life decisions, *joint authorization* from both the participant and their guardian/SDM is required. Consent is to be completed by the participant as well as the guardian or Substitute Decision Maker, and Assent will be given by the participant (either written, verbal, or via guardian or Substitute Decision Maker).

A copy of this consent form has been given to you to keep for your records and reference.

This research has been approved by the Education/Nursing REB If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC), (204) 474-7122 or email at humanethics@umanitoba.ca.

INFORMED CONSENT

Research Study: The effects of changing task difficulty in a goal-directed reach task in adults diagnosed with HCP

Signature of Participant____ Date ____________

AND (if appropriate)
Signature of Guardian / Substitute Decision Maker ____________________________________
Relationship ____ Date_____________

Researcher/ Delegate's Signature __________________________________Date ___________

SUMMARY OF FINDINGS: Would like to be contacted with a summary of the overall findings of this study? ☐ YES ☐ NO

If yes, please complete the following:
Name: ____
Phone Number: ____
Email Address: ____

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AND RECREATION
MANAGEMENT

319 Max Bell Centre
University of Manitoba
Winnipeg, MB R3T 2N2
Telephone (204) 474-8773
glazebro@cc.umanitoba.ca

INFORMED CONSENT - Matched group

The effects of changing task difficulty in a goal-directed reach task in adults diagnosed with HCP

Principal Investigator:	Dr. Cheryl Glazebrook Faculty of Kinesiology & Recreation Management University of Manitoba (204) 474-8773 cheryl.glazebrook@umanitoba.ca
Student Research Assistants:	Jacqueline Ladwig-Davidson, Niyousha Mortaza, Kayla Duna, Ilana Naiman, Bayonle Olakadun Perceptual Motor Behaviour Lab Rm 234, Investors Group Athletic Centre Faculty of Kinesiology & Recreation Management University of Manitoba (204) 480-1487 ladwigj@myumanitoba.ca

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PURPOSE: We are interested in learning how individuals with and without Cerebral Palsy plan and execute reaching movements of varying complexities, and how their posture may or may not be impacted by the movement.

DESCRIPTION: During the study, you will be asked to make a series of pointing movements to a cup on a shelf. An accelerometer will be used to record your postural changes when performing these tasks and an OPTOTRAK 3-D motion analysis system will be used to record your shoulder, arm, and hand movements of both arms. Prior to this task, you will be asked to fill out a brief demographics questionnaire that inquires about your age, gender, handedness, whether or not your vision and hearing are corrected (glasses, contact lenses, hearing aids), as well as the Waterloo Handedness Questionnaire. The whole procedure will take 30-60 minutes to complete.

RISKS AND BENEFITS: There are no evident risks inherent in the tasks you will perform but some of the tests may become repetitive and you may experience boredom and/or mild muscle fatigue in your arms. While this may be frustrating, the investigator with you will provide breaks throughout and you may request a break at anytime.

Your participation in this study will help us discover ways in which participants with cerebral palsy might use an external rhythm to improve control of arm movement, as well as broaden our understanding and perspective of how multisensory-motor integration changes with task difficulty.

COSTS AND PAYMENTS: There are no fees or charges to participate in this study. You will receive a gift card for Tim Hortons to thank you for donating your time. The amount of the gift card will be proportional to the time duration of the study. Specifically, ten dollars per hour, rounded up to the nearest half hour. For example, if the protocol is 60 minutes then you will receive a $10 gift card.

CONFIDENTIALITY: Your information will be kept confidential. Once you begin the study your name, information, and results will be referred to by a code number. All files containing identifying information will be stored in a locked cabinet separate from data with your code number. Your files will only be accessible by the investigators and will be destroyed by Dr. Glazebrook seven years after the completion of the study (approximately June, 2022). All papers containing personal information will be shredded. All electronic files will be deleted. Any CDs or DVDs containing data will be physically destroyed. Only Dr. Cheryl Glazebrook and the student research assistants listed will have access to any lists that contain identifying information.

Results will be presented at academic conferences, invited presentations, and published in peer-reviewed academic journals. In almost all cases only group averages will be presented. In some cases a drawing of an individual movement path will be presented. This data contains no identifiable information and therefore your anonymity will be maintained.

DEBRIEFING: Upon completion of the study the experimenter will describe the research questions being considered. If the participant would like to know the results of the study please indicate ‘yes’ on the consent form where indicated and the student research assistant will contact you with a summary of the findings in approximately 4 months.

VOLUNTARY CONSENT: If the participant *does not wish to participate* in the study or wishes withdraw from the study, you are free to leave without consequence at any point in time and we thank you for your consideration.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you choose to withdraw from the study you will still receive compensation for the time you have participated. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

A copy of this consent form has been given to you to keep for your records and reference.

This research has been approved by the Education/Nursing REB If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC), (204) 474-7122 or email at humanethics@umanitoba.ca.

INFORMED CONSENT – Matched group

Research Study: The effects of changing task difficulty in a goal-directed reach task in adults diagnosed with HCP

Signature of Participant____ Date ____________

Researcher/ Delegate’s Signature _________________________________Date ___________

SUMMARY OF FINDINGS: Would you like to be contacted by a student research assistant with a summary of the overall findings of this study? ☐ YES ☐ NO

If yes, please complete the following:

Name: ____

Phone Number: ______________________________________

Email Address: ______________________________________

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MANAGEMENT

319 Max Bell Centre
University of Manitoba
Winnipeg, MB R3T 2N2
Telephone (204) 474-8773
glazebro@cc.umanitoba.ca

ASSENT

The effects of changing task difficulty in a goal-directed reach task in adults diagnosed with HCP

PRINCIPAL INVESTIGATOR:

Dr. Cheryl Glazebrook
Faculty of Kinesiology & Recreation Management
Health, Leisure, & Human Performance
Research Institute
University of Manitoba
(204) 474-8773
Cheryl.glazebrook@umanitoba.ca

Student Research Assistants:

Jacqueline Ladwig-Davidson, Niyousha Mortaza, Kayla Duna, Ilana Naiman, Bayonle Olakadun
Perceptual Motor Behaviour Lab
Rm 234, Investors Group Athletic Centre
Faculty of Kinesiology & Recreation Management
University of Manitoba
(204) 480-1487
ladwigj@myumanitoba.ca

SOURCE OF SUPPORT: NSERC Discovery Grant

WHY ARE YOU HERE? We are interested in better understanding how you reach for objects with different levels of difficulty from a seated position. This form will explain the study and your role as a participant. If there is anything you do not understand, please ask your parent, your guardian, or the study staff.

WHY ARE THEY DOING THIS STUDY? We are doing this study to see how you perform reaching movements with and without hearing a rhythm before or during a movement, and how your posture might change during the movement. We want to learn about how you perform these tasks so that we can help design new activities and programs. You can choose to do one, more, or none of the activities that we tell you about.

WHAT WILL HAPPEN? If you participate in this study the following will happen:

1. We will ask to place a sensor at the base of the front of your neck so we can record body movements. If needed, the sensor will be secured with medical tape.

2. We will ask to put a small marker on your index finger, wrist, elbow and shoulder of each arm so that we can record your arm movements. These will be attached by tape and secured by a soft band wrapped loosely around your arm.

3. You will be asked to perform a reaching movement with alternating arms, to two different cups placed on a shelf. The study will last 30-60 minutes.

4. You will also be asked to complete a survey and a questionnaire, which your guardian may assist you with if necessary.

5. <u>**You may ask for a break at any time**</u>, you will also be offered a break approximately every 15 minutes.

6. Parents/guardians or support workers may be present for the study.

WHAT IF I HAVE QUESTIONS? You can ask questions at any time before, during or after the study.

WHO WILL KNOW WHAT I DID IN THE STUDY? All of the information you give to the study staff will be kept confidential. Only the researchers will be able to look at any of the information you provide to us. After today your personal information will be referred to by a participant number so your information and results will be kept confidential.

DO YOU HAVE TO BE IN THE STUDY? If at any point in time you decide that you do not want to participate in this study please let the research staff and/or your guardian/Substitute Decision Maker know.

DO YOU HAVE ANY QUESTIONS AT THIS TIME?

PARTICIPATION ASSENT

Research Study: The effects of changing task difficulty in a goal-directed reach task in adults diagnosed with HCP

I want to take part in this study and understand that I can change my mind at any time.

Name of participant (print): ______________________________________

Verbal assent given Yes ☐

___________________________________ ___________ _______________

Signature of Participant Age Date

OR

____ _______________

Signature of Guardian or Substitute Decision Maker Date

SUMMARY OF FINDINGS: Would like to be contacted with a summary of the overall findings of this study? ☐ YES ☐ NO

If yes, please complete the following:

Name: ____

Phone Number: ____

Email Address: ____

For the research assistant:

Printed name of research staff obtaining assent ______________________________________

Signature ______________________________________

Date __________________

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AND RECREATION
MANAGEMENT

319 Max Bell Centre
University of Manitoba
Winnipeg, MB R3T 2N2
Telephone (204) 474-8773
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INFORMED CONSENT (Guardian/Substitute Decision Maker)

The effects of changing task difficulty in a goal-directed reach task in adults diagnosed with HCP

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INFORMED CONSENT - Guardian/Substitute Decision Maker

Research Study: The effects of changing task difficulty in a goal-directed reach task in adults diagnosed with HCP

Signature of Participant____ Date ____________

AND/OR

Signature of Guardian / Substitute Decision Maker ____________________________________

Relationship ____ Date_____________

Researcher/ Delegate's Signature __________________________________Date ___________

SUMMARY OF FINDINGS: Would like to be contacted with a summary of the overall findings of this study? ☐ YES ☐ NO

If yes, please complete the following:

Name: ____

Phone Number: ____

Email Address: ____