Effects of Concentric Unilateral Training Utilizing an Isokinetic Dynamometer on Functional Outcomes and Lower Limb Muscular Power in Subacute Hemiparetic Individuals: A Case Series

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SUPERVISORY AND EXAMINING COMMITTEE

Pai-Chun Wu, candidate for the degree of Master of Science in Kinesiology & Health Studies**,** has presented a thesis titled, ***Effects of Concentric Unilateral Training Utilizing an Isokinetic Dynamometer on Functional Outcomes and Lower Limb Muscular Power in Subacute Hemiparetic Individuals: A Case Series,*** in an oral examination held on July 22, 2021. The following committee members have found the thesis acceptable in form and content, and that the candidate demonstrated satisfactory knowledge of the subject material.

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Abstract

Background. Stroke is a serious medical condition that is characterized by subsequent neurological deficits due to disruption in the brain vasculatures. Manifestation of neurological deficits varies between individuals and is highly dependent on the location, severity, and duration of the stroke. Neurological deficits and negative signs of upper motor neuron syndromes such as lower limb weakness, impaired inter-limb coordination, and greater fatigability may affect one’s rehabilitation outcome and ability to perform activities of daily living. Application of resistance training programs into post stroke (chronic and subacute) individuals’ exercise routine has been shown to increase functionality and improve both muscle function and mass. Unlike traditional resistance training exercises (e.g., free weights, weight stack machine), an isokinetic dynamometer is a safer and better option as it provides accommodating resistance that is equivalent to the force applied by the participant throughout a range of motion under a set angular velocity. *Objective.* The purpose of this study was to examine the effects of concentric lower limb isokinetic resistance training on tasks of functionality, muscular power, and neuromuscular activation and fatigue in individuals with sub-acute stroke (3-6 months). *Method*. Two participants were recruited through the Wascana Rehabilitation Centre and Regina General Hospital (Neuroscience Unit). Both participants completed four weeks of high intensity lower limb resistance training utilizing an isokinetic dynamometer. The program included hip flexion, knee flexion/extension, and ankle dorsiflexion/plantarflexion exercise at two different angular velocities (60°, 120°). Physiological and functional outcome testing was performed at baseline and again upon completion of the training program. Physiological testing was concurrently assessed using isokinetic dynamometry (muscular power) and surface electromyography (neuromuscular activation and fatigue) of the knee extensors and flexors. Functional outcome testing assessed gait velocity, gait endurance, balance, and transfer tasks. *Results*. After completion of the program, both participants demonstrated general improvements in paretic limb muscular power and time to peak power at both velocities in most of the tested muscles post-intervention. Although Participant 1 demonstrated higher neuromuscular activation in the knee flexors on his paretic side, both participants showed a general trend for decreased neuromuscular activation in most of the muscles tested post-intervention. Neuromuscular fatigability was decreased post-intervention in the paretic knee flexors for Participant 1 and in the paretic and non-paretic extensors for Participant 2; all other muscles showed either no change or an increase in neuromuscular fatigability post-intervention. Both participants improved their walking speed and endurance post-intervention, with the improvement in walking speed being deemed clinically important for Participant 2. No changes were found in dynamic balance ability, but the confidence in performing activities without losing balance improved in both participants. Stroke Impact Scale scores improved in almost all domains in both participants. *Conclusion*. Isokinetic-based, concentric-only resistance training of the paretic limb may have benefits in improving specific physiological and clinical outcomes in individuals with sub-acute stroke. Future studies are required to assess the influence of natural history on such improvements, compare the relative efficacy of concentric-only vs. eccentric-only isokinetic-based training programs, and determine whether a particular set of training parameters (e.g., duration, volume, intensity) leads to the best outcome for post stroke individuals.

Keywords: **Stroke, Isokinetic Dynamometer, Resistance Training**

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List of Abbreviations

Activities-Specific Balance Confidence (ABC)

Activities of Daily Living (ADLs)

Anterior Cerebral Arteries (ACA)

Anterior Choroidal Arteries (AChA)

Anterior Communicating Arteries (ACOM)

Berg Balance Scale (BBS)

Blood Pressure (BP)

Cardiovascular Diseases (CVD)

Central Nervous System (CNS)

Central Pattern Generators (CPGs)

Computed Tomography (CT)

Concentric-only Group (CON)

Corticobulbar Tract (CBT)

Corticospinal Tract (CST)

Delayed-Onset Muscle Soreness (DOMS)

Eccentric-Only Group (ECC)

Electromyography (EMG)

Heart Rate (HR)

Internal Carotid Arteries (ICA)

Intracerebral Hemorrhagic Stroke (ICH)

Isokinetic Dynamometer (ISD)

Magnetic Resonance Imaging (MRI)

Manual Muscle Testing (MMT)

Maximum Voluntary Isometric Contraction (MVIC)

Middle Cerebral Artery (MCA)

Minimal Clinically-Important Difference (MCID)

Modified Rankin Scale (MRS)

Movement-Related Cortical Potential (MRCP)

National Institute of Health Stroke Scale (NIHSS)

Negative Potential (NP)

Posterior Cerebral Arteries (PCA)

Posterior Communicating Arteries (PCOM)

Positive Potential (PP)

Range of Motion (ROM)

Resistance Training (RT)

Reticular Activating System (RAS)

Root Mean Square (RMS)

Six-Minute Walk Test (6MWT)

Subarachnoid Hemorrhage Stroke (SAH)

Submaximal Voluntary Isometric Contraction (sub-MVIC)

Supplemental Motor Area (SMA)

Timed Up and Go (TUG)

Wascana Rehabilitation Centre (WRC)

10-Metre Walk Test (10MWT)

1. Introduction

Stroke is a global health burden in both young and aging populations in many industrialized countries. In 2013, stroke was the second most common cause of mortality worldwide (11.8% of all deaths) and third most common cause of disability (Feigin, Norrving, & Mensah, 2017). While both stroke mortality and disability-adjusted life years rates had declined when compared to the data from 1990, the number of people who suffered a stroke and/or acquired disability due to stroke has significantly increased (Feigin et al., 2017). Stroke can be categorized into two main pathologies, ischemic or hemorrhagic. Ischemic strokes are more common and often are less severe than hemorrhagic strokes. Since the clinical presentation of post stroke syndromes is highly dependent on the mechanism, location, duration, and severity of the stroke, sensory and/or motor deficits that manifest post infarction are often different from one patient to another. While efficient acute management and increased awareness lead to greater clinical outcomes, many post stroke individuals still encounter difficulties with daily tasks due to the neurological conditions that manifest as a result of the infarction.

The main outcome goal for both the practitioner and patient is to restore the ability to perform many activities of daily living (ADLs). Motor control deficits (e.g., hemiparesis, spasticity) are common and major contributors in limiting the performance of ADLs and walking ability post stroke. Lower limbs weakness may manifest post stroke and correlates with reduced gait velocity and limitation to other ADLs (e.g., static standing performance, transfer tasks, stair climbing). Other post stroke symptoms (e.g., abnormal motor unit recruitment, muscle synergies, and muscle contracture) can also manifest to complicate the functional rehabilitation process.

As paresis negatively affects motor rehabilitation, strength training interventions are commonly applied to regain both strength and mobility post stroke. Different styles of strength training in paretic individuals include functional electrical stimulation, resistance tubing, or a typical weight stack resistance machine (Wist, Clivaz, Sattelmayer, 2016). Application of an isokinetic dynamometer (ISD) is common in both athletic and recreational populations for treating osteo-articular disorders (e.g., ACL rehabilitation) and has recently gained more popularity in stroke populations (Hammami et al., 2012). The main feature of ISD is to equalize the amount of force that is applied to the force pad (by the participant) at a criterion speed, and its use has been deemed both safe and effective in post stroke individuals (Hammami et al., 2012). With the dynamometer, the practitioner is able to manage the exercise protocols based on the needs of the individual (e.g., setting criterion speed or the contraction mode of the exercise).

Previous studies found ISD-based resistance training (RT) to be effective at improving physiological and clinical outcomes in individuals with chronic stroke. However, there is limited research on the use of ISD-based RT training in individuals with sub-acute (3-6 months) stroke, and the effects of this training method on clinical outcomes (e.g., walking capacity, dynamic balance). Therefore, the purpose of this study was to discover the effects of a four-week ISD-based RT training program targeting the paretic limb on physiological and clinical outcomes in individuals with sub-acute (3-6 months) stroke. We hypothesized that this intervention would lead to significant improvements in all outcomes.

2. Literature Review

2.1 Pathophysiology of Stroke

2.1.1. Overview of Stroke

Stroke is a condition characterized by subsequent neurological deficits due to an acute injury to the central nervous system (CNS), which is often caused by disruption in the brain vasculatures (Sacco, et al., 2013). Stroke is a serious neurological condition, and the leading cause of adult disability worldwide, and also one of the main causes of mortality in both younger and aging populations in developed countries (Feigin, Lawes, Bennett, Zorowitz, & Anderson, 2003). If one survives a stroke, neurological deficits due to the infarction (i.e., loss of blood supply) may lead to long term disability, which can be taxing on the patients, families, and the health care system (Feigin et al., 2003). Strong and colleagues (2007) estimated that approximately 16 million individuals experienced their first ever infarction in 2005, and predicted that this will increase to 77 million individuals by the year 2030. However, the prevalence of stroke is complex to measure, since most data are reported from cross-sectional surveys, cohort studies, or through estimation from follow up studies, and international data may not be generalizable as reported data largely varies between countries (Feigen et al., 2003). Through eight population studies, Feigin and colleagues (2003) were able to compile and report the proportion of the stroke subtypes that occurred in these studies, with ischemic stroke (67-81%) being more common than hemorrhagic stroke (7-21%).

Based on the location, severity, and duration of the infarction, neurological deficits vary largely in post stroke individuals in that some may require greater duration and more intensive rehabilitation modalities, while others do not. Thus, it is essential for health care providers to gain an accurate prognosis of recovery post stroke, for the sake of individualizing their rehabilitation and to avoid maladaptive plasticity, as this was found to be a potential source that can worsen one’s recovery (Brewer, Horgan, Hickey, & Williams, 2013; Takeuchi & Izumi, 2012; Harvey, Macko, Stein, Winstein, & Zorowitz, 2008). Other factors may also influence the recovery outcome of rehabilitation (e.g., the age of the patient). Kugler et al. (2003) reported that relative functional improvement decreased with greater age and younger patients exhibited a slightly faster functional recovery. Additionally, while younger individuals with stroke show a more complete recovery, age itself is a poor predictor of functional recovery after stroke as older individuals do recover.

2.1.2. Anatomy of the Brain and Blood Supply

During stroke care and rehabilitation, patients are being examined as the health care providers identify the impairments that may cause certain neurological deficits, in order to better individualize their rehabilitation plan (Harvey et al., 2008). Thus, a thorough understanding of neuroanatomy is warranted as an assistance for the practitioner to increase their accuracy of assessment and to individualize their rehabilitation plan based on the type of injury (Harvey et al., 2008).

An adult brain contains four major anatomical parts: cerebrum, brain stem, diencephalon, and cerebellum. The cerebrum is the largest region of the brain and governs many functions, such as the performance of ADLs, thoughts, emotions, communication, and learning (Tortora & Derrickson, 2013). Separated by the longitudinal fissure, the cerebrum is divided into right and left hemispheres, where each hemisphere is responsible for certain functional tasks. The left hemisphere is generally considered as the dominant hemisphere and associated with tasks that involve language and critical thinking, while the non-dominant hemisphere is generally considered to relate to tasks that require spatial orientation and visual comprehension. Each cerebral hemisphere is divided into four lobes that can be categorized by their functions: the frontal lobe is generally responsible for motor functions, while the temporal, occipital, and parietal lobes are more involved with sensory functions (Tortora et al., 2013). Actions such as mobility, object manipulation, eye movement, and verbal communication are all governed by the frontal lobe with assistance from the basal ganglia and the cerebellum (Tortora et al., 2013). Next, actions that involve sensory input will involve the visual, auditory, and somatosensory areas of the cerebrum, which are coordinated by the thalamus, parietal, occipital, and temporal lobes (Tortora et al., 2013). While the frontal lobe may be more involved with motor functions, it is crucial to note that significant and rich connections are formed between the frontal lobe systems and the primary sensory areas, and connections exist between various motor areas, motor cortex, basal ganglia, cerebellum, thalamus, superior and inferior colliculi, and several descending spinal tracts (Harvey et al., 2008).

While the cerebrum is responsible for many higher brain functions, the brain stem is also crucial for survival since this part of the brain regulates heart rate, blood vessel diameter, and one’s breathing pattern (Tortora et al., 2013). The brainstem is located between the spinal cord and the diencephalon, and is composed of three structures: medulla oblongata, pons, and midbrain (mesencephalon). The medulla contains many cranial nerve nuclei that relate to functions such as equilibrium, audition, coughing, and many other sensory functions (Young et al., 2008; Tortora et al., 2013; Waxman, 2008). Within the white matter of the medulla, fibers of the ascending (sensory) and descending (motor) tracts pass through as they connect areas of the brain to the spinal cord (Tortora et al., 2013; Young et al., 2008). The pons is vital for one’s survival as its nuclei are necessary for the coordination of the motor output to the rest of the body

(Waxman, 2008; Young et al., 2008). Nuclei located in the pons, especially at the pneumotaxic and apneustic areas are critical for controlling breathing, with the assistance from the medullary rhythmicity area (Harvey et al., 2008). Several descending and ascending pathways that extend from the brainstem to the spinal cord also travel through the pons (Waxman, 2008). For instance, at the base of the pons, fiber bundles of the corticospinal tract (CST) and pontine nuclei may project to the cerebellum for the initiation and correction of movement, and nearby serotonin releasing neurons (raphe nuclei) govern one's level of arousal, sleep-wake cycle, and nociceptive inputs (Waxman, 2008; Young et al., 2008). Additionally, the pons contains several cranial nerve nuclei, such as the trigeminal (V), abducens (VI), and facial (VII) nerves, to thus assist in tasks such as eye movement, mastication, facial expression, and many other sensory and motor functions (Waxman, 2008; Young et al., 2008).

While the pons is essential for certain sensory functions, the midbrain is essential for finer motor movements such as visual- and auditory-mediated activities (Tortora et al., 2013; Young et al., 2008). Some nuclei of the midbrain also are important in terms of dopamine release, to assist in controlling subconscious muscle activities (Waxman, 2008; Tortora et al., 2013). Located in the tegmentum of the midbrain, the red nuclei receive inputs from the motor cortex and the cerebellum to control flexor muscle activity via the rubrospinal tract (Young et al., 2008; Waxman, 2008). Next, a network of neurons extending from the superior part of the midbrain, through the brain stem to the inferior part of the medulla oblongata, is known as the reticular formation (Young et al., 2008; Waxman, 2008; Tortora et al., 2013). The nuclei that are involved with the ascending pathways from the reticular formation are known as the reticular activating system (RAS) (Young et al., 2008). The RAS contains neurons that are connected to the cerebral cortex, both directly and indirectly through the thalamus, which modulate the conscious perception of certain sensations (e.g., pain) as well as an individual’s level of alertness and consciousness (Young et al., 2008; Waxman, 2008). The descending pathways from the RAS are connected to the cerebellum and the spinal cord, and help control muscle tone through the extrapyramidal motor tracts (Tortora et al., 2013; Young et al., 2008; Waxman, 2008).

The cerebellum is located in the inferior and posterior portion of the cranial cavity, and contains the cerebellar cortex and the cerebellar white matter (Waxman, 2008). While the size of the cerebellum accounts for a small part of the brain mass, it contains almost half of the neurons that are present in the brain. The cerebellum does not initiate movement, but rather fine tunes the input from cerebral motor areas to precisely coordinate and sequence one’s movement (Tortora et al., 2013). Between the pons and the cerebellum, three paired cerebellar peduncles conduct impulses between the cerebellum and other parts of the brain (Waxman, 2008; Young et al., 2008). The superior cerebellar peduncles conduct impulses from the cerebellum to the red nuclei of the midbrain and also some nuclei of the thalamus (Waxman, 2008; Young et al., 2008). This pair of peduncles is crucially involved with coordinating the movements of the ipsilateral arm and leg. Some of these fibers cross in the caudal midbrain and extend to the ventral-lateral and ventral-anterior thalamic nuclei, and thus may also affect the contralateral side of the body since the ventral-lateral and ventral-anterior nuclei project to the motor cortex (Young et al., 2008; Hans, 2011). Of the three pairs of cerebellar peduncles, the middle cerebellar peduncles are the largest as they receive input from the pontine nuclei (nuclei of the pons that receive input from the motor cortex) (Young et al., 2008; Waxman, 2008). The inferior cerebellar peduncles contain axons of several tracts that are involved in different functions, including input and output connections with the vestibular nuclei (brainstem) and tracts that assist in proprioception of the trunk, limbs, and neck (Tortora et al., 2013; Waxman, 2008).

The basal ganglia are a group of nuclei located in the deep cerebral hemispheres that are crucial for one's motor control, motor learning, executive functions, behavior, and emotional control (Lanceigo, Luquin, & Obeso, 2012; Young et al., 2008). Functionally, the basal ganglia consist of the corpus striatum, the subthalamic nucleus, and the substantia nigra (Waxman, 2008; Young et al., 2008). Several related nuclei also reside in the diencephalon (subthalamic nucleus), mesencephalon (substantia nigra) and the pons (pedunculopontine nucleus) (Lanceigo et al., 2012). The corpus striatum is composed of the caudate nucleus and the putamen (Young et al., 2008; Waxman, 2008). Neurons that reside within the striatum are mostly (90%) medium spiny neurons (GABAergic neurons) that project to the lateral and medial portions of the globus pallidus, and the substantia nigra pars reticulata (Young et al., 2008; Lanciego et al., 2012; Purves, Augustine, & Fitzpatrick, 2001). The lentiform nucleus is composed of segments of the putamen and globus pallidus; the body of the nucleus is separated from the thalamus by the posterior limb of the internal capsule and is separated from the head of the caudate nucleus by the anterior limb of the internal capsule (Young et al., 2008; Purves et al., 2001). The subthalamic nucleus accounts for a majority of the mass of the subthalamus, which is located ventral to the thalamus (Young et al., 2008). Dorsal components of the subthalamic nucleus are associated with motor functions, while the ventral and medial components may be more involved with cognitive and behavioral functions (Weintraub & Zaghloul, 2013; Hamani, Saint-Cyr, Fraser, Kaplitt, & Lozano, 2003). Lastly, the substantia nigra is a nucleus that extends into the midbrain and may be divided into a compact part (often associated with Parkinson's disease as its function is to activate the striatum), and a reticular part (considered a processing center in the basal ganglia as its GABAergic neurons transmit signals to the thalamus and superior colliculus) (Young et al., 2008).

A complex input and output network is established in order for the basal ganglia to execute many of their functions. The main source of input to the basal ganglia is the striatum, which receives input from most of the cortical areas other than the primary visual and auditory cortices (Purves et al., 2001; Waxman, 2008). The thalamic nuclei, substantia nigra, amygdala, hippocampus, and raphe nuclei also provide input to the striatum (Purves et al., 2001; Waxman, 2008). The globus pallidus is the major output source of the basal ganglia (Purves et al., 2001; Waxman, 2008). Importantly, the basal ganglia can either enable or inhibit motor movements based on several feedback loops (Young et al., 2008; Waxman, 2008; Purves et al., 2001). Activation of a "direct pathway" causes the inhibition of internal pallidal neurons, which leads to a disinhibition of thalamic neurons and thus facilitates the activation of cortical neurons (Young et al., 2008; Waxman, 2008). On the contrary, activation of an "indirect pathway" causes the activation of the internal pallidal neurons, which leads to an inhibition of thalamic neurons and thus inhibits the activation of cortical neurons (Young et al., 2008). It is crucial to note that both the direct and indirect pathways work in parallel to thus regulate desired or unwanted movements (Young et al., 2008).

The internal capsule is a white matter structure that is located lateral to the diencephalon, where it contains anterior and posterior limbs and the genu, through which many ascending and descending axons pass (Purves et al., 2001; Young et al., 2008). The anterior limb of the internal capsule separates the lenticular nucleus from the caudate nucleus and contains thalamocortical and frontopontine fibers (Waxman, 2008; Young et al., 2008). The posterior limb separates the thalamus and the lenticular nucleus and contains major pathways such as the corticobulbar tract (CBT) and the CST (which innervate the facial, arm, and leg muscles), and thalamocortical projections from the motor ventral-anterior and ventral-lateral complex and the somatosensory ventral-posterior lateral and ventral-posterior medial complex (Waxman, 2008; Hans, 2011; Young et al., 2008).

2.1.3. Functional Areas of the Cerebrum

The cerebrum consists of many functional areas (Young et al., 2008). The primary somatosensory cortex (S1; areas 3, 1, 2) is located in the postcentral gyrus behind the motor cortex and receives somatotopic input from the ventral-posterior lateral and ventral-posterior medial nuclei of the thalamus (Waxman, 2008; Young et al., 2008). This area is responsible for receiving input related to tactile and proprioceptive information from the contralateral side of the body (Waxman, 2008; Young et al., 2008). The secondary somatosensory cortex (S2; area 40) is located in the inferior parietal lobe (Swenson, 2006; Young et al., 2008). S2 is considered to have both motor and sensory functions as this area covers a portion of the adjacent frontal and parietal lobes (Swenson, 2006). The primary gustatory cortex is located in the parietal operculum (area 43), where it represents the main sensory and motor functions of the tongue (Young et al., 2008). As part of the parietal association area, the superior and inferior parietal lobules give rise to areas 5 and 7 (Young et al., 2008; Swenson, 2006). Area 5 receives input from S1, while area 7 may receive input from both visual and motor areas and is involved with the control of eye movements (Young et al., 2008). The inferior parietal lobe also includes the supramarginal gyrus (area 40) and the angular gyrus (area 39), which are both able to assist S1 with the interpretation of tactile and proprioceptive information (Swenson, 2006; Young et al., 2008). Areas 5, 7, 39, and 40 are pivotal for performing tasks in a sequence, and a lesion to the parietal association area may lead to hemineglect of one side of the body and surroundings that is contralateral to the lesion (Young et al., 2008; Swenson, 2006).

The primary visual (striate) cortex (V1; area 17) is located in the medial surface of the occipital lobe on either side of the calcarine fissure (Waxman, 2008; Harvey et al., 2008). V1 projects to the cortical areas that surround it, which are known as the visual association areas (V2, V3; areas 18 and 19). Aside from receiving direct information from the visual cortex, areas 18 and 19 may receive inputs from the lateral geniculate body of the thalamus to assist with visual association (color and movement recognition) (Waxman, 2008; Swenson, 2006; Young et al., 2008). The primary auditory cortex (A1; area 41) is located in the transverse temporal gyrus, and receives input from the cochlea to allow the individual to differentiate between sounds of varied tone (Young et al., 2008; Swenson, 2006, Waxman, 2008). Adjacent to area 41 is the secondary auditory area (area 42), which assists in distinguishing noises of varying pitches such as humming or whistling (Waxman, 2008; Young et al., 2008).

As described in the previous section, the dominant hemisphere, which is the left hemisphere for most right handed individuals and over 50% of left handed individuals, is generally responsible for higher functions such as language production, emotional and intuitive thinking, and many other functions (Young et al., 2008). The language area contains two main regions: Broca's area (areas 44 and 45) and Wernicke's area (area 22) (Young et al., 2008; Waxman, 2008). Broca's area is usually located in the inferior frontal gyrus, and is involved with the motor and expressive language center (Young et al., 2008). Wernicke's area is located in the superior temporal gyrus and is involved with language comprehension (Young et al., 2008; Waxman 2008).

The motor cortex is an integral part of the cerebral cortex responsible for planning, controlling, and initiating voluntary movements. The primary motor cortex (M1; area 4) is located in the precentral gyrus, and is the main contributor to voluntary movements of the body as it contains the pyramidal neurons whose axons form the CST (Harvey et al., 2008; Waxman, 2008). The premotor cortex (M2; area 6) lies directly anterior to the primary motor cortex and may be divided into three areas: the supplementary motor area (SMA) (areas F3 and F6) located on the medial side of the hemisphere, the dorsal-lateral motor cortex (areas F2 & F7) located on the dorsal-lateral convexity, and the ventral-lateral motor cortex (areas F4 & F5) located on the ventral-lateral convexity (Waxman, 2008; Swenson, 2006). The premotor cortex receives input from the sensory association cortex and the basal ganglia through the ventral-anterior and ventral-lateral nuclei of the thalamus (Swenson, 2006).

2.1.4. Pyramidal Descending Tracts

Motor neurons involved with voluntary movements may be categorized as either "upper motor neurons" (which transmit signals from the cortex to the brainstem/spinal cord) or "lower motor neurons" (which transmit signals from the brainstem/spinal cord to skeletal muscles). Lower motor neurons can be further divided into alpha motor neurons (which innervate extrafusal skeletal muscle fibers) and gamma motor neurons (which innervate intrafusal skeletal muscle fibers) (Young et al., 2008). The upper motor (pyramidal) neurons are the excitatory cells that are located in the precentral gyrus and the anterior portion of the paracentral lobule, which are responsible for initiating and regulating voluntary movements on the contralateral side of the body (Young et al., 2008). Approximately 90% of the pyramidal neurons cross over to the opposite side at a junction just superior to the medulla, while the remaining 10% cross over at their target spinal cord segment. This decussation (crossing) of the pyramidal neurons explains how one side of the brain generally controls voluntary movements on the opposite side of the body.

The axons of the pyramidal neurons form two main descending tracts: the CST and the CBT. The CST originates from the primary motor cortex (M1), the primary somatosensory cortex (S1), the premotor areas, and the posterior portion of the paracentral lobule (Young et al., 2008). CST neurons that are responsible for upper limb movements are located in the more dorsal parts of the precentral gyrus, while those responsible for lower limb movements are located in the anterior portion of the paracentral lobule (Young et al., 2008). As the CST fibers travel through the cerebral white matter, they descend through the corona radiata, the posterior limb of the internal capsule, and the cerebral crus (Young et al., 2008). The CST separates into bundles of fibers at the caudal end of the midbrain before entering the pons (Young et al., 2008). The CST fibers that cross over in the brainstem form the lateral CST (which descends through the lateral funiculus of the spinal cord), while the uncrossed CST fibers form the ventral CST (which descends through the anterior funiculus) (Young et al., 2008; Waxman, 2008). Lateral CST fibers are generally responsible for controlling limb muscles, while anterior CST fibers are more responsible for controlling trunk muscles (Waxman, 2008; Waldman, 2009).

The other major pyramidal descending pathway (CBT) is formed by upper motor neurons located in the ventral portion of the precentral gyrus (Young et al., 2008; Rea, 2011). Along with the CST, the CBT also descends through the corona radiata and the internal capsule (Young et al., 2008; Rea, 2015). The CBT fibers terminate within the brainstem and connect with the lower motor neurons of several cranial nerves (e.g., trigeminal, facial, vagus, hypoglossal, and accessory nerves) (Young et al., 2008; Rea, 2015). Additionally, although some CBT fibers decussate like the fibers of the CST after passing through the internal capsule and the cerebral peduncle, some CBT fibers do not cross over to the opposite side of the body before connecting to lower motor neurons (Young et al., 2008). CBT fibers are essential for controlling the muscles of the face, tongue, jaw, and pharynx, and allow an individual to perform tasks such as mastication, speech, deglutition, and phonation (Young et al., 2008; Rea, 2015).

2.1.5. Extrapyramidal descending tracts

Aside from the main descending tracts (CST, CBT), motor pathways may also arise from the red nuclei, the tectum of the midbrain, the reticular formation, and the vestibular nuclei of the brain stem (Waxman, 2008). The rubrospinal tract originates in the red nucleus and decussates in the ventral tegmental decussation before entering the spinal cord (Waxman, 2008; Siegel & Sapru, 2006). The rubrospinal tract receives afferent input from the contralateral deep cerebellar nuclei and from the motor cortex of both hemispheres (Waxman, 2008). As this pathway is functionally parallel to the CST, its functions involve excitation of the flexor muscles (especially of the upper limbs) and inhibition of the extensor muscles, which is opposite to the functions of the pontine reticular neurons that are also under the influence of the cerebellum (Waxman, 2008; Young et al., 2008; Siegel et al., 2006).

The reticulospinal tract originates from the reticular formation of the brainstem, especially of the pons and the medulla oblongata (Sengul & Watson, 2015). The reticulospinal tract can be divided into two main tracts, based on the region of the brain stem that each tract arises. The lateral reticulospinal fibers originate from the medullary reticular formation and descend bilaterally in the anterior funiculus; some of the lateral reticulospinal fibers may remain uncrossed and descend ipsilaterally through the lateral funiculus (Young et al., 2008; & Sengul et al., 2015). Fibers of the medial reticulospinal tract arise from the pontine reticular formation and descend ipsilaterally through the anterior funiculus (Sengul et al., 2015; Mtui, Gruener & Fitzgerald 2011). This tract is involved with excitation of extensor muscles and inhibition of flexor muscles, as well as several functions related to posture control and movement preparation (Young et al., 2008; Sengul et al., 2015). The functions of the lateral reticulospinal tract may also include inhibition of the extensor muscles and excitation of the flexor muscles (Young et al., 2008; Waxman, 2008). Thus, as both the reticulospinal and rubrospinal tracts receive input from the cerebellum and cerebral cortex and produce different effects on the flexor and extensor muscles, these tracts may work together for one to perform coordinated and selective movements (Young et al., 2008; Gjelsvik et al., 2016).

The vestibulospinal tract originates from two of the vestibular nuclei that are located in the floor and wall of the 4th ventricle in the rostral medulla and caudal pons (Young et al., 2008; Waxman, 2008). The pathway that originates in the lateral vestibular nuclei is called the lateral vestibulospinal tract, which is thought to excite the extensor muscles of the ipsilateral side and flexor muscles of the contralateral side (Young et al., 2008; Dietz, 1992). The lateral vestibulospinal tract may also affect one's posture during sway and different body movements (Young et al., 2008; Waxman, 2008). The medial vestibulospinal tract originates in the medial and inferior vestibular nuclei and descends through the medial longitudinal fasciculus to affect the muscles of the head, neck, trunk and proximal limbs to maintain an erect posture and also contribute to the stabilization of the eyes during head movements (Gjelsvik et al., 2016; Young et al., 2008). The vestibulospinal tracts also innervate gamma motor neurons within the spinal cord, which may allow them to contribute to either an increase or decrease of muscle tone depending on the movement task (Siegel et al., 2006).

Lastly, the tectospinal tract originates in the superior colliculus and crosses in the midbrain (Waxman, 2008). As the tract descends, it passes through the anterior funiculus and terminates at the cervical levels of the spinal cord (Waxman, 2008). The tract's main function is to control reflex muscle activity of the trunk, neck, and eyes in response to incoming visual stimuli (Waxman, 2008; Li & Francisco, 2015).

2.1.6. Blood Supply of the Brain

Current best practice recommendations are that all patients with suspected acute stroke undergo brain imaging studies with computed tomography (CT) or magnetic resonance imaging (MRI) to evaluate for evidence of ischemic or hemorrhagic lesions. These imaging studies may be further enhanced with contrast to evaluate the structure of the cerebral vasculature, known as angiography (Boulanger et al., 2018). The main arterial supply to the brain is provided by the vertebral arteries and the internal carotid arteries (ICA) via the circle of Willis (*Figure 1*). Each ICA bifurcates into two major terminal arteries: the anterior cerebral arteries (ACA) and the middle cerebral arteries (MCA) (Purves et al., 2001). The right and left vertebral arteries course along the anterior surface of the brainstem and at the level of pons join together to form the basilar artery, which then bifurcates into the posterior cerebral arteries (PCA). Anastomoses are formed between vessels so that blood flow can reach a destination if one vessel is obstructed. For example, the anterior communicating arteries (ACOM) form collaterals between the ACAs to provide alternate routes of blood flow to the anterior regions of the brain, while the posterior communicating arteries (PCOM) form collaterals between the ICA and PCA to provide alternate routes of blood flow to the posterior regions of the brain (Harvey et al., 2008; Purves et al., 2001).

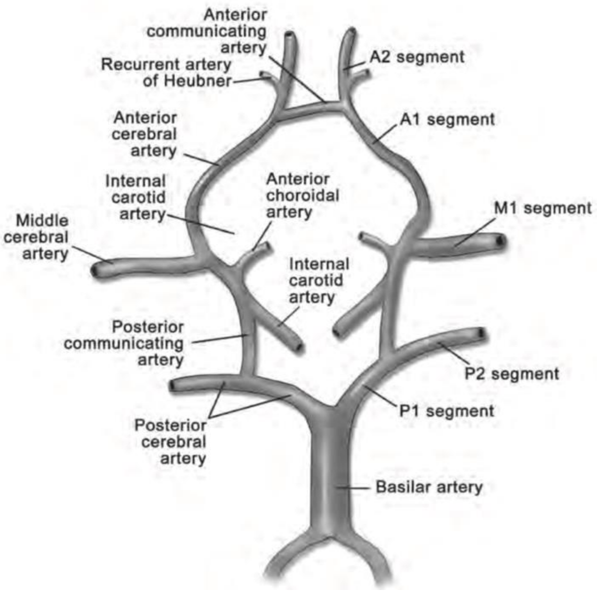

Figure 1. The circle of Willis and associated branches. (Harvey et al., 2008).

2.1.6.1. Anterior Choroidal Artery

The anterior choroidal artery (AChA) provides blood supply to several structures of the brain that are involved with vision and motor control (Hans, 2011). The AChA usually arises from the ICA or the MCA and supplies the optic tract, globus pallidus, anterior hippocampus, portions of the thalamus, deep white matter of the temporal lobe, inferior portion of the posterior limb of the internal capsule, and the choroid plexus of the lateral ventricle (Young et al., 2008; Harvey et al., 2008).

2.1.6.2. Anterior Cerebral Artery

The ACA arises from the ICA and contains three primary segments as it extends in an anterior-medial direction to supply blood to the corpus callosum and medial aspect of the cerebral hemisphere. The A1 segment extends from the ICA to the ACOM and supplies the anterior hypothalamus (Harvey et al., 2008; Young et al., 2008). The A2 segment extends from the ACOM to the bifurcation origin of the pericallosal and callosomarginal arteries. This segment has many perforating branches (e.g., Heubner's recurrent artery, orbitofrontal artery, frontopolar artery) that collectively supply the head of the caudate nucleus, anterior limb of the internal capsule, paraterminal gyrus, and anterior portion of the lentiform (Goetz, 2007; Hans, 2011; Young et al., 2008). The two terminal branches of the A2 segment are the pericallosal artery (A3 segment) and callosomarginal artery. The A3 segment supplies the corpus callosum, septum pellucidum, and fornix (Young et al., 2008; Hans, 2011). The callosomarginal artery supplies the frontal lobe, paracentral area, and anterior portion of the parietal lobe (Hans, 2011).

2.1.6.3. Middle Cerebral Artery

The MCA is the largest branch of the ICA and provides blood to most of the cerebral hemisphere, including the basal ganglia, internal capsule, inferior and lateral portions of the parietal lobe, anterior temporal lobe, frontal operculum and the lateral convexity of the frontal lobe (Harvey et al., 2008; Young et al., 2008). The MCA has four primary segments. The M1 (sphenoidal) segment extends from the ICA to the bifurcation that gives rise to the trunks of the M2 segment and supplies the basal ganglia, internal capsule, and portions of the temporal lobe (Young et al., 2008; Hans, 2011). The M2 segment is composed of superior and inferior trunks that form within the Sylvian fissure and course along the insula (Hans, 2011; Young et al., 2008). The M3 segment is a continuation of the superior trunk within the Sylvian fissure that often includes branches that supply the opercula (Hans, 2011; Young et al., 2008). Lastly, the M4 segments are the terminal arteries that emerge from the Sylvian fissure and course over the convex surface of the cerebral hemisphere supplying portions of the lateral parietal and temporal lobes (Harvey et al., 2008; Hans 2011).

2.1.6.4. Posterior Cerebral Artery

The PCA originates at the terminal branches of the basilar artery, and supplies blood to the occipital lobe and the inferior portions of the temporal lobe (Harvey et al., 2008; Young et al., 2008). Branches of the PCA also extend to supply the thalamus, midbrain, and deeper structures such as the choroid plexus through the posterior choroidal arteries (Young et al., 2008; Hans, 2011). The PCA has four primary segments. The P1 segment extends from the basilar artery to the bifurcation that gives rise to the PCOM and the P2 segment. The P2 segment courses posteriorly around the brainstem and gives rise to branches that supply portions of the temporal lobe (Hans, 2011; Young et al., 2008). The P2 segment also occasionally contains an anastomosis with the ACA to allow collateral circulation between these two arteries. (Young et al., 2008). The P3 (quadrigeminal) segment courses over the posterior-lateral surface of the midbrain to reach the parietal-occipital sulcus near the calcarine fissure where it gives rise to the P4 segment (Hans, 2011). The P4 segment has two terminal branches, the lateral occipital artery that courses over the posterior portion of the parahippocampal gyrus to supply the inferior surface of the occipital lobe, and the medial occipital artery whose branches supply the precuneus and cuneus, as well as the primary visual area in the occipital lobe (Hans, 2011; Young et al., 2008).

2.1.6.5. Vertebral-Basilar System

The vertebral-basilar system consists of the vertebral arteries and basilar artery and forms the posterior part of the circle of Willis. The posterior inferior cerebellar artery branches off the vertebral artery and supplies a portion of the cerebellum (Hans, 2011). The anterior inferior cerebellar artery, pontine arteries, superior cerebellar artery and the PCA branch off the basilar artery and collectively supply portions of the cerebellum, brain stem, and cerebral hemisphere (Hans, 2011).

2.2. Ischemic Stroke

Ischemic stroke is the most common subtype (80-85%) and leads to acute neurological deficits due to the lack of blood and oxygen supply to the brain resulting from a blockage of a blood vessel by a thrombus or embolus (Feigin et al., 2003; Liberato & Krakauer., 2007; Lindsay, Bone, & Fuller, 2010). A thrombus can develop in either a vein or an artery due to an imbalance in the blood coagulation system, which would alter the structure of the vessel wall, increase coagulability, and alter blood flow of the affected site (Mackman, 2008). If the thrombus detaches from the wall of the artery or vein, the plaque would then be considered an embolus, which may block a blood vessel and lead to ischemia, organ dysfunction, infarction, and potentially death (Layker, Tulman, Dimitrova, Pin, & Papadimos, 2013). Several factors may predispose one to a greater risk of stroke, such as hypertension, hyperlipidemia, diabetes mellitus, cardiovascular disease, dysrhythmia, and atherosclerosis, among many other chronic conditions (Liberato et al., 2007; Grau et al., 2001; Kamel et al., 2016). Ischemic strokes are often classified based on their etiology, which allows clinicians to individualize treatment and prognosis for their patients (Liberato et al., 2007). The most common mechanisms of ischemic stroke include large artery atherosclerosis, cardiac embolism, and cryptogenic stroke (Liberato et al., 2007; Grau et al., 2001).

Atherosclerosis, which is one of the most common causes of stroke, is a disease where plaque builds up in the arteries that increases the blood vessel wall thickness and changes the hemodynamics of blood flow (Banerjee, Chimowitz, 2017; Gorelick, Wong, Bae, & Pandey, 2008). Large artery atherosclerosis often occurs without a subsequent embolism and commonly takes place at the bifurcation of larger vessels (e.g., carotid arteries, vertebral-basilar system, the circle of Willis) (Liberato et al., 2007). Infarction of the large vessels can be due to two mechanisms: stenosis at the large vessel by in-situ disease (such as cancer) or local embolism to cause a low flow state (Liberato et al., 2007). These two mechanisms may coexist to result in an infarction; for example, if a stenosis occurs in the MCA, the low-flow rate will likely not allow any thromboembolic substances to be cleared from the distal arterial beds (Liberato et al., 2007; Wang et al., 2002). Atherosclerosis may also take place in smaller arteries, such as the blockage of a single perforating vessel, and lead to a lacunar infarct (Liberato et al., 2007; Grau et al., 2001). Lacunar infarcts account for 10 – 17% of thromboembolic stroke cases and generally lead to five common syndromes: pure motor hemiparesis, pure sensory syndrome, dysarthia/clumsy hand, ataxic hemiparesis, and sensorimotor syndrome (Liberato et al., 2007; Lindsay et al., 2010; Harvey et al., 2008).

Cardioembolic stroke may account for 20 – 40% of ischemic strokes and is commonly associated with the presence of atrial fibrillation cardiac rhythm (Kamel et al., 2016; Liberato et al., 2007). Atrial fibrillation results in incomplete emptying of the atria during a contraction, resulting in pooling of blood which can clot (form a thrombus). The thrombus can mobilize or break off (becoming an embolus) and move through the bloodstream to the brain (Kamel et al., 2016; Healey et al., 2012). For individuals under the age of 55, another cause is often the presence of interatrial septal deformities, such as a patent foramen ovale or atrial septal aneurysm (Liberato et al., 2007; Lindsay et al., 2010). Other uncommon causes include infectious and noninfectious endocarditis, fibroelastoma, and atrial myxoma (Liberato et al., 2007; Lindsay et al., 2010). Emboli often arise from the ICA or aorta, travel into the cranial cavity, and result in an infarction (Lindsay et al, 2010).

Approximately 20 – 40% of ischemic stroke are classified as cryptogenic stroke (Saver, 2016; Sanna et al., 2014; Liberato et al., 2007). While the diagnosis of cryptogenic stroke is often difficult since individuals may not have the risk factors or the imaging characteristics present in other types of ischemic stroke, cryptogenic stroke often presents with less severe neurologic deficits, and is associated with lower mortality and final disability (Saver, 2016; Sanna et al., 2014).

2.3. Hemorrhagic Stroke

Hemorrhagic stroke occurs less frequently (10- 15%), but generally has greater morbidity and mortality rates and a poorer prognosis for recovery at 6 months post stroke when compared to patients with ischemic strokes (Kim & Bae, 2017; Qureshi, Mendelow, & Hanley, 2009; Smith & Eskey, 2011). Hemorrhagic stroke may be categorized into two distinct mechanisms: intracerebral hemorrhagic stroke (ICH) and subarachnoid hemorrhage stroke (SAH) (Smith et al., 2011; Qureshi et al., 2009). The mechanism of ICH involves direct bleeding into the brain parenchyma, while the mechanism of the SAH involves direct bleeding into the cerebrospinal fluid of the subarachnoid space (Smith et al., 2011). A frequent risk factor of hemorrhagic strokes appears to be chronic hypertension, especially in smaller perforating vessels that supply the cerebral lobes, basal ganglia, thalamus, pons, and cerebellum (Smith et al., 2011; Qureshi et al., 2009). Chronic hypertension of the small perforating vessels may cause the development of weaker and more fragile vessels, thus resulting in a greater chance of focal necrosis and rupture of the vessels (Smith et al., 2011; Qureshi, 2009). In patients with hemorrhagic stroke that are due to hypertensive factors, microbleeding may also occur in the small perforating arteries, which tend to lead to chronic and multi-focal signs and symptoms (Smith et al., 2011). Aside from chronic hypertension, other conditions that may cause ICH include cerebral amyloid angiopathy, capillary or venous malformation, brain tumors, and cerebral aneurysm (Smith, et al., 2011; Qureshi et al., 2009). SAH, which accounts for 3 – 5% of all cases of strokes, has a poorer prognosis and higher mortality rate compared to ICH (Smith et al., 2011; Lloyd-Jones, et al., 2009; Bederson et al., 2009). Approximately 85% of SAH is due to a cerebral aneurysm, which tends to occur at either the anterior circulation (origins of PCOM & ACOM) or at the bifurcation of the MCA (Smith et al., 2011; van Gijn & Rinkel, 2001; Rhoton, 2002).

The pathophysiology of hemorrhagic stroke can be differentiated into primary and secondary brain injury (Shi, 2017; Qureshi et al., 2009). Within the first few hours after the onset of bleeding, physical disruption (e.g., imbalanced neurotransmitter release, mitochondrial dysfunction, dysfunctional membrane depolarization) will occur within the affected brain structures (Shi, 2017; Qureshi et al., 2009). Chronic hypertension may contribute to the rate of hemorrhage growth to further worsen the extent of the injury and prognosis (Shi, 2017). After the initial hematoma expansion, secondary brain injury will result from the activation of the coagulation, cytotoxic, excitotoxic, and inflammatory pathways (Shi, 2017). About four hours after the initial injury, the active release of microglia will lead to a breakdown of the blood brain barrier, vasogenic edema, and apoptosis of the neurons and glia cells (Qureshi et al., 2011).

2.4. Stroke Syndromes

Manifestation of the deficits vary greatly in this population since the lesion location, duration, severity, and mechanism can all affect the clinical presentation. A stroke syndrome can be described as a set of signs and symptoms that assist physicians to identify the region of the brain that has been affected. By identifying the lesion location and cerebral territories affected, certain characteristics of the impairments can be expected by the treating therapist. Knowledge and understanding of clinical presentation can improve the therapists' efficiency, accuracy of the neurological assessment, and perhaps the rehabilitation outcome of a patient. Stroke syndromes that arise due to occlusions in the major arteries will be discussed in the next sections.

2.4.1. Anterior Choroidal Artery Syndrome

As mentioned previously, the AChA supplies many structures of the brain through its deep perforating branches, and an injury to the artery may result in severe neurological deficits (Harvey et al., 2008; Bruno, Graff-Radford, Biller, & Adams, 1989). According to a cohort study by Bruno and colleagues (1989), infarction of the AChA is a small vessel disease, where the most important risk factor is chronic hypertension. AChA syndrome often causes sequelae such as aneurysms, Moyamoya disease, and brain tumors. Specifically, if the AChA is occluded, it often results in symptoms such as contralateral hemiparesis, hemianesthesia, and hemianopia (Yu, Xu, Zhao, & Yu, 2018; Liberato et al., 2007). Hemiparesis often manifests if occlusion occurs in this artery since the posterior limb of the internal capsule is supplied by its deep perforating branches (Harvey et al., 2008; Bruno et al., 1989). Hemianesthesia may also take place due to the loss of blood supply to the ventral-posterior lateral nucleus of the thalamus (Bruno et al., 1989). The optic radiation receives blood supply from the AChA, and hemianopia (loss of vision or blindness in half of the visual field) may occur if a lesion occurs to the geniculocalcarine tract in the medial temporal lobe (Helgason, Caplan, Goodwin, & Hedges, 1986; Harvey 2008). Lastly, lesions at the AChA often do not cause any language deficit if the infarct occurs in the dominant hemisphere, but a left hemineglect syndrome may occur if the lesion occurs in the non-dominant hemisphere (Harvey et al., 2008).

2.4.2. Carotid Artery Syndrome

The definite incidence rates of ICA occlusion have not been properly established as it can often remain asymptomatic for the individual (Thanvi & Robinson, 2007). Clinical features of an ICA occlusion are on a spectrum, and can range from a complete asymptomatic occlusion to death (Thanvi et al., 2007). A common symptom to suggest ICA occlusion is transient amaurosis fugax, where visual obstruction, clouding, or fogginess occurs in one or both visual fields (Thanvi et al., 2007). A complete occlusion to the ICA may also cause hemiplegia on the contralateral side of the body (Harvey et al., 2008). Common causes of ICA occlusions include thromboembolism and hemodynamic disturbances (Thanvi et al., 2007). Embolism may occur from either the distal or proximal vessels, or plaques built up in the common carotid arteries or the external carotid artery, which happens to 2/3 of patients with ICA occlusion (Thanvi et al., 2007; Pessin, Hinton, Davis, 1979). Although collateral circulation may help restore blood hemodynamics when cerebral blood flow is compromised, a sudden occlusion of the artery can still result in an infarction (Thanvi et al., 2007; Hartkamp, Macko, Winstein, & Zorowitz, 2008). Large vessel cardiovascular disease can lead to a border zone/ watershed infarction, which occurs between the territories of two non-anastomosing arteries (e.g., between the ACA and MCA territories) (Hans, 2011). Two distinct areas that may encounter this type of infarction are between the cortical territories of the ACA, MCA, and PCA (cortical watershed or external watershed infarction), and in the white matter proximal to the lateral ventricle (subcortical or internal watershed infarction) (Hans, 2011; Zülch, Mennel, & Zimmermann, 1974). Internal watershed infarction may also occur at the junction between the lenticulostriate arteries and the MCA (Mangla, Kolar, Almast, & Ekholm, 2011). Internal watershed infarctions may negatively affect the corona radiata and lead to hemiparesis on the side ipsilateral to the lesion (Hans, 2011; Song, Lee, Park, Yoon & Roh, 2005). External watershed infarctions may cause visual abnormalities due to either a stenosis or occlusion to the occipital horn of the lateral ventricle; infarctions occurring at the anterior border zone between the ACA and MCA may lead to weakness in the arm and thigh (Hans, 2011).

2.4.3. ACA Infarcts Syndrome

Infarctions that occur in the ACA and its branches are quite uncommon when compared to other types of stroke as ACA infarcts accounted for 1.3% of all cases of stroke in a 19 year longitudinal cohort study performed by Arboix and colleagues (2009) in Spain. Arboix et al. (2009) compared their findings with similar studies and concluded that the prevalence may range from 1.1% to 2.3%. While uncommon, patients with ACA infarction often require prolonged rehabilitation due to the physical and cognitive deficits that develop (Harvey et al., 2008; Kumral, Bayulkem, Evyapan, & Yunten, 2002). The ACA supplies areas such as the anterior and medial portions of the frontal lobe, the SMA, and the cortical region for bladder control (Hans, 2011; Harvey et al., 2008; Liberato et al., 2007). A left side infarction often leads to contralateral weakness of the leg and shoulder (sparing the arm and face), transient akinetic mutism (brief reduction of moving or speaking), transcortical motor aphasia, disrupted proprioception, and contralateral deficits in higher order sensory functions (Liberato et al., 2007; Hans, 2011). A right side infarction often leads to acute confusion, motor hemineglect, transient akinetic mutism, contralateral hemiparesis, and contralateral deficits in higher order sensory functions (Liberato et al., 2007; Hans, 2011). Limb apraxia often occurs regardless of the side of the ACA infarction due its supplying the anterior corpus callosum (Harvey et al., 2008). In rare cases, bilateral ACA infarction may occur and leads to persistent akinetic mutism, urinary incontinence, paraplegia, or even tetraplegia (Liberato et al., 2007; Hans, 2011). Although ACA infarction and MCA infarction may present with similar clinical symptoms, assessing for the presence of these distinct syndromes may assist clinicians in distinguishing the location of the infarction (Liberato et al., 2007).

2.4.4. MCA Infarcts Syndrome

The MCA provides roughly 80% of the blood flow to the cerebral hemispheres to supply various structures of the frontal lobe, and lateral portions of the parietal and temporal lobes (Liberato et al., 2007; Warren & Ruppert, 2011). The MCA is a common location for infarctions to occur, and patients tend to have poorer prognosis for recovery and greater risk of mortality (Liberato et al., 2007; Smith et al., 2009). Patients who experience a MCA infarction often become more reliant on care-aids or others to perform ADLs as the MCA supports structures of the cerebral hemisphere that are essential for initiation and preparation of motor functions (Jang, 2012; Liberato et al., 2007). Neurological syndromes that arise from a MCA occlusion vary greatly since occlusion of the MCA may produce more severe neurological signs and symptoms than occlusions occurring in the smaller distal branches that the main MCA supports (Liberato et al., 2007). If an occlusion occurs at the M1 segment of the MCA, it will likely compromise the blood supply to the entire lateral convexity of the cerebral hemisphere (Harvey et al., 2008). Additionally, it may cause significant edema and increased intracranial pressure, and therefore contralateral cerebral injury, uncal herniation, or potentially death (Harvey et al., 2008).

Occlusion of the M1 segment would affect both the medial and lateral lenticulostriate arteries, and may also affect the superior and inferior divisions of the M2 segment (Liberato et al., 2007; Harvey et al., 2008). As the lenticulostriate arteries struggle to receive blood flow from the MCA, structures such as the external capsule, posterior limb of the internal capsule, corona radiata, striatum, and lateral portion of the temporal lobe are affected, leading to a variety of clinical syndromes (Harvey et al., 2008; Liberato et al., 2007). Often, a patient would exhibit contralateral hemiplegia in both the arm and leg, variable severity of abnormal primary sensory functions, dysphagia, and hemianopia (Liberato et al., 2007). Injury to the primary somatosensory cortex and the subcortical sensory tracts cause hemisensory loss and hemianesthesia (Harvey et al., 2008). The geniculocalcarine tract is commonly affected due to the occlusion of the M1 segment, which leads to homonymous hemianopia in the contralateral visual field (Harvey et al., 2008; Young et al., 2008). If the MCA infarction occurs in the dominant hemisphere, language disorders often emerge as Broca’s area, Wernicke’s area, the angular gyrus, and the arcuate fasciculus are affected (Harvey et al., 2008; Hans, 2011). A MCA infarction in the non-dominant hemisphere would lead to severe visual and perceptual deficits, such as the lack of spatial-body orientation and apraxia, and a severe left hemineglect syndrome may arise due to the reduced attention and awareness of the left side of the body (Harvey et al., 2008). Structures of the lateral frontal lobe and the corona radiata may be affected, leading to hemiparesis of the face, arm and leg on the side contralateral to the lesion, forced head and eye deviation towards the side ipsilateral to the lesion, aphasia, and hemineglect (Liberato et al., 2007). Hemiparesis is more pronounced in the face and arm than the leg with an absence of a visual disorder as the internal capsule is generally not affected (Liberato et al., 2007). If the occlusion happens on the dominant superior division of the M2 segment, global aphasia may initially result and later reduce into Broca’s aphasia and speech apraxia (Liberato et al., 2007). However, visuospatial neglect may happen to a small degree if the occlusion occurs on the non-dominant side, and is often less severe when compared to a M1 occlusion (Liberato et al., 2007). If occlusion occurs at the inferior division of the M2 segment, sensory dysfunctions may result due to the hypoperfusion to the lateral temporal lobe, caudal parietal lobe and the angular gyrus (Liberato et al., 2007). Language and behaviour abnormalities are more common if occlusion occurs at the site; however, patients often have a better prognosis for recovery as the area of injury is often small with the absence of major motor and sensory deficits.

2.4.5. PCA Infarcts Syndrome

Infarction of the PCA and its branches are frequently a result of an embolus as the PCA is the terminal branch of the posterior circulation (Liberato et al., 2007). Since the PCA supplies the midbrain, thalamus, and the medial and lateral geniculate bodies, sensory deficits are likely to emerge rather than motor deficits (Liberato et al., 2007; Harvey et al., 2008). Headache, visual field abnormalities, and hemisensory disturbances are the most frequent clinical presentations for patients with PCA infarctions (Liberato et al., 2007).

2.4.6. Lacunar Infarcts Syndrome

Lacunar infarcts are often small in size (2 – 20mm in diameter) and occur in the basal ganglia, internal capsule, thalamus, and pons (Liberato et al., 2007; Harvey et al., 2008). Blockage due to an embolus or arterial narrowing at the small perforating vessels (e.g., the lenticulostriate or thalamostriate arteries) are considered as the main cause of lacunar infarctions (Liberato et al., 2007; Harvey et al., 2008). Clinical studies have identified hypertension and diabetes mellitus as risk factors associated with lacunar infarctions (Fisher, 1982; Arboix & Marti-Vilalta, 2009). The five most common clinical syndromes of lacunar strokes are pure motor hemiparesis, pure sensory syndrome, dysarthia/clumsy hand, ataxic hemiparesis, and sensorimotor syndrome (Liberato et al., 2007; Arboix et al., 2009).

Pure motor hemiparesis is the most common syndrome, which occurs in roughly one third of all patients with lacunar stroke (Arboix et al., 2009). Structures that are commonly affected include the CBT, corona radiata, base of the pons, and posterior limb of the internal capsule (Liberato et al., 2007). Pure motor hemiparesis may involve the face, arm, and leg, while incomplete hemiplegia may involve the face and the arm, or the arm and the leg, to varying degrees, along with spastic dystonia on the affected side(s) of the body (Arboix et al., 2009; Liberato et al., 2007; Harvey et al., 2008). Individuals with pure motor hemiparesis often do not present with any sensory, visual, or language deficits (Harvey et al., 2008; Liberato et al., 2007).

Individuals with pure sensory syndrome present with a sensory deficit and/or paresthesias, and can be due to an infarction of the ventral-posterior medial and ventral-posterior lateral nuclei of the thalamus (supplied by the P2 segment of the PCA), or an infarction of the corona radiata as it may affect the thalamocortical projections (Liberato et al., 2007; Arboix et al., 2009). Some patients that present with pure sensory syndrome may develop chronic post stroke pain syndrome, which involves dyesthesias and parestheshias on the contralateral side of the thalamic lesion, and often occur 6-12 months post stroke (Liberato et al., 2007; Harvey et al., 2008).

A combination of sensory and motor deficits (sensorimotor syndrome) may also emerge in patients with lacunar stroke (Liberato et al., 2007; Arboix et al., 2009). Hemiparesis of the face, arm, and leg, along with mild to severe sensory loss of one side of the body, may develop due to infarction of the ventral-lateral thalamus and descending fibers that pass through the internal capsule (Harvey et al., 2008; Arboix et al., 2009; Liberato et al., 2007). Dysarthia/clumsy hand syndrome is a rare clinical presentation of lacunar stroke, which may be due to an infarction of the anterior limb or genu of the internal capsule, and the base of the pons (Liberato et al., 2007; Arboix et al., 2009). Patients with dysarthia also present with unilateral weakness in the face and the upper limb, but generally have an excellent prognosis for recovery (Arboix et al., 2009; Liberato et al., 2007; Harvey et al., 2008).

Lastly, ataxic hemiparesis is a syndrome that develops from an infarction of the corticopontocerebellar or somesthetic proprioceptive pathways that pass through the posterior limb of the internal capsule, or the base of the pons (Liberato et al., 2007; Arboix et al., 2009). Individuals with ataxic hemiparesis present with ipsilateral limb ataxia or distal leg paresis without facial and arm weakness (Liberato et al., 2007; Arboix et al., 2009).

2.5. Overview of Common Deficits due to Stroke

After an individual has experienced a stroke, their ability to perform ADLs, return to work, or participate in community events is limited (Higginson, Zajac, Neptune, Kautz, & Delp, 2006). Strokes affecting the motor cortex and/or descending motor tracts commonly lead to the development of upper motor neuron syndromes (UMNS). Individuals with UMNS may develop positive and/or negative signs, which will not only substantially limit their ability to perform ADLs, but also complicate their prognosis and process of rehabilitation (Li & Francsico, 2015; Mayer & Esqeunzai, 2003). Positive signs such as exaggerated muscle tone and stretch reflex activity often lead to the development of spasticity (Li et al., 2015; Mayer et al., 2003). Negative signs such as weakness, impaired coordination, and easy fatigability are common and develop secondary to a stroke affecting the motor cortex and/or descending tracts (Li et al., 2015).

2.5.1. Paresis

Paresis (weakness) commonly develops immediately or acutely (from hours to days) after the infarction (Liberato et al., 2007; Andrews & Bohannon, 2002). Pure motor hemiparesis is one of the common syndromes that patients develop after a lacunar infarction and may lead to a loss of motor control of the face, upper limbs, and lower limbs, with or without the development of spastic dystonia (Harvey et al., 2008; Liberato et al., 2007). Post stroke fatigability occurs in 20 - 40% of hemiparetic patients and may interfere with rehabilitation and become an obstacle in stroke rehabilitation (Dobkin, 2008; Park et al., 2009). Particularly in individuals with spastic paresis, increased fatigability may be due to greater work being required by the nervous systems to transmit neuronal information from cerebral regions and the descending pathways when attempting to perform diverse motor tasks (Gracies, 2005). Individuals who are more severely affected by paresis may encounter a longer duration for motor recovery, as the greater fatigability leads to more central fatigue rather than peripheral fatigue, which may impair learning and adaptations (Riley & Bilodeau, 2002). Immobilization, which may develop in the first six hours post-stroke, may increase the rate of muscle atrophy and further complicate recovery (Booth, 1982; Booth & Seider., 1979).

2.5.2. Spasticity

Positive signs of UMNS include exaggerated muscle tone and stretch reflex activity, which lead to spasticity, spastic dystonia, and spastic co-contraction (Francisco & McGuire, 2009; Mayer et al., 2003). A commonly accepted definition for spasticity is “a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex, as one component of the upper motor neuron syndrome" (Lance, 1980; Francisco et al., 2009; Mayer et al., 2003). The reported prevalence of spasticity varies widely, from 19% to 92% of post stroke individuals (Sommerfeld et al., 2004; Malhorta et al., 2011). Spasticity typically emerges anywhere from the first few days to six to twelve months post stroke (Li et al., 2015; Ward, 2012; Balakrishnan & Ward, 2013).

Spasticity, spastic dystonia, and spastic co-contraction may all be explained through two main mechanisms, where the CNS is unable to appropriately process intraspinal stretch reflex activity and/or regulate descending information (Li et al., 2015). Abnormal processing of intraspinal stretch reflex activity may be due to increased sensitivity of muscle spindles, or alterations of the intrinsic properties of the spinal motor neurons resulting in greater motoneuronal excitability (e.g., reduced presynaptic inhibition of Ia afferents, and/or reciprocal inhibition) (Li et al., 2015; Gracies, 2005). Alpha-motoneuron hyperexcitability is considered to be the primary intraspinal alteration in spastic individuals (Li et al., 2015; Katz & Rymer, 1989). Furthermore, the likely mechanism of abnormal intraspinal processing and alpha-motoneurone hyperexcitability is the plastic rearrangement of the CNS secondary to imbalanced excitatory and inhibitory descending input to the spinal reflex circuits (Li et al., 2015; Gracies, 2005). In this instance, accentuated spinal reflex activity alter normal reflexes (e.g., deep tendon reflexes, flexor withdrawal reflexes) and cause the reemergence of primitive reflexes (e.g., Babinski sign) (Sheean & McGuire, 2009; Thibaut et al., 2013).

In addition to exaggerated spinal reflex activity, spasticity is also commonly associated with spastic dystonia at rest or during a motor activity (Sheean et al., 2009). While spastic dystonia may not be directly related to exaggerated spinal reflex activity, contributions from peripheral reflex activity may cause an inability to relax muscles due to tonic muscle contraction (Gracies, 2005; Sheean et al., 2009). In general terms, spasticity occurs during passive movements, but spastic dystonia may occur during both active and passive movements, and interfere with movements such as gait. It should also be noted that spasticity in isolation may not be very disabling, but rather secondary conditions (e.g., soft tissue contracture, spastic co-contraction, spastic dystonia) further challenge the individual during motor tasks (Gracies, 2005; Mayer, 2004).

2.5.3. Abnormal Synergies

Strokes affecting the motor cortex and/or descending pathways may also impair an individual's ability to selectively activate muscle groups, resulting in abnormal coupling of joint movements to make a desired movement more difficult (Neckel, Pelliccio, Nichols, & Hidler, 2006; Brunnstrom, 1970; Ng & Sheperd, 2000; Scherbakob & Doehner, 2011; Shumway-Cook & Woollacott, 2007; Gracies, 2005). For example, abnormal joint coupling in the upper limb has been observed, such as the coupling of elbow flexion and shoulder extension with either internal or external rotation (Twitchell, 1951). Varying degrees of abnormal coupling can also affect the lower limbs, which are grouped into extension or flexion synergies that involve the affected hip, knee, and ankle joints (Neckel et al., 2006; Shumway-Cook et al., 2007). For instance, an extension synergy involves internal rotation, adduction, and extension of the hip, knee extension, and plantarflexion with inversion of the ankle, while a flexion synergy involves external rotation, abduction, and flexion of the hip, knee, and plantarflexion and eversion of the ankle (Waters, Frazier, Garland, Jordan, & Perry, 1982).

2.6. Effects of Stroke on Gait

2.6.1. Central Pattern Generators

Many neurological deficits and conditions often coexist to challenge the rehabilitation process and one's ability to perform ADLs. Frequently, gait rehabilitation is considered the main goal in post stroke individuals with motor deficits (Beyaert, Vasa, & Frykberg, 2015; Dickstein, 2008). Approximately 40% of post stroke individuals require walking assistance and 60% are not able to ambulate within their communities (Verma, Arya, Sharma, & Garg, 2010; Jorgensen, Nakayama, Rasschou, & Olsen, 1995). Moreover, 80% of post stroke individuals experience difficulties with walking three months post infarction (Alguren, Lundgren-Nilsson, & Sunnerhagen, 2010; Duncan, 2005). Post stroke gait dysfunction is also associated with a higher fall incidence, where 14% - 65% of individuals fall at least once during hospitalization and between 37% - 73% fall in the first six months after being discharged from the hospital (Batchelor, Mackintosh, Said, & Hill, 2012; Teasell, McRae, Foley, & Bhardwaj, 2002; Mackintosh, Hill, Dodd, Goldie, & Culham, 2005).

A normal gait pattern can be described as a smooth and rhythmic progression of the limbs, trunk, and pelvis by managing the center of gravity within certain ranges in both sagittal and transverse planes (Mayer, 2002; Beyaert et al., 2015). As simple as the task may seem, gait involves intricate control and feedback mechanisms that engage higher brain centers (e.g., motor cortex, cerebellum, brain stem), and sensory and proprioceptive organs, to properly coordinate the muscle contractions in various body segments (Beyaert et al., 2015; Verma et al., 2010; Dietz, 1992). The spinal cord involves the production of simple reflexes (e.g., withdrawal and crossed-extension reflexes), and contributes to the regulation of complex motor tasks through the involvement of central pattern generators (CPGs) (Guertin, 2009). CPGs are networks of neural circuits that produce rhythmic activity (e.g., gait) without the need for conscious effort or peripheral input (MacKay-Lyons, 2002; Minassian, Hofstoetter, Dzeladini, Guertin, & Ilspeert, 2017). Several CPG models have been proposed based on animal studies and the evidence of stepping reflexes found in infants (MacKay-Lyons, 2002; Minassian et al., 2017). However, stepping reflexes that are exhibited during infantile stages are not found in neurologically intact adults, especially during plantigrade locomotion (i.e., walking with the toes and feet flat the ground) (Minassian et al., 2017; MacKay-Lyons, 2002). Forssberg (1985) proposed that such stepping reflexes observed in infants are retained and then adapted to specific human gait events as one matures. Danner and others (2015) and Dominici and others (2011) provided additional findings that support Forssberg (1985) where infant stepping reflexes were observed in adults with spinal cord injuries and pre-schoolers.

Several animal based CPG models have been proposed to support the presence of CPGs in humans, but these models fail to provide definitive evidence of CPGs (MacKay-Lyons, 2002). It has also been suggested that CPGs are not the sole source of neuronal information that is required for gait, and that inputs from supraspinal centres are also involved to complete locomotion tasks (e.g., the ventral spinocerebellar tract receives output information from the CPGs and relays information to the cerebellum) (Shumway-Cook et al., 2007; Arshavsky, Berkinblit, Fukson, Gelfand, & Orlovsky, 1972; Minassian et al., 2017).

To measure progress in rehabilitation, clinicians may utilize various outcome measures to quantify the symmetry of gait parameters between the affected and unaffected sides (Balaban & Tok, 2014). Hemiparetic gait is commonly characterized by asymmetrical gait parameters, poor motor control, reduced weight bearing ability of the affected limbs, poor response to external perturbations, and an inability to propel the body forward in a smooth and symmetrical manner

(Balaban et al., 2014; Woolley, 2001). Common changes in the temporal parameters of hemiparetic gait are greater swing time in the paretic limb and greater stance time in the non-affected limb. These factors combine to reduce the individual’s gait velocity (Balaban et al., 2014; Woolley, 2001; Brandstater, de Bruin, Gowland & Clark, 1983; Kim & Eng, 2003; Dickstein, 2008; Beyaert et al., 2015; Verma et al., 2012). Reduction of gait velocity is one of the hallmark signs post stroke where gait velocity of the chronic stroke individuals ranged from 0.23 ± 0.11m/s (preferred walking speed) to 0.73 ± 0.33 m/s (maximum walking speed). Gait velocity of more than 0.80 m/s has been suggested as being necessary for performing ambulation tasks within the community (e.g., crossing a crosswalk) (Olney & Richards, 1996; Fritz & Lusardi, 2009).

Asymmetrical spatiotemporal parameters in post stroke individuals led researchers to measure lower limb joint kinematics and kinetics (Olney et al., 1996). Reduced hip extension range of motion was reported during the late stance and push off phase due to either adaptive hip extensor shortening or excessive hip flexor activation (Balaban et al., 2014; Yavuzer, Oken, Elhan, & Stam, 2008; Trueblood, Walker, Perry, & Gronley, 1989). Moreover, a reduced hip extension moment during the stance phase could be due to overactive plantarflexor muscles or a lack of eccentric control of dorsiflexor muscles (Balaban et al., 2014; Milovanović & Popović, 2012). Compensations such as hip hiking and foot dragging often emerge due to a combination of these changes in joint kinematics (Balaban et al., 2014; Woolley, 2001). As the ankle joint anatomically relates to the knee joint, changes in ankle joint kinematics can result in abnormal knee joint kinematics. In the affected limb, Woolley (2001) reported increased knee flexion at initial foot contact, or excessive knee hyperextension throughout most of the stance phase. Excessive knee hyperextension of the affected limb can be due to either early plantarflexor contraction, or as a compensatory mechanism to stabilize the affected knee during the stance phase (Williams, Galna, Morris, & Olver, 2010; Bleyenheuft, Cockx, Caty, Stoquart, Lejeune, & Detrembleur, 2009). Additionally, a greater degree of extension in the non-paretic knee was found during mid and late stance phase (Higginson et al., 2006). Abnormal knee joint kinematics were also observed during the swing phase in hemiparetic individuals such as the presence of a stiff knee gait pattern (i.e., a reduced degree of knee extension prior to heel strike). Stiff knee gait pattern can be attributable to several mechanisms such as inadequate push off, reduced hip flexion moment, excessive knee flexor activity, or the lack of knee extensor activation prior to heel strike (Balaban et al., 2014; Wagenaar & Beck, 1992).

2.7. Effects of Resistance Training as Rehabilitation Intervention

Aside from neurological deficits, post stroke individuals also develop sarcopenia. Sarcopenia is defined as the loss of both muscle quality and quantity due to the aging process, which has negative effects on muscular strength, power, the ability to perform ADLs, and body composition (Cruz-Jentoft et al., 2018; Roubenoff, 2000; Thompson, 2009; Evans, Connis, Bishop, Hendricks & Haselkorn 1995; Short & Nair, 2000). Van Kan (2009) and Doherty (2003) stated that muscular atrophy occurs at an annual rate of 1-2 % after the age of 50. Muscular strength continues to decline up to 1.5% per year between the ages of 50 to 60, and up to 3% annually after the age of 60 (Van Kan, 2009; Doherty, 2003). Rates of atrophy may be accentuated in post stroke populations due to the population generally being older or immobilized post infarction (Scherbakov et al., 2011). Sarcopenia negatively influences both the composition and contractile properties of skeletal muscle and is more pronounced in fast twitch muscle fibres (Lang, Streeper, Cawthon, Baldwin, Taaffe, & Harris, 2010). Denervation of fast twitch muscle fibers jeopardizes one’s ability to produce strength and power, which could lead to negative clinical outcomes (e.g., physical disability, falls, fracture) (Lang et al., 2010; Hurley & Roth, 2000). This loss of muscle power generating capacity is generally centralized in the lower limbs (Lang et al., 2010).

While various intervention methods are available to combat sarcopenia, the most common and effective method is exercise through RT. RT is a promising intervention that has been shown to slow the rate of atrophy and decline of muscular strength and power due to aging. Progressive RT programs can also lead to increased motor unit recruitment, discharge rate, doublet firing rate, synchronization of motor units, and central activation in agonistic and antagonistic muscles (Falvo, Sirevaag, Rohrbaugh & Earhaut, 2010; Van Cutsem, Duchateau, & Hainaut, 1998; Gracies, 2005; Sale, 1998). Bobath (1990) proposed that RT may increase the spasticity of affected muscles and lead to reinforcement of abnormal movements and coordination. This influenced some clinicians to refrain from implementing RT programs as part of stroke rehabilitation programs (Sharp et al., 1997). However, recent studies have reported that RT programs resulted in muscular strength and functional status improvement (e.g., walking distance, gait velocity, balance, less time need to complete TUG Task) and did not produce greater spasticity in the affected limb (Kim & Eng, 2004; Andersson, Grroten, Hellsten, Kaping & Mattsson, 2003, Wist et al., 2016; Hurley et al., 2000; Liu & Latham, 2009; Lee, Kilbreath, Singh, Zeman, & Davis, 2010). However, it is essential to note that the implementation of a RT program for individuals with severe muscle weakness or spasticity is generally not advisable (Abdollahi, Taghizadeh, Shakeri, Eivazi, Jaberzadeh, 2015).

2.7.1. Eccentric Muscular Contractions

Muscle contractions can be differentiated into concentric (shortening) or eccentric (lengthening) contractions. The unique characteristics of eccentric contractions have influenced clinicians and strength coaches to apply eccentric exercises for rehabilitation and performance enhancement. Features of an eccentric contraction (compared to a concentric contraction) are as follows: 1) a lower activation of the muscle for the same level of force output at a given velocity, 2) reduced ability to fully activate the muscle fibres, 3) altered motor unit recruitment strategy due to the size principle, 4) lower CST neuron excitability and monosynaptic reflex excitability, 5) reduced smoothness of the movement, and 6), greater damage to the muscle tissue (Fang, Siemionow, Sahgal, Xiong & Yue, 2004; Tesch, Dudley, Duvoisin, Hather, & Harris, 1990; Sekiguchi, Kimura, Yamanaka, & Nakazawa, 2001; Sale, 1988; Fang, Siemionow, Sahgal, Xiong, & Yue, 2001; Nardone, Romano & Schieppati, 1989; Moritanai, Muramatsu & Muro, 1988; Bigland & Lippold, 1954; Abbruzzese, Morena, Spadavecchia, & Schieppati, 1994).

Eccentric contractions may require alternate descending supraspinal control when compared to concentric contractions (Fang et al., 2001; Perrey, 2018). A distinct activation pattern was first discovered through electroencephalography, which was used to collect movement-related cortical potentials (MRCP) (Fang et al., 2001). MRCP are collections of excitatory post-synaptic potentials of the apical dendrites during voluntary muscular contractions (Falvo et al., 2010; Shibasaki & Hallet, 2006). MRCP can be divided into two major components, negative potential (NP) and positive potential (PP) (Fang et al., 2001). NP is associated with movement preparation, planning, and execution, while PP is associated with sensory information processing (Deecke, Grozinger, Kornhuber, 1976; Siemionow, Fang, Yue, 2000). Greater NP and PP amplitudes were recorded during submaximal eccentric contractions compared to concentric contractions of the elbow flexors (Fang et al., 2001). Additionally, the onset of NP for eccentric contractions of the elbow flexor was recorded approximately 100 ms earlier than the concentric contractions (Fang et al., 2001). The earlier onset of NP during eccentric elbow flexor contractions may represent heightened cortical activities due to the planning of a more difficult movement, or CNS modulation of monosynaptic reflex excitability and a unique motor unit recruitment strategy (Fang et al., 2001). A heightened PP amplitude can be explained by the force fluctuation that occurs during eccentric movements and adaptations that process additional sensory information (Fang et al., 2001). Fang et al. (2004) suggested that a greater intensity of cortical signals reflects the specific planning and execution needed for performing eccentric contractions. More functional regions and a greater number of neurons were engaged during eccentric contractions than concentric contractions (Fang et al., 2004).

During eccentric contractions, certain functional regions of the brain are more activated than others, especially in cortices that relate to motor activities. Kwon and Park (2011) found increased activity in many functional regions (e.g., SMA, anterior cingulate cortex, inferior parietal lobe, cerebellum) during eccentric wrist flexion and extension tasks. Furthermore, other studies reported a greater activation of the prefrontal cortex during eccentric muscle contractions (submaximal and maximal) (Kwon et al., 2011; Fang et al., 2004; Olsen, Moses, Riggs & Ryan, 2012; Miller & Cohen, 2001; Perrey, 2018).

One concern that is commonly reported among participants who perform eccentric exercises is delayed-onset muscle soreness (DOMS). DOMS is a form of exercise induced muscle soreness that is dull and aching and experienced during movement or palpation of the affected tissue (Douglas, Pearson, Ross, & McGuigan, 2016). The acute effects of exercise induced muscular damage include both inflammation and short term decreases in muscular force output. Smith et al. (1994) evaluated the impact of repeated bouts of eccentric chest press exercise on muscular strength, soreness, and levels of creatine kinase in a group of untrained males. No changes in strength, serum creatine kinase concentration, or perception of soreness were found when repeating another bout of exercise 48 hours after the initial session (Smith et al., 1994). Nosaka and Clarkson (1997) conducted a similar experiment in which they tested similar outcome variables and reported that performing eccentric exercises three and six days after an initial bout did not exacerbate muscle soreness nor did it affect the recovery process. In conclusion, although there is a risk of soreness and muscle damage when performing regular bouts of eccentric exercise, evidence suggests that the implementation of eccentric exercise is safe, feasible, and advantageous.

2.8. Isokinetic Dynamometry

An isokinetic contraction is a type of muscular contraction where the angular velocity of the contracting muscle around a joint is constant, and is performed with the utilization of ISD (Dvir, 2004; Baltzopoulos & Brodie, 1989). ISD can measure strength output, torque development, and fatigue, and has been popular among patients with musculo-tendinous injuries (e.g., ACL rehabilitation) and post stroke individuals (Baltzopoulos et al., 1989). Since post stroke neurological deficits vary (e.g., the inability to stand on the weight bearing limb), traditional free weight training exercises can be dangerous in this patient group. In turn, ISD is a safer option for post stroke individuals to perform exercises as it provides accommodating resistance. ISD uses variable resistance that is equal to the force applied by the participant throughout the range of motion (ROM), which is useful to accommodate either pain or muscular fatigue during exercise and may lower the possibility of overload injury (Baltzopoulos et al., 1989; Osternig, 1986).

While the eccentric mode is employed less often with post stroke individuals, this population is able to tolerate eccentric exercises using ISD. Positive results were found in a study by Clark et al. (2013) in which chronic stroke individuals performed a five week high intensity RT program followed by a three week clinic based gait training program. Their participants performed a lower body focused program with the ISD (hip flexion/extension, knee flexion/extension, and ankle plantar/dorsiflexion) on the affected limb three times per week. Participants were randomized into performing either the concentric or eccentric portion of the selected exercises. Improvements in muscular strength, power output, and walking velocity (self-selected and fastest) were reported for both groups; however, the eccentric only group demonstrated greater improvements when compared to the concentric group (Clark & Patten, 2013). Alike other previous studies, Clark et al. (2013) applied their training paradigm for chronic stroke individuals, and there is limited research on the effects of isokinetic exercises in acute and subacute stroke individuals. Thus, Chen et al. (2015) implemented an ISD based RT program with subacute (less than six months) stroke individuals who completed a four-week bilateral, high frequency training program (five sessions per week) focusing on the knee flexors and extensors. Patients were randomized into performing either isokinetic or isotonic exercises in addition to their regular treatment plans. Both groups demonstrated improvements in strength, TUG performance, and plasma inflammatory cytokine levels (IL-6, TNF-α, & Lipoprotein-a); the eccentric exercise group also demonstrated greater improvements in quality of life compared to the isotonic group. The RT program of Chen et al. (2015) did not isolate exercises into concentric only or eccentric only groups. Additionally, a study by Sen, Demir, & Ozgirgin

(2015) applied a bilateral ISD based RT program with subacute stroke individuals who completed a three-week high frequency training program (five sessions per week) on the knee and ankle musculatures. Sen et al. (2015) also recruited neurological intact and healthy individuals to serve as a control group and found that both groups achieved improvements in bilateral muscular strength and several functional outcomes (gait speed, gait endurance, balance, and quality of life).

2.9. Measurement

2.9.1. Surface Electromyography

Electromyography (EMG) signals are often collected to quantify neuromuscular activity, and can be acquired by either invasive or non-invasive methods (Reaz, Hussain, & Mohd-Yasin, 2006; Criswell, 2011). The latter method is more prevalent in clinical and research environments due to its simplicity and ability to assess the activation of superficial muscle groups (Reaz et al., 2006; Chowdhury et al., 2013).

To ensure high EMG signal quality, electrical noise and other factors that potentially affect signal detection and collection need to be addressed by the researcher or clinician. Although inherent noise created by all electronic equipment cannot be eliminated, it can be reduced by utilizing high quality electrodes. Movement of the EMG electrode relative to the skin (i.e., movement artifact) will affect the signal quality, and can be minimized by careful and appropriate preparation. Undesired EMG signal collected from a neighboring muscle group (i.e., crosstalk) will also affect the signal quality, and can be minimized by proper electrode placement and the use of double differential filtering techniques (van Vugt & van Dijk, 2000). Unnecessary filtering and distortion of the EMG signal should also be avoided (Reaz et al., 2006).

Other extrinsic and intrinsic factors can directly affect the quality of EMG signals. Extrinsic factors include the structure of the electrode and its placement (e.g., detection surface area, electrode shape, inter-electrode distance, and the placement of the electrode relative to the motor point of a muscle) (Reaz et al., 2006). Intrinsic factors (e.g., physiological, anatomical biochemical) include local blood flow, fibre diameter, fibre type composition, and the amount of tissue between the muscle and electrode (Reaz et al., 2006). For instance, although signal quality of the gluteus medius may be affected by movement artifacts that are difficult to avoid (due to short muscle fibre length), this issue may not be as problematic in the biceps femoris muscle (Rainoldi et al., 2004). Proper electrode placement is required to minimize the effects of extrinsic and intrinsic factors on EMG signal quality. It is generally recommended that EMG electrodes should be placed along the longitudinal midline of the chosen muscle, and between the innervation zone and the tendon insertion (De Luca, 1997; Mesin, Merletti, & Rainoldi, 2009). Since muscles shift with respect to the skin and EMG electrode placement during dynamic contractions, the relative location of the innervation zone can change by one to two centimetres, which may be affected by intrinsic factors (e.g., joint angle and muscle type variation) (Rainoldi et al., 2004). Geometrical artifacts can be problematic if the purpose of surface EMG is to assess neuromuscular fatigue. However, this issue often can be addressed by utilizing a multi-channel approach to collect EMG signals with multiple electrodes (Zwarts & Stegeman, 2003; Rainoldi et al., 2000; Farina, Merletti, Nazzaro, Caruso, 2001). To ensure that the quality of EMG signals is high, the researcher or clinician must ensure that there is a good signal to noise ratio (i.e., a high EMG component in the signal with minimal contamination from electrical noise) (Reaz et al., 2006).

After reducing electrical noise, EMG signals are amplified before further processing. Signal filtering is the initial level of processing, which can be achieved either electronically through system hardware (e.g., resistors, capacitors, inductors) or digitally through software. Filters consisting of a common mode rejection scheme will eliminate additional noise from the recording environment. For instance, the use of a notch filter with a set bandwidth (e.g., 59-61Hz) will prevent the system from collecting any signals that are within that bandwidth (e.g., 60Hz). In general, notch filters are not recommended since they remove actual EMG frequencies from the signal. To eliminate additional noise without jeopardizing EMG signal collection, a band pass filter is considered a better alternative. A band pass filter has a greater bandwidth (e.g., 10-450 Hz) to allow clinicians to eliminate noise outside the lower range of the bandwidth (e.g., swaying of wire or miscellaneous biological artifacts) and higher range of the bandwidth (e.g., tissue noise at the site of electrode placement) (Criswell, 2010).

After utilizing strategies to reduce noise during data collection, and applying appropriate filters, suitable EMG processing methods must be employed to ensure the accuracy and quality of EMG signal interpretation. EMG signals are often rectified (converting all negative signal values to positive values) prior to further analysis. However, rectification is not necessary with the root-mean-square (RMS) method, which is a form of integrated EMG analysis that squares all EMG signal values before calculating the square root of the average EMG amplitude during a designated time interval. RMS is often chosen since it can reflect the total amount of physiological activity in selected motor units during contraction (Fukuda et al., 2010; Fukuda, Alvarez, Nassri, & Godoy, 2008).

Surface EMG can also be used to quantify neuromuscular fatigue. Calculating the median frequency component in an EMG signal is often selected as this method provides variables (e.g., variance, standard deviation, rate of decrease) that allow for the determination of the onset of fatigue (Costa et al., 2010; Reaz et al., 2006). This type of analysis is commonly performed through Fourier transform spectral analysis during fatiguing protocols (Costa et al., 2010). Two forms of Fourier transform analysis (fast-time or short-time) can quantify local neuromuscular fatigue. Limitations exist in the fast-time Fourier analysis as it requires a static contraction for accurate EMG signal processing, while short-time Fourier analysis is more appropriate for determining neuromuscular fatigue in both static and dynamic exercise conditions (Costa et al., 2010; Dantas et al., 2010).

Normalization of EMG signals is required if the researcher or clinician is comparing EMG signal amplitudes between individuals, muscle groups, or sessions since EMG amplitudes can differ based on a participant’s anatomical and physiological variables (Lehmann & McGill, 1999; Burden, 2010; De Luca, 1997). Normalized EMG signals are expressed as the amplitude of the EMG signal during the activity of interest relative to that obtained during a reference contraction. One standard technique is to normalize the EMG signal relative to a maximum voluntary isometric contraction (MVIC) (Merletti & Torino, 1999). However, this technique may not be suitable for some pathological populations (e.g., low back pain patients, stroke patients) who have difficulty fully activating affected muscles or experience pain during such contractions (Allison, Godfrey, & Robinson, 1998; Allison, Marshall & Singer, 1993). Another potential drawback with the MVIC method is that factors such as training status and motivation can alter the amplitudes collected during the reference muscle contraction (Soderberg & Knuttson, 2000).

As such, alternate normalization methods have been proposed for use in studies involving post stroke individuals. For example, several studies normalized EMG signals relative to the amplitude achieved by the same muscle in the non-affected limb during a MVIC (Vinstrup et al., 2016; Jung et al., 2015; Vinstrup et al., 2017). One main limitation of this MVIC method is that it may be applicable only when measuring and comparing desired neuromuscular activities within a single session. Other researchers normalized EMG signals relative to peak EMG amplitude achieved by the same muscle in the non-affected lower limb at the same phase of the gait cycle (Laufer, Dickstein, Chefez, & Marcovitz, 2001; Boonsinsukh, Panichareon, & Phansuwam-Pujito, 2009). A limitation to this method is that paretic individuals have been shown to exhibit abnormal EMG patterns in the non-affected limb during bilateral tasks (e.g., gait) (Hirschberg & Nathanson, 1952; Marks & Hirschberg, 1958; Shiavi, Bugle, & Limbird, 1987; Wortis, Marks, Hirschberg, & Nathanson, 1995). Additional methods, such as normalizing relative to baseline activity (e,g., standing) or to all phases of the gait cycle, have also been used (Lee et al., 2017; Kirker, Simpson, Jenner & Wing, 2000; Betschart, Lauziere, Mieville, McFayden, & Nadeau, 2017; Lamontagne, Richards, & Malouin, 2000).

With such a variety of normalization techniques reported in the literature, the most appropriate technique to use for post stroke individuals is unclear. Previous systematic reviews have concluded that normalizing to sub-maximal voluntary isometric contractions (sub-MVIC) provide reliable results that allow for comparisons between sessions and individuals (Burden, 2010). Recently, Tabard-Fougere et al. (2018) investigated the reliability of normalizing EMG amplitudes relative to the amplitude obtained during a MVIC and the amplitude obtained during a sub-MVIC Grade 3 manual muscle test (MMT) for four lower limb muscles (gluteus medius, rectus femoris, tibialis anterior, and semitendinosus) in a group of heathy neurologically intact individuals. The body positions and joint angles used in the MVIC and MMT tests were performed according to the Daniels and Worthingham's MMT method (Hislop, Montgomery & Brown, 2013). Both within- and between-day reliability were excellent for all lower limb muscles using the sub-MVIC (MMT) normalization method. However, there are limitations to the use of this method. First, it may not be reliable to assess the gastrocnemius and soleus muscles since standardized force for Grade 3 MMT can be difficult to apply for these muscles (Tabard-Fougere et al., 2018). Another limitation is that direct comparisons between muscles is problematic since the lower limb positions required for Grade 3 MMTs (and therefore the neuromuscular activation requirements to sustain those positions) is not constant for different lower limb muscles. However, if comparisons are restricted to be within a particular muscle (e.g., pre-intervention vs. post-intervention), this method may be appropriate and has the added benefit of not involving maximal contractions (which may change over time in post stroke patients) as the protocol directly corresponds to their ability to hold their limbs at a standardized position against gravity. This method is also not dependent on factors such as an individual's training status, psychological factors (e.g., motivation), or pain/discomfort level (Tabard-Fougere et al., 2018).

Prior to actual surface EMG data collection, a few additional steps must also be taken, such as the preparation of the skin. To reduce skin impedance, one can abrade the skin and use an alcohol pad or apply a small amount of lotion or electrode gel (Criswell, 2010). A pre-amplifier can be used to reduce input impedance and boost EMG signals to a certain amplification (gain) prior to that signal reaching the main instrumentation amplifier (Criswell, 2010). The amount of pre-amplifier gain must be carefully selected as too large of a gain can result in distortion of EMG signals. If high frequency artifacts occur, a pre-amplifier with a relatively low gain is more advantageous as it would not saturate the subsequent amplification process. Furthermore, high- or low- pass filters can be applied to filter the EMG data. A high-pass filter omits the collection of lower frequencies within the EMG signal (e.g., motion artifact) and collects higher EMG signal frequencies, while a low-pass filter (e.g., anti-aliasing filter) omits the collection of higher frequencies within the EMG signal and collects lower EMG signal frequencies (Criswell, 2010).

In many digital sampling systems, analog signals are converted into digital signals prior to analysis. Analog signals represent the physical signals that are collected while digital signals are sequences of numbers that illustrate the analog signals at a specific time during collection. Sampling frequency is the rate which the EMG data is being sampled or measured and must be properly selected to ensure the accuracy and reproducibility of the sampled signals. A sampling rate that is too low can cause EMG signal distortion (e.g., aliasing). Over sampling of EMG data may occur if the analog recording system is not able to convert analog to digital signals at a fast rate. Thus, the potential of aliasing or signal distortion can be eliminated by following the Nyquist theorem (i.e., use a sampling rate that is at least double the highest frequency component of the signal), or through the application of an anti-aliasing filter (Clancy, Morin, & Merletti, 2002).

Surface EMG signals are often evaluated in the spatial domain through various signal averaging methods. Signal averaging or EMG smoothing will result in smoother deflections by removing the high frequency components within the signals (De Luca, 2003). EMG signal averaging analysis can be performed through either a moving average, linear envelope, or the RMS method. The RMS method is generally considered more reliable than the other two methods and, as described previously, is often chosen since it can reflect the amount of total amount of physiological activity in selected motor units during contraction (Fukuda et al., 2010; Fukuda, Alvarez, Nassri, & Godoy, 2008).

Since motor unit action potentials fire at different ranges of frequencies, frequency analyses are often performed to quantify the amplitude distribution of the EMG signals (e.g., local neuromuscular fatigue). The frequency spectrum can shift based on many physiological factors (e.g., motor unit synchronization, muscle spindle dysfunction, propagation velocity change). Frequency analysis can be performed by calculating either the mean or median frequency of the signal, with the median frequency being more advantageous as it is less sensitive to noise. Fourier transform and wavelet transform are common frequency analysis methods to assess local neuromuscular fatigue. It has been proposed that wavelet transform (discrete or continuous) methods produce more reliable and accurate results than the Fourier transform methods (Costa et al., 2010). However, comparable results were found when determining local neuromuscular fatigue through the short-time Fourier transform and the wavelet transform method in static and dynamic fatiguing exercises (Costa et al., 2010; Sparto, Parnianpour, Barria, & Jagadeesh, 1999; Barria & Jaggadeesh, 1994; Da Silva, Lariviere, Arsenault, Nadeau, & Plamondon, 2008).

2.9.2. Clinical/Functional Outcomes

Clinical/functional outcomes are often administered by clinicians to objectively and quantitatively assess a patient's progress in their rehabilitation. The measurement scales discussed in the subsequent sections are related to the outcome measures that were used in the current study.

2.9.2.1. Berg Balance Scale

The Berg Balance Scale (BBS) was initially developed to evaluate dynamic balance and transfer ability in older adults (Berg, Wood-Dauphine, Williams, & Gayton, 1989). The BBS is comprised of 14 items that assess an individual’s ability to complete transfer tasks of varying difficulty (Berg et al., 1989). The internal consistency of this measure was found to be excellent across three different studies that involved post stroke individuals (Berg et al., 1989; Mao, Hseuh, Tang, Sheu, Hsieh, 2002; Chou, Chien, & Hsueh, 2006). The inter- and intra-rater reliability were both deemed excellent in acute and chronic stroke individuals (Mao et al., 2002; Liston & Brouwer, 1996). The construct validity was rated adequate to excellent compared to other impairment measures (e.g., Barthel Index, Fugl-Meyer balance subscale) in studies of post stroke individuals with varying recovery timelines (14 to 180 days post stroke) (Mao et al., 2002; Chou et al., 2006; Wee, Bagg & Palepu, 1990). In terms of the responsiveness of this scale, various studies have reported that the BBS has moderate to excellent sensitivity to detect improvements over time after stroke (Blum & Korner-Bitensky, 2008; Liaw et al., 2008). While a minimal clinically-important difference (MCID) has not been fully established for the BBS, Song and colleagues (2018) found that a MCID of 12.5 points on the BBS was associated with a greater improvement in self-reported Global Ratings of Change. However, the authors caution that this MCID value may only be applicable for acute stroke individuals (one to two months post stroke) and not chronic stroke individuals or other populations.

2.9.2.2. Activities-Specific Balance Confidence Scale

The Activities-specific Balance Confidence (ABC) Scale is a questionnaire that assesses an individual’s confidence in performing activities without losing balance. The ABC Scale is a

16-item self reported survey (0-100 scale) that can be used with post stroke individuals, geriatric patients, older adults, and individuals with balance and/or vestibular disorders. This scale demonstrates excellent internal consistency and test-retest reliability in chronic stroke individuals (Botner, Miller, & Eng, 2005; Salbach, Mayo, Hanley, Richards & Wood-Dauphinee, 2001), and adequate convergent validity with many functional measures (e.g., BBS, gait speed, Barthel Index, 36 Item Short Form Health Survey) in chronic and subacute stroke individuals (Botner et al., 2005; Salbach et al., 2001). A MCID value has not been established for the ABC Scale in post stroke populations.

2.9.2.3. Timed Up and Go Test

Similar to the BBS, the TUG Test is another commonly administered clinical outcome that assesses an individual's functional capacity. This test requires the participant to stand up from a chair, walk three metres, turn around a cone, return to the chair, and sit back down. The time taken to complete the test is determined using a stopwatch. The TUG Test demonstrates excellent intra- and inter-rater reliability, and convergent validity (with the BBS and Barthel Index) (Chan, Tou, Tse & Ng, 2017; Hafsteinsdottir, Rensink, & Schuurmans, 2014; Berg, Maki, Williams, Holliday, & Wood-Dauphinee 1992). Although concerns have been expressed in the literature that turning direction (i.e., to the affected or unaffected side) may affect the outcome in paretic individuals, it has since been reported that turning side does not significantly affect the outcome (Leigh Hollands et al., 2010). However, the seat height of the assessment chair can impact the outcome, and this factor is often unreported in the literature. Heung and Ng (2009) measured the effect of seat height and turning direction on TUG performance in acute and subacute stroke patients. They found that a shorter duration is required to perform TUG when the seat height was 115% of the participant's lower leg length (from the lateral knee joint to the ground with footwear on) compared to a seat height of 65% of the lower leg length. A MCID has not been established for the TUG Test in post stroke populations.

2.9.2.4. Six Minute Walk Test

The Six Minute Walk Test (6MWT) was originally developed for individuals with chronic respiratory or cardiovascular diseases, and later implemented with healthy older adults and pathological populations (Enright, 2003; Kosak & Smith, 2005). The main objective of the 6MWT is to assess an individual's functional capacity. On a flat hard surface, the participant is to cover as much distance as possible in six minutes at their preferred walking pace with rest if needed (Kosak et al., 2005; Pohl et al., 2002). The standard length of the track to be used is 30 metres, and the participants are to perform multiple 180° turns when they reach the ends of the track. 6MWT trials should be performed according to the protocols set by the American Thoracic Society, since variable track lengths result in poorer performance in hemiparetic individuals (Dunn et al., 2015; ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories, 2002; Ng et al., 2011). Although this test is commonly administered to determine gait endurance in post stroke individuals, a MCID is not well established (Fulk & He, 2018). Fulk et al. (2018) examined the responsiveness of the 6MWT at two months post stroke and again at 6 months post stroke, and improvements were anchored to the Stroke Impact Scale and the modified Rankin Scale (MRS). A MCID of 34 metres was associated with a greater score on the Stroke Impact Scale in slow walkers (gait speed < 0.40 m/s), and a MCID of 130 metres was associated with a greater score for fast walkers (gait speed ≥ 0.40 m/s) (Fulk et al., 2018). A MCID of 44 metres was associated with a greater improvement on the MRS in slow walkers, and a MCID of 71 metres was associated with a greater score for fast walkers (Fulk et al., 2018). Due to the disparate MCID values for fast walkers, Fulk et al. (2018) suggested that caution should be used when applying their MCID results in post stroke individuals with gait speed ≥ 0.40 m/s.

2.9.2.5. 10-metre Walk Test

The 10-Metre Walk Test (10MWT) is another measure of functional capacity and measures the time that an individual takes to walk 10 metres. Protocols for this test that are reported in the literature vary (e.g., using a static or dynamic starting position) (Middleton, Fritz, & Lusardi, 2015). Trials that used a “rolling start and finish” have been found to produce more valid and reliable results than static start trials (Macfarlane & Looney, 2008; Phan-Ba et al., 2012; Tyson et al., 2009). As with the 6MWT, although the 10MWT is a commonly used functional outcome measure in stroke patients, the MCID for this population has not been fully established. Tilson and colleagues (2010) investigated the responsiveness of self-selected gait speed through the 10MWT at 20 and 60 days post stroke, with improvements at 60 days being anchored to the MRS. They concluded that a MCID of 0.16 m/s was associated with a greater improvement on the MRS in first time stroke patients with severe gait impairments (Tilson et al., 2010).

2.9.2.6. Stroke Impact Scale

The Stroke Impact Scale (SIS) is a questionnaire that includes various domains that measure how a stroke has affected one’s health and life. The SIS has 59 items within 8 domains that assesses strength, hand function, ADLs, mobility, communication, emotion, memory and thinking, and community participation. Each item is scored using a 5-point Likert scale to rate the difficulty that the individual has experienced after their stroke.

2.10. Purpose

The original purpose of the current study was to examine and compare the effects of two 4-week programs of progressive RT (eccentric only RT, concentric only RT) utilizing an ISD on neuromuscular and clinical outcomes in a sample of subacute (three to six months) post stroke individuals. The research questions that were to be addressed are:

1) What effect does a 4-week program of progressive lower limb resistance training (ISD: eccentric mode) have on: muscular strength and power output (measured by ISD), neuromuscular activation and fatigue (measured by EMG), and clinical outcomes related to functional capacity?

   It was hypothesized that the program will lead to significant improvements in all outcomes.

2) What effect does a 4-week program of progressive lower limb resistance training (ISD: concentric mode) have on: muscular strength and power output (measured by ISD), neuromuscular activation and fatigue (measured by EMG), and clinical outcomes related to functional capacity?

   It was hypothesized that the program will lead to significant improvements in all outcomes.

3) Are there differences between the effects that the eccentric-mode program and concentric-mode program have on: muscular strength and power output (measured by ISD),

neuromuscular activation and fatigue (measured by EMG), and clinical outcomes related to functional capacity?

It was hypothesized that the eccentric-mode program will lead to significant improvements in all outcomes compared to the concentric-mode program.

Recruitment for this study was set to start in January 2020. However, this coincided with the onset of the COVID-19 pandemic, which resulted in restrictions to conducting research involving human participants at the University of Regina for a significant portion of that year. Further complications and difficulties in recruiting participants for the study occurred once these restrictions were sufficiently lifted to permit the study to proceed. Two participants were recruited and completed the study, both of whom had been randomized to complete the concentric only RT program (no participants completed the eccentric only RT program). After months of further complications and difficulties in recruiting participants due to the ongoing pandemic, and with time to completion being a growing concern, a joint decision between the student and supervisory committee was made to suspend the study and proceed with this thesis as a case series based on the data that had been collected to that point (February 2021).

3. Methods

3.1 Participants

Participants were recruited through Unit 5A of the Regina General Hospital (Neuroscience Unit), the Wascana Rehabilitation Centre (WRC), and local neurologist clinics (Regina, SK) via purposive sampling. Recruitment cards were provided for the treating neurologists and nurses within the hospital, WRC, and clinics that explained the research purpose, inclusion/exclusion criteria, requirements, contact information, and other pertinent information. A two-stage screening process was performed to determine if a post stroke individual was eligible for enrollment. This was completed in person at the University of Regina's Centre for Health, Wellness and Performance. Stage one was to assess the following eligibility criteria: (1) participant was over the age of 18, (2) clinical presentation of first ever unilateral stroke (diagnosed by physician), (3) time since stroke was ≥ 3 months (90 days) and ≤ 12 months (365 days) prior to enrollment, (4) able to sit with or without support for at least five minutes, (5) no prior history of severe cardiovascular diseases (CVD) or metabolic diseases (e.g., uncontrolled hypertension >190/110 mmHg, myocardial infarction or cardiac bypass surgery within the past three months, congestive heart failure, arrhythmia, consistent/uncontrolled diabetes), (6) no lower limb pain associated with stroke, (7) no lower limb musculoskeletal injuries (e.g., sprained ankle) within the past three months, (8) no history of severe musculoskeletal injuries (e.g., ACL injury, fractured ankle, hip fracture), (9) able to communicate in English and understand instructions, and (10) able to provide written consent.

In the second stage of screening, the following criteria were assessed: (1) able to fully complete the TUG Test, (2) visual deficit score measured through the National Institute of Health Stroke Scale (NIHSS) (part three) was ≤ 1, and (3) no significant lower limb musculoskeletal restrictions as measured by a goniometer (i.e., hip flexion > 125°, hip extension > 20°, knee flexion > 130°, knee extension > 0°, plantarflexion > 50°). Additional information such as a current list of medications (e.g., for CVD, metabolic conditions, spasticity) and the presence of weakness or loss of feeling in the lower limbs (through part eight of the NIHSS) were collected. Resisted hip flexion, knee flexion/extension, and ankle dorsi/plantarflexion were graded through manual muscle testing.

The study was approved by the University of Regina and Saskatchewan Health Authority Research Ethics Boards prior to the study, and all participants provided written informed consent prior to entering the study.

3.2 Study Design

It was originally intended to implement a randomized controlled experimental study design with participants being randomized on a 1:1 basis to one of two groups: eccentric only RT group and concentric only RT group. However, this design was changed to a case series (two cases) due to ongoing complications and difficulties resulting from the COVID-19 pandemic (see *2.10*).

3.3 Procedure

Both participants completed a four-week (two sessions/week) intensive dynamic RT program involving only concentric contractions using a Biodex System 3 Pro ISD (Computer Sports Medicine, Inc., Stoughton, MA, USA). The length of the program was only four weeks to focus on potential neurological changes in muscle function rather than physiological changes (e.g., muscular hypertrophy). The training was performed only on the participant’s paretic lower limb under the supervision and guidance of a CSEP Certified Exercise Physiologist. Resting heart rate (HR) and blood pressure (BP) were measured at the start and end of all training sessions to ensure that pre- and post- training HR and BP met CSEP requirements (i.e., HR < 100 beats per minute, systolic BP ≤144 mmHg and diastolic BP ≤ 94 mmHg). Participants were also instructed to breathe properly during the exercises since the physiological effects of a Valsalva maneuver can be dangerous to post stroke individuals.

Each session began with a five-minute full body warm up on a Nu-Step Recumbent Cross-Trainer. After the warm up, the participant was positioned in the seat of the Biodex System 3 ISD. The participant was instructed to "push as hard and as fast as you can against the force pad". A rest break of a minute was provided between each set of exercise. Two sets of 10 repetitions of maximal effort hip flexion, knee flexion/extension, and ankle dorsiflexion/plantarflexion of the paretic limb at two different angular velocities (60°, 120°) were performed. Progression of angular velocities started from the slowest (60°) to the fastest (120°). Each training session ended with a brief cool down routine that consisted of five minutes of mild lower limb muscle stretching.

For hip flexion, the participants lay supine such that the axis of the dynamometer was aligned with the greater trochanter of the femur. After being properly aligned, the force pad was positioned just proximal to the knee joint. Adjustments were made based on the participant's body dimensions to ensure both their safety and accuracy of the force that were applied during the hip flexion exercise. Lastly, the participants were stabilized with a pelvis strap while the non-exercising limb rested on a foot rest.

For knee flexion and extension, the participants were in a seated position such that the axis of the dynamometer was aligned with the lateral femoral epicondyle. The participants were adjusted so that the back of their knee was just lightly resting on the edge of the seat cushion. After being properly aligned, the force pad was positioned just proximal to the medial malleolus. A thigh stabilizer strap was administered on the exercising leg at the distal third or middle of the participant's thigh while a contralateral limb stabilizer was installed to provide balance for the participant during the exercise.

For dorsiflexion and plantarflexion, participants lay supine such that the axis of the dynamometer was aligned with the lateral malleolus. In this position, the exercising limb rested on a shoulder stabilizer while the foot was strapped onto a footplate. Pelvis and knee straps were used to ensure the stabilization and position of the participant. Similar to hip flexion, a foot rest was also used for the non-exercising limb.

3.4. Measurements

Both physiological outcomes (i.e., torque development, neuromuscular activation, and neuromuscular fatigue) and clinical/functional outcomes (i.e., balance, functional mobility) were assessed. All outcomes were assessed at baseline (pre-intervention) and after the four-week training program (post-intervention).

3.4.1. Physiological Outcomes

Physiological outcomes that were assessed include peak torque, time to peak torque, neuromuscular activation, and neuromuscular fatigue of the knee flexor and extensor muscles. Positioning and set up of the participants were performed as required for knee flexion and extension on the ISD (see *3.3*). Participants were encouraged to "push and pull as hard as possible" during concentric and eccentric portions of each exercise. Testing was conducted on both limbs at two different angular velocities (i.e., 60°/s, 180°/s). Prior to the testing trials, the participant performed five sub-maximal repetitions for familiarization and to ensure that they were able to perform the exercise through 3 to 104 degrees of knee flexion.

To assess maximum voluntary concentric and eccentric joint torque of the knee flexors and extensors, three trials of five maximal contractions at 60°/s were performed with one minute rest between trials. The best repetition of the 3 sets was used to determine the peak torque (measured in Newton-metres). Time to peak torque (measured in seconds) was also measured as this parameter evaluated the participant's ability to produce power rapidly. To assess neuromuscular fatigue in the knee flexor and extensor, one trial of 15 maximal contractions at 180°/s was performed.

During each trial, peak torque development and time to peak torque development of the knee flexors and extensors was assessed by the ISD, while neuromuscular activation and fatigue of the rectus femoris (knee extensor) and hamstrings (knee flexor) were assessed using surface EMG. Additionally, to ensure the accuracy of the tests, the isokinetic dynamometer was calibrated according to its instrumental manual monthly and the measurements were accurate to within ± 1 N-m.

At the EMG electrode sites, the skin was shaved (if required), abraded, and sanitized with an alcohol pad. Four silver 5x1 mm Delsys Trigno double differential wireless electrodes (Delsys Inc., Boston, MA, USA) were attached on the rectus femoris and hamstrings as follows:

- Rectus femoris – Approximately half the distance between the anterior superior iliac spine and patella, parallel to the muscle fibres (Criswell, 2010).
- Hamstrings – Approximately half the distance between the gluteal fold and the popliteal

fossa, parallel to the muscle fibres (Criswell, 2010).

The EMG electrodes were pre-amplified (gain = 300 V/V), and had an intra-electrode distance of 1 cm, common mode rejection ratio > 80 dB, 20-450 Hz bandpass filter, and sampling rate of 2000 Hz. EMG signals for each muscle were normalized to sub-maximal contractions, through the application of Grade 3 MMTs (see *2.9.1*). This method was found to produce reliable within- and between-day measures of neuromuscular activity in lower limb muscles, and is more appropriate than MVICs for EMG normalization in the study population (Tabard-Fougere et al., 2018). The normalization tasks for the rectus femoris and hamstrings were as follows:

- Rectus femoris – Sitting at the edge of an examination table, the knee extended through its available ROM and not beyond 0° without any rotation of the thigh. The participant held their lower leg perpendicular against gravity for 5 seconds. Three trials were performed with one minute rest between trials, and the average of the three trials was calculated.
- Hamstrings – In a standing position and using a table for stability, the knee was flexed to 90° while the other foot is on the ground and the pelvis is horizontal. The participant held their lower leg parallel against gravity for 5 seconds. Three trials were performed with one minute rest between trials, and the average of the three trials was calculated.

Delsys EMGworks software (Delsys Inc., Boston, MA, USA) was used to collect and analyze the EMG data. To assess neuromuscular activation, RMS amplitude values were calculated for each 60°/s repetition and normalization contraction. These values were used to calculate the normalized neuromuscular activation (% sub-MVIC) for each repetition, which were then used to calculate an average value for each set. To assess neuromuscular fatigue, median frequency values were calculated for each 180°/s repetition.

3.4.2. Clinical/Functional Outcomes

Clinical/functional outcomes that were assessed include balance, functional mobility and quality of life. Balance was assessed using the BBS (see *2.9.2.1*) and ABC Scale (see *2.9.2.2*). The BBS determines one's ability to perform 14 functional tasks that are required for ADLs while maintaining balance. Each item of the BBS was rated (0-4 scale), with a score of zero indicating a low level of functioning and a score of four indicating a high level of functioning. The ABC Scale consists of 16 items related to an individual's perceived ability to perform ambulation activities without losing balance that were each rated by the individual (0-100 scale).

Functional mobility was assessed using the 6MWT (see *2.9.2.4*), and 10MWT (see *2.9.2.5*). The 6MWT measured the total distance covered by a participant during 6 minutes (timed using a stopwatch) of walking at their preferred speed back and forth on a straight 30-metre portion of the track in the University of Regina's Fitness and Lifestyle Centre (with rest if needed). To ensure the validity and reliability of the results, the test was performed according to the guidelines set by the American Thoracic Society. Walking aids or orthoses were permitted during the test, and the examiner provided standardized encouragement using phrases such as "keep up the good work" or "you are doing great" every 30 seconds during the test. Participants received encouragement and an update on the duration remaining after completing each minute of the test. The test would have been terminated if the participant reported angina, intolerable shortness of breath, leg cramps, staggering, or pale appearance (American Thoracic Society Committee on Proficiency Standards for Clinical Pulmonary Functions Laboratories, 2002).

Next, the 10MWT was measured using a 10-metre portion of the track in the University of Regina's Fitness and Lifestyle Centre. White strips of tape were placed on the track at the 0-metre, 2-metre, 8-metre, and 10-metre marks. The participant performed a dynamic start and started walking from the 0-metre mark with the time taken to walk between the 2-metre and 8-metre marks being used to calculate average gait speed (i.e., speed = distance/time). Participants completed the test at their preferred walking speed and at a self-perceived maximal walking speed. As with the 6MWT, since this test requires proper instructions to ensure the validity and reliability of this assessment, instructions provided were consistent between trials and participants. For the preferred walking speed trials, the participants were instructed to walk at a comfortable speed. For the maximal walking speed trials, the participants were instructed to walk as fast as possible and safely, but without jogging/running (e.g., speed used to reach a bus which is about to pull out). Three trials were performed for each condition, and the mean trial times for each participant were used in the subsequent analyses.

Finally, quality of life was assessed through the use of the SIS. SIS is a stroke-specific survey that measure one’s health status. Participants completed all 59 items that assessed 8 domains that related to how a stroke had impacted an individual’s life. The final score of each domain were then calculated based on the instructions.

4. Results

4.1. Participants

Two participants completed the study and attended all intervention and data collection sessions with no adverse events. The demographics of each participant are outlined in Table 1.

Table 1: Participant Demographics at Baseline

Participant 1	
Age	75
Time Since Stroke	6 months and 27 days
Side of Stroke/Affected Side	R/L
Sex	Male
TUG Completion Time	8.9 s
Participant 2	
Age	77
Time Since Stroke	5 months and 10 days
Side of Stroke/Affected Side	L/R
Sex	Female
TUG Completion Time	17.7 s

Abbreviations: TUG; Timed up and go test.

4.2 Physiological Outcomes

Pre- and post-intervention data for the physiological outcomes for both participants are presented in Table 2 (peak torque, time to peak torque), Table 3 (neuromuscular activation), and Figures 2, 3, 4, and 5 (neuromuscular fatigue).

Participant 1 increased the peak torque at 60º/s and 180 º/s in the extensors and flexors on his paretic side, and in the flexors on his non-paretic side. Conversely, the peak torque in the extensors on his non-paretic side decreased. Notably, the peak torque at 180 º/s increased by 144% in the flexors on his paretic side. The time to peak torque at 60º/s was reduced post-intervention for the flexors and extensors on his paretic and non-paretic sides. Time to peak torque at 180º/s was reduced after the intervention in all but the paretic extensors. Therefore, he was able to reach peak torque in a shorter period of time for almost all muscles tested at both velocities post-intervention.

Participant 2 increased the peak torque at 60º/s and 180 º/s in the extensors on her paretic side and in the flexors on her non-paretic side. Conversely, the peak torque at 60º/s and 180 º/s in the flexors on her paretic side and in the extensors on her non-paretic side either showed no change or decreased. The time to peak torque at 60 º/s decreased post-intervention for the extensors and flexors on her paretic side, and increased for the extensors and flexors on her non-paretic side. The time to peak torque at 180 º/s decreased for the flexors of her paretic side and the extensors of her non-paretic side. However, the time increased on her extensors of her paretic side and flexors of her non-paretic side. Therefore, she was able to reach peak torque in a shorter period of time for both muscle groups on her paretic side, but not on her non-paretic side at 60 º/s. At the 180 º/s velocity, she was able to reach peak torque in a shorter amount of time in two of the four muscles.

Table 2: Pre- and Post-Intervention Data for Peak Torque and Time to Peak Torque for Both Participants

	Extensors (Paretic)		%Δ	Extensors (Non-Paretic)		%Δ	Flexors (Paretic)		%Δ	Flexors (Non-Paretic)		%Δ
Participant 1												
	Pre	Post		Pre	Post		Pre	Post		Pre	Post	
Peak Torque 60∘/s (N-m)	125	146	16.8%	123	123	0%	50	57	14.0%	56	69	23.2%
Time to Peak Torque 60∘/s (Seconds)	0.87	0.79	-9.2%	0.93	0.94	1.1%	0.72	0.62	-13.9%	0.86	0.54	-37.2%
Peak Torque 180∘/s (N-m)	77	84	9.1%	80	73	-8.8%	34	83	144.0%	37	72	94.6%
Time to Peak Torque 180∘/s (Seconds)	0.36	0.27	-25.0%	0.41	0.38	-7.3%	0.26	0.27	3.85%	0.32	0.19	-40.6%
Participant 2												
Peak Torque 60∘/s (N-m)	45	52	15.6%	64	54	-15.6%	20	20	0%	19	23	21.1%
Time to Peak Torque 60∘/s (Seconds)	1.05	1.01	-3.8%	1.03	1.17	13.6%	0.85	0.72	-15.3%	0.56	0.57	1.8%
Peak Torque 180∘/s (N-m)	34	35	2.9%	41	34	-17.1%	15	12	-20.0%	12	14	16.7%
Time to Peak Torque 180∘/s (Seconds)	0.40	0.42	5.0%	0.44	0.43	-2.3%	0.29	0.23	-20.7%	0.24	0.26	8.3%

Abbreviations: %Δ (percent change).

In Participant 1, the average neuromuscular activation (% sub-MVIC) over the three sets in the flexors on his paretic side was higher post-intervention. For his remaining muscles, as well as all muscles in Participant 2, the average neuromuscular activation was lower post-intervention. Therefore, in general, both participants demonstrated lower activation levels when performing their 60 °/s repetitions post-intervention.

Table 3: Pre- and Post-Intervention Data for Neuromuscular Activation for Both Participants

	Participant 1 - Pre (uV)				Participant 1 – Post (uV)			
	Set 1	Set 2	Set 3	Avg (%)	Set 1	Set 2	Set 3	Avg (%)
Extensors (Paretic)	460.06	495.04	460.93	472.01	356.65	*	*	356.65
Flexors (Paretic)	150.04	243.29	226.83	206.72	263.68	373.20	194.06	276.98
Extensors (Non-paretic)	414.30	452.62	473.16	446.69	394.39	384.21	390.88	389.82
Flexors (Non-paretic)	235.23	244.00	232.17	237.13	117.18	124.24	118.85	120.09
	Participant 2 - Pre (uV)				Participant 2 – Post (uV)			
Extensors (Paretic)	138.21	124.61	131.54	131.45	91.93	92.18	93.96	92.69
Flexors (Paretic)	173.00	173.61	189.94	178.85	76.06	71.74	72.18	73.32
Extensors (Non-paretic)	173.97	243.85	262.39	226.73	96.93	88.69	79.79	88.47
Flexors (Non-paretic)	241.43	280.68	302.56	274.89	312.65	257.35	169.12	246.37

Abbreviations: Avg (Average).

** Post-intervention data for participant 1 was not complete due to equipment failure during data collection.*

In Participant 1, fatigability was less in the flexors of his paretic side. Conversely, fatigability was approximately the same in the flexors of his non-paretic side, and greater in the extensors of his paretic and non-paretic sides. For Participant 2, fatigability was less in the extensors of her paretic and non-paretic limbs. Conversely, fatigability was approximately the same in the flexors of her non-paretic side and greater in the flexors of her paretic side.

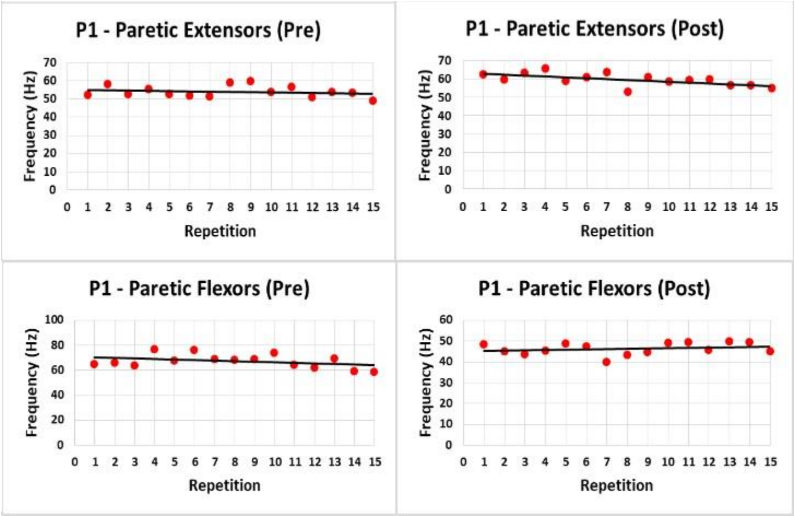

Figure 2: Pre- and Post-Intervention Data for Neuromuscular Fatigue in the Paretic Limb for Participant 1. The slope of the trend line indicates the fatigability of the muscle over the course of the set (increased positive slope = increased fatigability, increased negative slope = decreased fatigability).

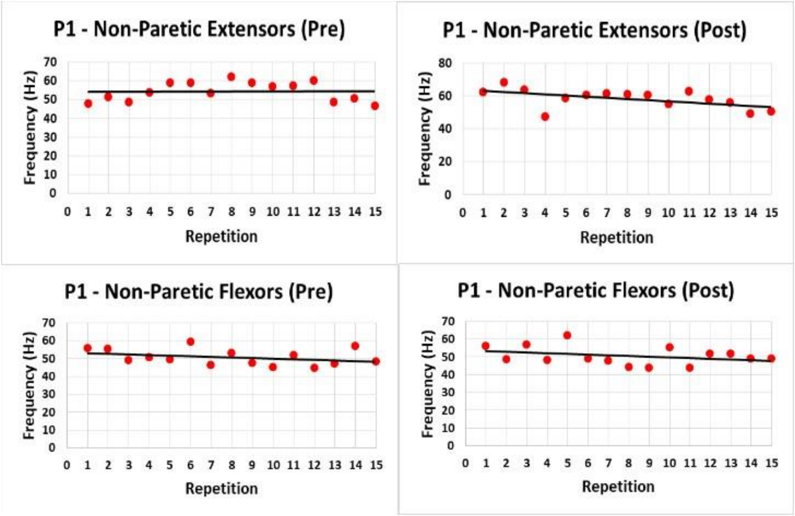

Figure 3: Pre- and Post-Intervention Data for Neuromuscular Fatigue in the Non-paretic Limb for Participant 1. The slope of the trend line indicates the fatigability of the muscle over the course of the set (increased positive slope = increased fatigability, increased negative slope = decreased fatigability).

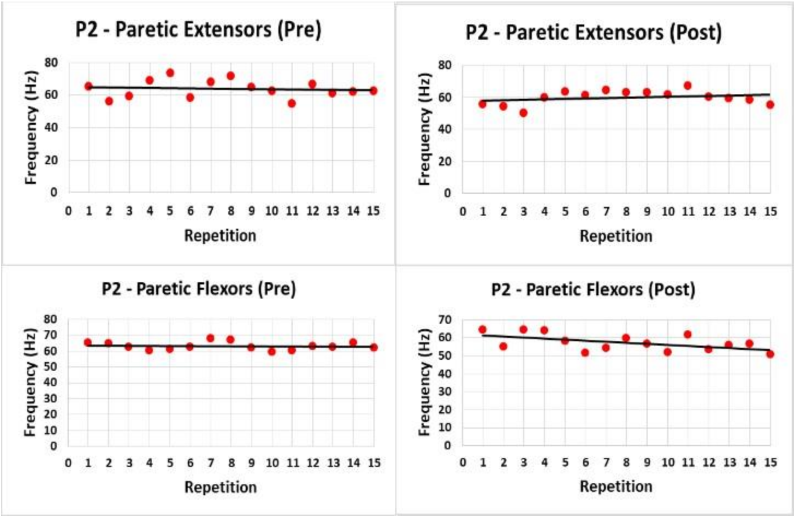

Figure 4: Pre- and Post-Intervention Data for Neuromuscular Fatigue in the Paretic Limb for Participant 2. The slope of the trend line indicates the fatigability of the muscle over the course of the set (increased positive slope = increased fatigability, increased negative slope = decreased fatigability).

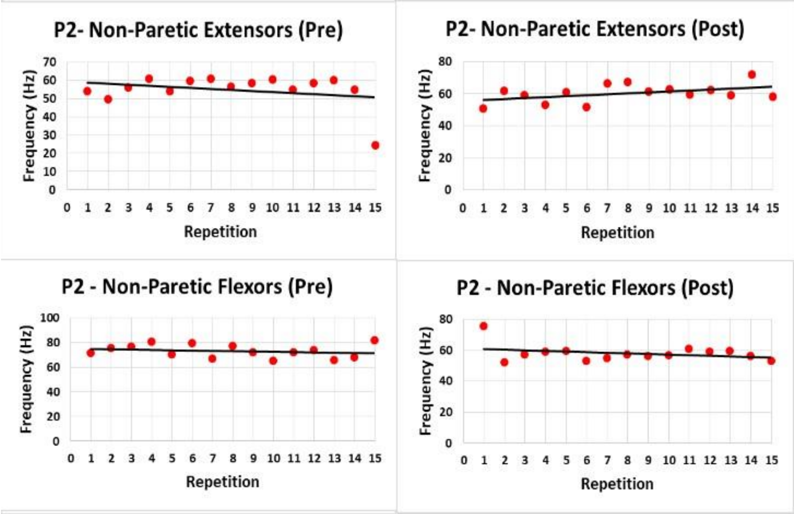

Figure 5: Pre- and Post-Intervention Data for Neuromuscular Fatigue in the Non-Paretic Limb for Participant 2. The slope of the trend line indicates the fatigability of the muscle over the course of the set (increased positive slope = increased fatigability, increased negative slope = decreased fatigability).

4.3 Functional Outcomes

Pre- and post-intervention data for the clinical/functional outcomes for both participants are presented in Table 4.

Participant 1 improved his walking speed and endurance. His self-selected walking speed (10MWT) increased from 1.33 m/s to 1.35 m/s, and his maximal walking speed (10MWT) increased from 2.04 m/s to 2.10 m/s. Neither of these changes met the threshold for a MCID (see *2.9.2.5*). His walking endurance (6MWT) improved from 480 meters to 535 meters. This change did not meet the threshold for a MCID for fast walkers (see *2.9.2.4*). His dynamic balance and transfer ability (BBS) demonstrated no change post-intervention. However, his confidence in performing activities without losing balance (ABC Scale) improved from 88.8% to 91.9%. A threshold for a MCID for this outcome has not been established for this outcome in stroke patients (see *2.9.2.2*). All domains of the SIS improved post intervention, with the exception of the communication and mobility domains.

Participant 2 also improved her walking speed and endurance. Her self-selected walking speed (10MWT) increased from 0.60 m/s to 0.77 m/s, and her maximal walking speed (10MWT) increased from 0.91 m/s to 1.07 m/s. Both of these changes met the threshold for a MCID (see *2.9.2.5*). Her walking endurance (6MWT) also improved from 215 meters to 240 meters. This change did not meet the threshold for a MCID for fast walkers (see *2.9.2.4*). Her dynamic balance and transfer ability (BBS) improved from 43 to 49. This change did not meet the threshold for a MCID in acute stroke patients (see 2.9.2.1). Her confidence in performing activities without losing balance (ABC Scale) improved from 63.8% to 86.9%. A threshold for a MCID for this outcome has not been established in stroke patients (see *2.9.2.2*). All domains of the SIS improved post-intervention, with the exception of the participation domain.

In summary, both participants demonstrated a general improvement on each of the clinical/functional outcomes post-intervention. The improvements met the threshold for a MCID for the 10MWT for Participant 2, but did not meet the threshold for Participant 1. The improvements did not meet the thresholds for a MCID for the 6MWT or the BBS for either participant. Improvements for the ABC Scale were relatively small for Participant 1 (3.5% change) and relatively large for Participant 2 (36.2% change).

Table 4: Pre- and Post-Intervention Data for the Clinical/Functional Outcomes for Both Participants

	Participant 1 (Pre)	Participant 1 (Post)	%Δ	Participant 2 (Pre)	Participant 2 (Post)	%Δ
10 MWT (Self-Selected Speed)	1.33 m/s	1.35 m/s	1.5%	0.60 m/s	0.77 m/s	27.7%
10 MWT (Fastest Speed)	2.04 m/s	2.10 m/s	2.9%	0.91 m/s	1.07 m/s	17.7%
BBS	54	54	0%	43	49	14.0%
ABC Scale	88.8%	91.9%	3.5%	63.8%	86.9%	36.2%
6 MWT	480 meters	535 meters	11.5%	215 meters	240 meters	11.6%
Stroke Impact Scale						
Physical Strength	48	60		50	70	
Memory/Thinking	60	69		66	74	
Emotion	42	49		42	36	
Communication	71	69		77	77	
ADL	70	70		74	74	
Mobility	71	69		69	69	
Hand Function	64	72		48	71	
Participation	63	73		68	63	
Overall Recovery	80	95		75	90	

Abbreviations: 10MWT, 10 meter walk test; BBS, Berg balance scale; ABC Scale: Activities specific balance scale; 6MWT, 6 minute walk test; ADL, Activities of daily living.

5. Discussion

This case series examined the effects of a 4-week progressive isokinetic RT program on neuromuscular and clinical outcomes in two participants with a history of stroke. While both participants generally improved their walking capacity, clinical outcomes, and quality of life, the results of their physiological outcomes after the intervention were quite different.

5.1 Effects of Intervention on Physiological Outcomes

Both participants improved certain aspects of their muscular strength and power development after the intervention. The differing responses between the two participants for the physiological outcomes were unexpected since both participants received the same treatment program. However, since the effects of a stroke will differ between individuals, it is reasonable to suggest that the response to a RT program may also vary between individuals.

Changes in neuromuscular activation and fatigue were examined in this case series. Our findings suggest that the total volume, intensity, and/or modality used in the current study may not be sufficient for this population. In comparison to previous studies, the current study used a lower total training volume. A study by Clark et al. (2012) demonstrated improved torque output in both the paretic and non-paretic limbs of chronic stroke individuals after 5 weeks of RT training only on the paretic limb and 3 weeks of gait training. However, there are several important differences between the RT program used in this study and the one used in the current study. In the study by Clark et al. (2012), participants completed an ISD-based RT program that targeted the hip, knee, ankle muscles, and functional tasks that involved hip flexion/extension, knee flexion/extension and ankle plantarflexion/dorsiflexion. Additionally, participants in the study by Clark et al. (2012) were progressed over the 5-week program by either increasing the weekly training volume or training intensity.

The level of neuromuscular activation generally decreased after the intervention in both participants. Since both participants concurrently demonstrated improvements in muscular strength and power in their paretic limb post-intervention, it could be argued that the lower activation levels represent a change in muscle recruitment strategies post-intervention (e.g., a change from recruiting motor units containing primarily Type I muscle fibers pre-intervention to recruiting motor units containing primarily Type II muscle fibers post-intervention). It is difficult to compare our findings related to neuromuscular activation to what has been reported in previous studies (Clark et al., 2012; Engardt, Knutsson, Jonsson, & Sternhog, 1995). When comparing signals between sessions, individuals, or muscle groups, EMG signals must be normalized (see *2.9.1*). Neither Clark et al. (2012) nor Engardt et al. (1995) described whether the EMG signals collected in their studies were normalized or (if they were) the method(s) of normalization that was used. Therefore, a direct comparison of the results of the current study with those of these two studies is problematic. In the current study, the normalization method was based on the protocol described by Tabard-Fougere et al. (2018) and included the use of sub-maximal contractions obtained during MMT techniques (see *2.9.1*). The major limitation of this normalization method is that the results of Tabard-Fougere et al. (2018) are based on healthy individuals with no neurological conditions. Since the use of traditional MVIC-based normalization methods is problematic in individuals post-stroke (see *2.9.1*), the lack of a validated method to normalize EMG amplitudes in such individuals is a major limitation in this area and requires further investigation in the future.

It is important to note that the degree of change in neuromuscular activation and fatigue during the testing procedures used in the current study may not correspond to the degree of change in clinical outcomes. Although investigating such neuromuscular parameters may be important from a theoretical standpoint in terms of explaining physiological changes in muscle function post-intervention, it could be argued that the degree of change in clinical outcomes is more important and relevant to the individual.

Regarding changes noted in the participants' non-paretic (untrained) limb, cross education is a well-known phenomenon that has been used to explain increases in muscular strength and power in an untrained limb following RT programs that involve the training of a single limb (Munn, Herbert, Hancock, & Gandevia, 2005). In the current study, the effects of cross education may have occurred to some extent as both participants demonstrated certain changes in the peak torque, time to peak torque, neuromuscular activation, and neuromuscular fatigue in their non-paretic (untrained) limb. These results are consistent with Clark et al. (2012), who also found that concentric training improved non-paretic leg strength in a group of chronic stroke individuals (although these changes were generally not statistically significant). While improving physiological outcomes in the non-paretic leg was not the main focus of this study, it would be interesting to see whether eccentric unilateral RT through the use of an ISD may provide greater neural adaptations in the paretic (trained) and/or non-paretic (untrained) limbs. Clark et al. (2012) found that eccentric training of the paretic leg was more effective than concentric-focused training in improving the power output and neuromuscular activation of non-paretic limb muscles (e.g., rectus femoris and vastus medialis). However, it is important to note that this finding should be interpreted with caution since Clark et al. (2012) did not describe the EMG normalization method that was used in their study.

5.2 Effects of Intervention on Walking and Clinical Outcomes

Walking speed and endurance are both important aspects that influence one's walking capacity. Walking speed has been shown to be sensitive to changes over time and is often used to reflect the amount of recovery in post stroke individuals (Salbach et al., 2001; Schmid et al., 2007). The results of the current study suggest that isokinetic muscle strengthening of the lower extremities may lead to improvements in walking capacity even when the training frequency and volume is relatively low and only performed on the paretic limb. These results are comparable to those of Kim et al. (2001), who reported improvements in gait velocity in a sample of chronic stroke individuals after performing a 6-week unilateral (paretic limb) ISD-based RT program. Additionally, Dalgas, Severisen, & Overgaard (2012) reported a positive correlation between the improvement in walking speed (measured with the 10MWT) and walking endurance (measured with the 6MWT) in their study. Although a correlation analysis was not performed in the current study, it is worth noting that both participants accomplished positive changes in both walking speed (10MWT) and walking endurance (6MWT).

Community participation and quality of life were measured in the current study through the SIS. Both participants reported a lower score for the Participation item and the same score for the ADL item in the SIS after the intervention. In prior studies, walking speed has been shown to be positively associated with an individual's ability to ambulate within their household, but may not be a significant predictor of an individual's ability to ambulate within their community (Fulk, Reynolds, Mondal, & Deustch, 2010; Lord & Rochester, 2008). Additionally, walking endurance also has also been shown to be positively associated with an individual's walking ability in their community (Fulk et al., 2010). Neither of these associations was observed in the current study as the scores in the Participation and ADL items in the SIS were lower, despite improvements in the walking speed (10MWT) and walking endurance (6MWT), after the intervention. However, it is important to note that the Participation item may have been decreased to some extent due to the COVID-19 restrictions placed in the community during the time the study was conducted.

Dynamic and self-perceived ability to balance were also used as outcomes in the current study. The participants' dynamic balance did not change after the intervention, which suggests that only training the paretic limb may not be sufficient to affect this outcome for this population. Sen et al. (2015) reported improvements in dynamic balance (measured with the BBS) post-intervention in a group of individuals with sub-acute stroke. However, the RT program used in their study incorporated a significantly greater training volume and targeted both limbs instead of only the paretic limb. It is also interesting to note that, in the current study, both participants' self-perceived ability to balance improved post-intervention while their dynamic balance remained the same. This may suggest that the two outcomes are assessing different constructs, or reflect that the participants' fear of falling was improved after the intervention due to other improvements in the physiological and clinical outcomes.

5.3 Limitations & Future Directions

The major limitations of the current study is the small sample size, which prevented the use of statistical analyses to make inferences regarding effects of the training program that may be expected within the sub-acute stroke population. Additionally, the lack of a control intervention prevents any inferences to be made regarding the relative impact of the training program and natural history. Finally, although the original aim of the study was to compare the relative effects of a concentric-only ISD-based RT program and an eccentric-only ISD-based RT program, the impact of the COVID-19 pandemic prevented the inclusion of any participants who completed the eccentric-only program. It would be beneficial to conduct further studies in the future to explore the application of an eccentric-only RT program for individuals with sub-acute stroke as previous studies have found significant improvements in both physiological and clinical outcomes following such a program in individuals with chronic stroke. It would also be important to conduct further studies to compare different training parameters (e.g., duration, volume, intensity) to determine whether a particular set of parameters leads to the best outcome for post stroke individuals.

References

Abbruzzese, G., Morena, M., Spadavecchia, L., & Schieppati, M. (1994). Response of arm flexor muscles to magnetic and electrical brain stimulation during shortening and lengthening tasks in man. *The Journal of Physiology, 481*(2), 499-507.

Abdollahi, I., Taghizadeh, A., Shakeri, H., Eivazi, M., & Jaberzadeh, S. (2015). The relationship between isokinetic muscle strength and spasticity in the lower limbs of stroke patients. *Journal of Bodywork and Movement Therapies*, *19*(2), 284-290.

Allison, G. T., Godfrey, P., & Robinson, G. (1998). EMG signal amplitude assessment during abdominal bracing and hollowing. *Journal of Electromyography and Kinesiology, 8*(1), 51-57.

Allison, G. T., Marshall, R. N., & Singer, K. P. (1993). EMG signal amplitude normalization technique in stretch-shortening cycle movements. *Journal of Electromyography and Kinesiology, 3*(4), 236-244.

Algurén, B., Lundgren-Nilsson, Å., & Sunnerhagen, K. S. (2010). Functioning of stroke survivors–a validation of the ICF core set for stroke in Sweden. *Disability and Rehabilitation, 32*(7), 551-559.

Andersson, C., Grooten, W., Hellsten, M., Kaping, K., & Mattsson, E. (2003). Adults with cerebral palsy: walking ability after progressive strength training. *Developmental Medicine and Child Neurology, 45*(4), 220-228.

Andrews, A. W., & Bohannon, R. W. (2000). Distribution of muscle strength impairments following stroke. *Clinical Rehabilitation, 14*(1), 79-87.

Arboix, A., García-Eroles, L., Sellarés, N., Raga, A., Oliveres, M., & Massons, J. (2009). Infarction in the territory of the anterior cerebral artery: clinical study of 51 patients. *BMC neurology, 9*(1), 30.

Arboix, A., & Martí-Vilalta, J. L. (2009). Lacunar stroke. *Expert Review of Neurotherapeutics, 9*(2), 179-196.

Arshavsky, Y. I., Berkinblit, M. B., Fukson, O. I., Gelfand, I. M., & Orlovsky, G. N. (1972). Recording of neurones of the dorsal spinocerebellar tract during evoked locomotion. Brain research.

ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. (2002). ATS statement: guidelines for the six-minute walk test. *American Journal of Respiratory Critical Care Medicine, 166*, 111-117.

Balaban, B., & Tok, F. (2014). Gait disturbances in patients with stroke. *Physical Medicine and Rehabilitation, 6*(7), 635-642.

Balakrishnan, S., & Ward, A. B. (2013). The diagnosis and management of adults with spasticity. In Handbook of Clinical Neurology (Vol. 110, pp. 145-160). Elsevier.

Baltzopoulos, V., & Brodie, D. A. (1989). Isokinetic dynamometry. *Sports Medicine, 8*(2), 101-116.

Banerjee, C., & Chimowitz, M. I. (2017). Stroke caused by atherosclerosis of the major intracranial arteries. *Circulation Research, 120*(3), 502-513.

Barria, E., & Jagadeesh, J.M. (1994). Multiresolution estimation of motion using the wavelet transform. *Proceedings of the SPIE, 2303*, 542-553.

Batchelor, F. A., Mackintosh, S. F., Said, C. M., & Hill, K. D. (2012). Falls after stroke. *International Journal of Stroke, 7*(6), 482-490.

Bederson, J. B., Connolly Jr, E. S., Batjer, H. H., Dacey, R. G., Dion, J. E., Diringer, M. N., ... & Rosenwasser, R. H. (2009). Guidelines for the management of aneurysmal subarachnoid hemorrhage: a statement for healthcare professionals from a special writing group of the stroke council, american heart association. *Stroke, 40*(3), 994-1025.

Berg, K. O., Maki, B. E., Williams, J. I., Holliday, P. J., & Wood-Dauphinee, S. L. (1992). Clinical and laboratory measures of postural balance in an elderly population. *Archives of Physical Medicine and Rehabilitation, 73*(11), 1073-1080.

Berg, K., Wood-Dauphine, S., Williams, J. I., & Gayton, D. (1989). Measuring balance in the elderly: preliminary development of an instrument. *Physiotherapy Canada, 41*(6), 304-311.

Betschart, M., Lauzière, S., Miéville, C., McFadyen, B. J., & Nadeau, S. (2017). Changes in lower limb muscle activity after walking on a split-belt treadmill in individuals post-stroke. *Journal of Electromyography and Kinesiology, 32*, 93-100.

Beyaert, C., Vasa, R., & Frykberg, G. E. (2015). Gait post-stroke: pathophysiology and rehabilitation strategies. *Clinical Neurophysiology, 45*(4-5), 335-355.

Bigland, B., & Lippold, O. C. J. (1954). The relation between force, velocity and integrated electrical activity in human muscles. *The Journal of Physiology, 123*(1), 214-224.

Bleyenheuft, C., Cockx, S., Caty, G., Stoquart, G., Lejeune, T., & Detrembleur, C. (2009). The effect of botulinum toxin injections on gait control in spastic stroke patients presenting with a stiff-knee gait. *Gait & Posture, 30*(2), 168-172.

Bobath B. *Adult Hemiplegia: Evaluation and Treatment*, third edition. Oxford, England: Heinemann, 1990.

Booth, F. W. (1982). Effect of limb immobilization on skeletal muscle. *Journal of Applied Physiology, 52*(5), 1113-1118.

Booth, F. W., & Seider, M. J. (1979). Early change in skeletal muscle protein synthesis after limb immobilization of rats. *Journal of Applied Physiology, 47*(5), 974-977.

Boonsinsukh, R., Panichareon, L., & Phansuwan-Pujito, P. (2009). Light touch cue through a cane improves pelvic stability during walking in stroke. *Archives of Physical Medicine and Rehabilitation, 90*(6), 919-926.

Boulanger, J. M., Lindsay, M. P., Gubitz, G., Smith, E. E., Stotts, G., Foley, N., ... & Butcher, K. (2018). Canadian stroke best practice recommendations for acute stroke management: prehospital, emergency department, and acute inpatient stroke care, update 2018. *International Journal of Stroke, 13*(9), 949-984.

Brandstater, M. E., Gowland, C., & Clark, B. M. (1983). Hemiplegic gait: analysis of temporal variables. *Archives of Physical Medicine and Rehabilitation, 64*(12), 583-587.

Brewer, L., Horgan, F., Hickey, A., & Williams, D. (2013). Stroke rehabilitation: recent advances and future therapies. *QJM: An International Journal of Medicine, 106*(1), 11-25.

Bruno, A., Graff-Radford, N. R., Biller, J., & Adams Jr, H. P. (1989). Anterior choroidal artery territory infarction: a small vessel disease. *Stroke*, *20*(5), 616-619.

Brunnstrom, S. (1970). Movement therapy in hemiplegia. *A Neurophysiological Approach*, 113-122.

Burden, A. (2010). How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. *Journal of Electromyography and Kinesiology, 20*(6), 1023-1035.

Chan, P. P., Tou, J. I. S., Mimi, M. T., & Ng, S. S. (2017). Reliability and validity of the timed up and go test with a motor task in people with chronic stroke. *Archives of Physical Medicine and Rehabilitation, 98*(11), 2213-2220.

Chen, C. L., Chang, K. J., Wu, P. Y., Chi, C. H., Chang, S. T., & Cheng, Y. Y. (2015). Comparison of the effects between isokinetic and isotonic strength training in subacute stroke patients. *Journal of Stroke and Cerebrovascular Diseases, 24*(6), 1317-1323.

Chou, C. Y., Chien, C. W., Hsueh, I. P., Sheu, C. F., Wang, C. H., & Hsieh, C. L. (2006). Developing a short form of the Berg Balance Scale for people with stroke. *Physical Therapy, 86*(2), 195-204.

Chowdhury, R., Reaz, M., Ali, M., Bakar, A., Chellappan, K., & Chang, T. (2013). Surface electromyography signal processing and classification techniques. *Sensors, 13*(9), 12431-12466.

Clancy, E. A., Morin, E. L., & Merletti, R. (2002). Sampling, noise-reduction and amplitude estimation issues in surface electromyography. *Journal of Electromyography and Kinesiology, 12*(1), 1-16.

Clark, D. J., & Patten, C. (2013). Eccentric versus concentric resistance training to enhance neuromuscular activation and walking speed following stroke. *Neurorehabilitation and Neural Repair*, *27*(4), 335-344.

Costa, M. V., Pereira, L. A., Oliveira, R. S., Pedro, R. E., Camata, T. V., Abrão, T., ... & Altimari, L. R. (2010, August). Fourier and wavelet spectral analysis of EMG signals in maximal constant load dynamic exercise. In Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE (pp. 4622-4625). IEEE.

Criswell, E. (2010). *Cram's introduction to surface electromyography*. Jones & Bartlett Publishers.

Cruz-Jentoft, A. J., Bahat, G., Bauer, J., Boirie, Y., Bruyère, O., Cederholm, T., ... & Schneider, S. M. (2018). Sarcopenia: revised European consensus on definition and diagnosis. Age and ageing.

Dalgas, U., Severinsen, K., & Overgaard, K. (2012). Relations between 6 minute walking distance and 10 meter walking speed in patients with multiple sclerosis and stroke. *Archives of Physical Medicine and Rehabilitation, 93*(7), 1167-1172.

Danner, S. M., Hofstoetter, U. S., Freundl, B., Binder, H., Mayr, W., Rattay, F., & Minassian, K. (2015). Human spinal locomotor control is based on flexibly organized burst generators. *Brain, 138*(3), 577-588.

Dantas, J. L., Camata, T. V., Brunetto, M. A., Moraes, A. C., Abrão, T., & Altimari, L. R. (2010, August). Fourier and Wavelet spectral analysis of EMG signals in isometric and dynamic maximal effort exercise. In Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE (pp. 5979-5982). IEEE.

da Silva, Larivière, C., Arsenault, A. B., Nadeau, S., & Plamondon, A. (2008). The comparison of wavelet-and Fourier-based electromyographic indices of back muscle fatigue during dynamic contractions: validity and reliability results. *Electromyography and Clinical Neurophysiology, 48*(3-4), 147-162.

Deecke, L., Grözinger, B., & Kornhuber, H. H. (1976). Voluntary finger movement in man: cerebral potentials and theory. *Biological Cybernetics, 23*(2), 99-119.

De Luca, C. J. (1997). The use of surface electromyography in biomechanics. Journal of Applied Biomechanics, 13(2), 135-163.

De Luca, G. (2003). Fundamental concepts in EMG signal acquisition. *Copyright Delsys Inc.*

Dickstein, R. (2008). Rehabilitation of gait speed after stroke: a critical review of intervention approaches. *Neurorehabilitation and Neural Repair, 22*(6), 649-660.

Dietz, V. (1992). Human neuronal control of automatic functional movements: interaction between central programs and afferent input. *Physiological Reviews, 72*(1), 33-69.

Dobkin, B. H. (2008). Training and exercise to drive poststroke recovery. *Nature Reviews Neurology, 4*(2), 76.

Doherty, T. J. (2003). Invited review: aging and sarcopenia. *Journal of Applied Physiology*.

Dominici, N., Ivanenko, Y. P., Cappellini, G., d'Avella, A., Mondì, V., Cicchese, M., ... & Lacquaniti, F. (2011). Locomotor primitives in newborn babies and their development. *Science, 334*(6058), 997-999.

Douglas, J., Pearson, S., Ross, A., & McGuigan, M. (2017). Chronic adaptations to eccentric training: a systematic review. *Sports Medicine, 47*(5), 917-941.

Duncan, P. W., Zorowitz, R., Bates, B., Choi, J. Y., Glasberg, J. J., Graham, G. D., ... & Reker, D. (2005). Management of adult stroke rehabilitation care: a clinical practice guideline. *Stroke, 36*(9), e100-e143.

Dunn, A., Marsden, D. L., Nugent, E., Van Vliet, P., Spratt, N. J., Attia, J., & Callister, R. (2015). Protocol variations and six-minute walk test performance in stroke survivors: a systematic review with meta-analysis. *Stroke Research and Treatment*.

Dvir, Z. (2004). *Isokinetics: muscle testing, interpretation, and clinical applications.* Elsevier Health Sciences.

Engardt, M., Knutsson, E., Jonsson, M., & Sternhag, M. (1995). Dynamic muscle strength training in stroke patients: effects on knee extension torque, electromyographic activity, and motor function. *Archives of Physical Medicine and Rehabilitation, 76*(5), 419-425.

Enright, P. L. (2003). The six-minute walk test. *Respiratory Care, 48*(8), 783-785.

Evans, R. L., Connis, R. T., Bishop, D. S., Hendricks, R. D., & Haselkorn, J. K. (1994). Stroke: a family dilemma. *Disability and Rehabilitation, 16*(3), 110-118.

Falvo, M. J., Sirevaag, E. J., Rohrbaugh, J. W., & Earhart, G. M. (2010). Resistance training induces supraspinal adaptations: evidence from movement-related cortical potentials. *European Journal of Applied Physiology, 109*(5), 923-933.

Fang, Y., Siemionow, V., Sahgal, V., Xiong, F., & Yue, G. H. (2004). Distinct brain activation patterns for human maximal voluntary eccentric and concentric muscle actions. *Brain Research, 1023*(2), 200-212.

Fang, Y., Siemionow, V., Sahgal, V., Xiong, F., & Yue, G. H. (2001). Greater movement-related cortical potential during human eccentric versus concentric muscle contractions. *Journal of Neurophysiology, 86*(4), 1764-1772.

Farina, D., Merletti, R., Nazzaro, M., & Caruso, I. (2001). Effect of joint angle on EMG variables in leg and thigh muscles. *IEEE Engineering in Medicine and Biology Magazine, 20*(6), 62-71.

Fisher, C.M. (1982). Lacunar strokes and infarcts: a review. *Neurology, 32*. 871-876

Feigin, V. L., Norrving, B., & Mensah, G. A. (2017). Global burden of stroke. *Circulation research, 120*(3), 439-448.

Feigin, V. L., Barker-Collo, S., McNaughton, H., Brown, P., & Kerse, N. (2008). Long-term neuropsychological and functional outcomes in stroke survivors: current evidence and perspectives for new research. *International Journal of Stroke, 3*(1), 33-40.

Forssberg, H. (1985). Ontogeny of human locomotor control I. Infant stepping, supported locomotion and transition to independent locomotion. *Experimental Brain Research, 57*(3), 480-493.

Francisco, G. E., & McGuire, J. R. (2012). Poststroke spasticity management. *Stroke, 43*(11), 3132-3136.

Fritz, S., & Lusardi, M. (2009). White paper: “walking speed: the sixth vital sign”. *Journal of Geriatric Physical Therapy, 32*(2), 2-5.

Fukuda, T. Y., Alvarez, A. S., Nassri, L. F. G., & Godoy, C. M. G. D. (2008). Quantitative electromyographic assessment of facial muscles in cross-bite female children. *Brazilian Journal of Biomedical Engineering, 24*(2), 121-129.

Fukuda, T. Y., Echeimberg, J. O., Pompeu, J. E., Lucareli, P. R. G., Garbelotti, S., Gimenes, R. O., & Apolinário, A. (2010). Root mean square value of the electromyographic signal in the isometric torque of the quadriceps, hamstrings and brachial biceps muscles in female subjects. *The Journal of Applied Research, 10*(1), 32-39.

Fulk, G. D., & He, Y. (2018). Minimal clinically important difference of the 6-minute walk test in people with stroke. *Journal of Neurologic Physical Therapy, 42*(4), 235-240.

Fulk, G. D., Reynolds, C., Mondal, S., & Deutsch, J. E. (2010). Predicting home and community walking activity in people with stroke. *Archives of Physical Medicine and Rehabilitation, 91*(10), 1582-1586.

Gjelsvik, B. E. B., & Syre, L. (2016). T*he Bobath concept in adult neurology*. Thieme.

Goetz, C. G. (Ed.). (2007). *Textbook of clinical neurology* (Vol. 355). Elsevier Health Sciences.

Gorelick, P. B., Wong, K. S., Bae, H. J., & Pandey, D. K. (2008). Large artery intracranial occlusive disease: a large worldwide burden but a relatively neglected frontier. Stroke, 39(8), 2396-2399.

Gracies, J. M. (2005). Pathophysiology of spastic paresis. I: Paresis and soft tissue changes. *Muscle & Nerve: Official Journal of the American Association of Electrodiagnostic Medicine, 31*(5), 535-551.

Gracies, J. M. (2005). Pathophysiology of spastic paresis. II: Emergence of muscle overactivity. *Muscle & Nerve: Official Journal of the American Association of Electrodiagnostic Medicine, 31*(5), 552-571.

Grau, A. J., Weimar, C., Buggle, F., Heinrich, A., Goertler, M., Neumaier, S., ... & Diener, H. C. (2001). Risk factors, outcome, and treatment in subtypes of ischemic stroke: the German stroke data bank. *Stroke, 32*(11), 2559-2566.

Guertin, P. A. (2009). The mammalian central pattern generator for locomotion. *Brain Research Reviews, 62*(1), 45-56.

Hafsteinsdóttir, T. B., Rensink, M., & Schuurmans, M. (2014). Clinimetric properties of the Timed Up and Go Test for patients with stroke: a systematic review. *Topics in Stroke Rehabilitation, 21*(3), 197-210.

Hans, J. (2011). *Clinical neuroanatomy: brain circuitry and its disorders*. Springer Science & Business Media.

Hamani, C., Saint-Cyr, J. A., Fraser, J., Kaplitt, M., & Lozano, A. M. (2004). The subthalamic nucleus in the context of movement disorders. Brain, 127(1), 4-20.

Hammami, N., Coroian, F. O., Julia, M., Amri, M., Mottet, D., Hérisson, C., & Laffont, I. (2012). Isokinetic muscle strengthening after acquired cerebral damage: a literature review. *Annals of Physical and Rehabilitation Medicine, 55*(4), 279-291.

Hartkamp, M. J., van der Grond, J., van Everdingen, K. J., Hillen, B., & Mali, W. P. (1999). Circle of Willis collateral flow investigated by magnetic resonance angiography. *Stroke, 30*(12), 2671-2678.

Harvey, R. L., Macko, R. F., Stein, J., Winstein, C. J., & Zorowitz, R. D. (2008). *Stroke recovery and rehabilitation*. Demos Medical Publishing.

Healey, J. S., Connolly, S. J., Gold, M. R., Israel, C. W., Van Gelder, I. C., Capucci, A., ... & Hohnloser, S. H. (2012). Subclinical atrial fibrillation and the risk of stroke. *New England Journal of Medicine, 366*(2), 120-129.

Helgason, C., Caplan, L. R., Goodwin, J., & Hedges, T. (1986). Anterior choroidal artery territory infarction: report of cases and review. *Archives of Neurology, 43*(7), 681-686.

Heung, T. H., & Ng, S. S. (2009). Effect of seat height and turning direction on the timed up and go test scores of people after stroke. *Journal of Rehabilitation Medicine, 41*(9), 719-722.

Higginson, J. S., Zajac, F. E., Neptune, R. R., Kautz, S. A., & Delp, S. L. (2006). Muscle contributions to support during gait in an individual with post-stroke hemiparesis. *Journal of Biomechanics, 39*(10), 1769-1777.

Hirschberg, G. G., & Nathanson, M. (1952). Electromyographic recording of muscular activity in normal and spastic gaits. *Archives of Physical Medicine and Rehabilitation, 33*(4), 217-225.

Hislop, H., Avers, D., & Brown, M. (2013). *Daniels and Worthingham's muscle Testing-E-Book: Techniques of manual examination and performance testing*. Elsevier Health Sciences.

Jang, S. H. (2012). Motor recovery mechanisms in patients with middle cerebral artery infarct: a mini-review. *European Neurology, 68*(4), 234-239.

Jørgensen, H. S., Nakayama, H., Raaschou, H. O., & Olsen, T. S. (1995). Recovery of walking function in stroke patients: the Copenhagen Stroke Study. *Archives of Physical Medicine and Rehabilitation, 76*(1), 27-32.

Jung, K., Kim, Y., Cha, Y., In, T. S., Hur, Y. G., & Chung, Y. (2015). Effects of gait training with a cane and an augmented pressure sensor for enhancement of weight bearing over the affected lower limb in patients with stroke: a randomized controlled pilot study. *Clinical Rehabilitation, 29*(2), 135-142.

Katz, R. T., & Rymer, W. Z. (1989). Spastic hypertonia: mechanisms and measurement. *Archives of Physical Medicine and Rehabilitation, 70*(2), 144-155.

Kim, J. Y., & Bae, H. J. (2017). Spontaneous intracerebral hemorrhage: management. *Journal of Stroke*, *19*(1), 28.

Kim, C. M., & Eng, J. J. (2003). Symmetry in vertical ground reaction force is accompanied by symmetry in temporal but not distance variables of gait in persons with stroke. *Gait & Posture*, *18*(1), 23-28.

Kim, C. M., & Eng, J. J. (2004). Magnitude and pattern of 3D kinematic and kinetic gait profiles in persons with stroke: relationship to walking speed. *Gait & Posture*, *20*(2), 140-146.

Kirker, S. G. B., Simpson, D. S., Jenner, J. R., & Wing, A. M. (2000). Stepping before standing: hip muscle function in stepping and standing balance after stroke. *Journal of Neurology, Neurosurgery & Psychiatry, 68*(4), 458-464.

Kosak, M., & Smith, T. (2005). Comparison of the 2-, 6-, and 12-minute walk tests in patients with stroke. *Journal of Rehabilitation Research and Development , 42*, 103-7.

Kugler, C., Altenhöner, T., Lochner, P., & Ferbert, A. (2003). Does age influence early recovery from ischemic stroke?. *Journal of neurology, 250*(6), 676-681.

Kumral, E., Bayulkem, G., Evyapan, D., & Yunten, N. (2002). Spectrum of anterior cerebral artery territory infarction: clinical and MRI findings. *European Journal of Neurology, 9*(6), 615-624.

Kwon, Y. H., & Park, J. W. (2011). Different cortical activation patterns during voluntary eccentric and concentric muscle contractions: an fMRI study. *NeuroRehabilitation, 29*(3), 253-259.

Lamontagne, A., Richards, C. L., & Malouin, F. (2000). Coactivation during gait as an adaptive behavior after stroke. *Journal of Electromyography and Kinesiology, 10*(6), 407-415.

Lance, J. W. (1980). The control of muscle tone, reflexes, and movement: Robert Wartenbeg Lecture. *Neurology, 30*(12), 1303-1303.

Lanciego, J. L., Luquin, N., & Obeso, J. A. (2012). Functional neuroanatomy of the basal ganglia. *Cold Spring Harbor Perspectives in Medicine*.

Lang, T., Streeper, T., Cawthon, P., Baldwin, K., Taaffe, D. R., & Harris, T. B. (2010). Sarcopenia: etiology, clinical consequences, intervention, and assessment. *Osteoporosis International, 21*(4), 543-559.

Laufer, Y., Dickstein, R., Chefez, Y., & Marcovitz, E. (2001). The effect of treadmill training on the ambulation of stroke survivors in the early stages of rehabilitation: a randomized study. *Journal of Rehabilitation Research and Development, 38*(1), 69-78.

Lee, D. K., An, D. H., Yoo, W. G., Hwang, B. Y., Kim, T. H., & Oh, J. S. (2017). The effect of isolating the paretic limb on weight-bearing distribution and EMG activity during squats in hemiplegic and healthy individuals. *Topics in Stroke Rehabilitation, 24*(4), 223-227.

Lee, M. J., Kilbreath, S. L., Singh, M. F., Zeman, B., & Davis, G. M. (2010). Effect of progressive resistance training on muscle performance after chronic stroke. *Medicine and Science in Sports and Exercise, 42*(1), 23-34.

Lehmann, J. F., DeLateur, B. J., Fowler, J. R., Warren, C. G., Arnhold, R., Schertzer, G., ... & Chambers, K. H. (1975). Stroke rehabilitation: Outcome and prediction. *Archives of Physical Medicine and Rehabilitation, 56*(9), 383-389.

Lehman, G. J., & McGill, S. M. (1999). The importance of normalization in the interpretation of surface electromyography: a proof of principle. *Journal of Manipulative and Physiological Therapeutics*, *22*(7), 444-446.

Leigh Hollands, K., Hollands, M. A., Zietz, D., Miles Wing, A., Wright, C., & Van Vliet, P. (2010). Kinematics of turning 180 during the timed up and go in stroke survivors with and without falls history. *Neurorehabilitation and Neural Repair, 24*(4), 358-367.

Li, S., & Francisco, G. E. (2015). New insights into the pathophysiology of post-stroke spasticity. *Frontiers in Human Neuroscience, 9,* 192.

Liaw, L. J., Hsieh, C. L., Lo, S. K., Chen, H. M., Lee, S., & Lin, J. H. (2008). The relative and absolute reliability of two balance performance measures in chronic stroke patients. *Disability and Rehabilitation*, *30*(9), 656-661.

Liberato, B., & Krakauer, J. W. (2007). Ischemic stroke: mechanisms, evaluation, and treatment. In *Neurology and clinical neuroscience*. Elsevier Inc..

Lindsay, K. W., Bone, I., & Fuller, G. (2010). Neurology and Neurosurgery Illustrated E-Book. Elsevier Health Sciences.

Liston, R. A., & Brouwer, B. J. (1996). Reliability and validity of measures obtained from stroke patients using the Balance Master. *Archives of Physical Medicine and Rehabilitation, 77*(5), 425-430.

Liu, C. J., & Latham, N. K. (2009). Progressive resistance strength training for improving physical function in older adults. *Cochrane Database of Systematic Reviews*, (3).

Lloyd-Jones, D., Adams, R. J., Brown, T. M., Carnethon, M., Dai, S., De Simone, G., ... & Go, A. (2009). Heart disease and stroke statistics - 2010 update. a report from the American Heart Association. *Circulation*.

Lyaker, M. R., Tulman, D. B., Dimitrova, G. T., Pin, R. H., & Papadimos, T. J. (2013). Arterial embolism. *International Journal of Critical Illness and Injury Science, 3*(1), 77.

Macfarlane, P. A., & Looney, M. A. (2008). Walkway length determination for steady state walking in young and older adults. *Research Quarterly for Exercise and Sport, 79*(2), 261-267.

Mackintosh, S. F., Hill, K., Dodd, K. J., Goldie, P., & Culham, E. (2005). Falls and injury prevention should be part of every stroke rehabilitation plan. *Clinical Rehabilitation, 19*(4), 441-451.

MacKay-Lyons, M. (2002). Central pattern generation of locomotion: a review of the evidence. *Physical therapy, 82*(1), 69-83.

Mackman, N. (2008). Triggers, targets and treatments for thrombosis. *Nature, 451*(7181), 914-918.

Malhotra, S., Pandyan, A. D., Rosewilliam, S., Roffe, C., & Hermens, H. (2011). Spasticity and contractures at the wrist after stroke: time course of development and their association with functional recovery of the upper limb. *Clinical Rehabilitation, 25*(2), 184-191.

Mangla, R., Kolar, B., Almast, J., & Ekholm, S. E. (2011). Border zone infarcts: pathophysiologic and imaging characteristics. *Radiographics*, *31*(5), 1201-1214.

Mao, H. F., Hsueh, I. P., Tang, P. F., Sheu, C. F., & Hsieh, C. L. (2002). Analysis and comparison of the psychometric properties of three balance measures for stroke patients. Stroke, 33(4), 1022-1027.

Marks, M., & Hirschberg, G. G. (1958). Analysis of the hemiplegic gait. *Annals of the New York Academy of Sciences*, *74*(1), 59-77.

Mayer, N. H., & Esquenazi, A. (2003). Muscle overactivity and movement dysfunction in the upper motoneuron syndrome. *Physical medicine and rehabilitation clinics of North America*, *14*(4), 855-883.

Mayer, N. H. (2004). Choosing upper limb muscles for focal intervention after traumatic brain injury. *The Journal of Head Trauma Rehabilitation*, *19*(2), 119-142.

Merletti, R., & Di Torino, P. (1999). Standards for reporting EMG data. *Journal of Electromyography and Kinesiology*, *9*(1), 3-4.

Mesin, L., Merletti, R., & Rainoldi, A. (2009). Surface EMG: the issue of electrode location. *Journal of Electromyography and Kinesiology*, *19*(5), 719-726.

Middleton, A., Fritz, S. L., & Lusardi, M. (2015). Walking speed: the functional vital sign. *Journal of Aging and Physical Activity*, *23*(2), 314-322.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*(1), 167-202.

Milovanović, I., & Popović, D. B. (2012). Principal component analysis of gait kinematics data in acute and chronic stroke patients. *Computational and mathematical methods in medicine*, 2012.

Minassian, K., Hofstoetter, U. S., Dzeladini, F., Guertin, P. A., & Ijspeert, A. (2017). The Human Central Pattern Generator for Locomotion: Does It Exist and Contribute to Walking? *The Neuroscientist, 23*(6), 649-663.

Moritani, T., Muramatsu, S., & Muro, M. (1987). Activity of motor units during concentric and eccentric contractions. American journal of physical medicine, 66(6), 338-350.

Mtui, E., Gruener, G., & FitzGerald, M. T. (2011). *Clinical Neuroanatomy and Neuroscience E-Book*. Elsevier Health Sciences.

Munn, J., Herbert, R. D., Hancock, M. J., & Gandevia, S. C. (2005). Resistance training for strength: effect of number of sets and contraction speed. *Medicine and Science in Sports and Exercise, 37*(9), 1622.

Nardone, A., Romano, C., & Schieppati, M. (1989). Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. *The Journal of Physiology, 409*(1), 451-471.

Neckel, N., Pelliccio, M., Nichols, D., & Hidler, J. (2006). Quantification of functional weakness and abnormal synergy patterns in the lower limb of individuals with chronic stroke. *Journal of Neuroengineering and Rehabilitation, 3*(1), 17.

Ng, S. S., Tsang, W. W., Cheung, T. H., Chung, J. S., To, F. P., & Phoebe, C. Y. (2011). Walkway length, but not turning direction, determines the six-minute walk test distance in individuals with stroke. *Archives of Physical Medicine and Rehabilitation, 92*(5), 806-811.

Ng, S. S., & Shepherd, R. B. (2000). Weakness in patients with stroke: implications for strength training in neurorehabilitation. *Physical Therapy Reviews*, *5*(4), 227-238.

Nosaka, K., & Clarkson, P. M. (1997). Influence of previous concentric exercise on eccentric exercise-induced muscle damage. *Journal of Sports Sciences*, *15*(5), 477-483.

Nosaka, K., & Newton, M. (2002). Repeated eccentric exercise bouts do not exacerbate muscle damage and repair. *The Journal of Strength & Conditioning Research*, *16*(1), 117-122.

Olney, S. J., & Richards, C. (1996). Hemiparetic gait following stroke. Part I: Characteristics. *Gait & Posture*, *4*(2), 136-148.

Olsen, R. K., Moses, S. N., Riggs, L., & Ryan, J. D. (2012). The hippocampus supports multiple cognitive processes through relational binding and comparison. *Frontiers in Human Neuroscience*, 6, 146.

Osternig, L. R. (1986). Isokinetic dynamometry: implications for muscle testing and rehabilitation. *Exercise and Sport Sciences Reviews*, *14*, 45-80.

Park, J. Y., Chun, M. H., Kang, S. H., Lee, J. A., Kim, B. R., & Shin, M. J. (2009). Functional outcome in poststroke patients with or without fatigue. *American Journal of Physical Medicine & Rehabilitation*, *88*(7), 554-558.

Perrey, S. (2018). Brain activation associated with eccentric movement: a narrative review of the literature. *European Journal of Sport Science, 18*(1). 75-82.

Pessin, M. S., Hinton, R. C., Davis, K. R., Duncan, G. W., Roberson, G. H., Ackerman, R. H., & Mohr, J. P. (1979). Mechanisms of acute carotid stroke. Annals of Neurology: Official *Journal of the American Neurological Association and the Child Neurology Society, 6*(3), 245-252.

Phan-Ba, R., Calay, P., Grodent, P., Delrue, G., Lommers, E., Delvaux, V., ... & Belachew, S. (2012). A corrected version of the Timed-25 Foot Walk Test with a dynamic start to capture the maximum ambulation speed in multiple sclerosis patients. *NeuroRehabilitation, 30*(4), 261-266.

Pohl, P. S., Duncan, P. W., Perera, S., Liu, W., Lai, S. M., Studenski, S., & Long, J. (2002). Influence of stroke-related impairments on performance in 6-minute walk test. *Journal of Rehabilitation Research and Development, 39*(4), 439-444.

Purves, D., Augustine, G. J., & Fitzpatrick, D. (2001). The blood supply of the brain and spinal cord. In *Neuroscience*. Sinauer Associates, Sunderland (MA).

Qureshi, A. I., Mendelow, A. D., & Hanley, D. F. (2009). Intracerebral haemorrhage. *The Lancet, 373*(9675), 1632-1644.

Rainoldi, A., Melchiorri, G., & Caruso, I. (2004). A method for positioning electrodes during surface EMG recordings in lower limb muscles. *Journal of Neuroscience Methods, 134*(1), 37-43.

Rainoldi, A., Nazzaro, M., Merletti, R., Farina, D., Caruso, I., & Gaudenti, S. (2000). Geometrical factors in surface EMG of the vastus medialis and lateralis muscles. *Journal of Electromyography and Kinesiology, 10*(5), 327-336.

Rea, P. (2015). Spinal tracts-descending/motor pathways. *Essential Clinical Anatomy of the Nervous System,* 161-176.

Reaz, M. B. I., Hussain, M. S., & Mohd-Yasin, F. (2006). Techniques of EMG signal analysis: detection, processing, classification and applications. *Biological procedures online, 8*(1), 11.

Rhoton Jr, A. L. (2002). Aneurysms. *Neurosurgery, 51*(s4), 1-121.

Riley, N. A., & Bilodeau, M. (2002). Changes in upper limb joint torque patterns and EMG signals with fatigue following a stroke. *Disability and Rehabilitation, 24*(18), 961-969.

Rinkel, G. J. (2001). Subarachnoid haemorrhage: diagnosis, causes and management. *Brain: A Journal of Neurology, 124*(2), 249-278.

Roubenoff, R. (2000). Sarcopenia and its implications for the elderly. *European Journal of Clinical Nutrition, 54*(3), S40-S47.

Sacco, R. L., Kasner, S. E., Broderick, J. P., Caplan, L. R., Connors, J. J., Culebras, A., ... & Hoh, B. L. (2013). An updated definition of stroke for the 21st century: a statement for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke, 44*(7), 2064-2089.

Salbach, N. M., Mayo, N. E., Higgins, J., Ahmed, S., Finch, L. E., & Richards, C. L. (2001). Responsiveness and predictability of gait speed and other disability measures in acute stroke. Archives of physical medicine and rehabilitation, 82(9), 1204-1212.

Sale, D. G. (1988). Neural adaptation to resistance training. *Medicine and science in sports and exercise, 20*(s5), S135-45.

Sanna, T., Diener, H. C., Passman, R. S., Di Lazzaro, V., Bernstein, R. A., Morillo, C. A., ... & Lindborg, K. (2014). Cryptogenic stroke and underlying atrial fibrillation. *New England Journal of Medicine, 370*(26), 2478-2486.

Saver, J. L. (2016). Cryptogenic stroke. *New England Journal of Medicine, 374*(21), 2065-2074.

Scherbakov, N., & Doehner, W. (2011). Sarcopenia in stroke—facts and numbers on muscle loss accounting for disability after stroke. *Journal of Cachexia, Sarcopenia and Muscle, 2*(1), 5-8.

Schmid, A., Duncan, P. W., Studenski, S., Lai, S. M., Richards, L., Perera, S., & Wu, S. S. (2007). Improvements in speed-based gait classifications are meaningful. *Stroke, 38*(7), 2096-2100.

Sekiguchi, H., Kimura, T., Yamanaka, K., & Nakazawa, K. (2001). Lower excitability of the corticospinal tract to transcranial magnetic stimulation during lengthening contractions in human elbow flexors. *Neuroscience Letters, 312*(2), 83-86.

Sengul, G., & Watson, C. (2015). Ascending and descending pathways in the spinal cord. In The Rat Nervous System (Fourth Edition) (pp. 115-130).

Şen, S. B., Demir, S. Ö., Ekiz, T., & Özgirgin, N. (2015). Effects of the bilateral isokinetic strengthening training on functional parameters, gait, and the quality of life in patients with stroke. *International Journal of Clinical and Experimental Medicine, 8*(9), 16871.

Sharp, S. A., & Brouwer, B. J. (1997). Isokinetic strength training of the hemiparetic knee: effects on function and spasticity. *Archives of Physical Medicine and Rehabilitation, 78*(11), 1231-1236.

Sheean, G., & McGuire, J. R. (2009). Spastic hypertonia and movement disorders: pathophysiology, clinical presentation, and quantification. *PM&R, 1*(9), 827-833.

Shi, Z. (2017). Pathophysiology of Hemorrhagic Stroke. In Translational Research in Stroke (pp. 77-96). Springer, Singapore.

Shiavi, R., Bugle, H.J., & Limbird, T. (1987). Electromyographic gait assessment, part 2: preliminary assessment of hemiparetic synergy patterns. *Journal of Rehabilitation Research and Development*, *24*(2), 24-30.

Shibasaki, H., & Hallett, M. (2006). What is the Bereitschaftspotential? *Clinical Neurophysiology, 117*(11), 2341-2356.

Shumway-Cook, A., & Woollacott, M. H. (2007). *Motor control: translating research into clinical practice*. Lippincott Williams & Wilkins.

Siegel, A., & Sapru, H. N. (2006). *Essential neuroscience*. Lippincott Williams & Wilkins.

Siemionow, V., Yue, G. H., Ranganathan, V. K., Liu, J. Z., & Sahgal, V. (2000). Relationship between motor activity-related cortical potential and voluntary muscle activation. *Experimental Brain Research, 133*(3), 303-311.

Smith, S. D., & Eskey, C. J. (2011). Hemorrhagic stroke. *Radiologic Clinics, 49*(1), 27-45.

Smith, W. S., Lev, M. H., English, J. D., Camargo, E. C., Chou, M., Johnston, S. C., ... & Furie, K. L. (2009). Significance of large vessel intracranial occlusion causing acute ischemic stroke and TIA. *Stroke, 40*(12), 3834-3840.

Soderberg, G. L., & Knutson, L. M. (2000). A guide for use and interpretation of kinesiologic electromyographic data. *Physical therapy, 80*(5), 485-498.

Sommerfeld, D. K., Eek, E. U. B., Svensson, A. K., Holmqvist, L. W., & von Arbin, M. H. (2004). Spasticity after stroke: its occurrence and association with motor impairments and activity limitations. *Stroke, 35*(1), 134-139.

Song, Y. M., Lee, J. Y., Park, J. M., Yoon, B. W., & Roh, J. K. (2005). Ipsilateral hemiparesis caused by a corona radiata infarct after a previous stroke on the opposite side. *Archives of Neurology, 62*(5), 809-811.

Song, M. J., Lee, J. H., & Shin, W. S. (2018). Minimal clinically important difference of berg balance scale scores in people with acute stroke. *Physical Therapy Rehabilitation Science, 7*(3), 102-108.

Sparto, P. J., Parnianpour, M., Barria, E. A., & Jagadeesh, J. M. (1999). Wavelet analysis of electromyography for back muscle fatigue detection during isokinetic constant-torque exertions. *Spine, 24*(17), 1791.

Strong, K., Mathers, C., & Bonita, R. (2007). Preventing stroke: saving lives around the world. *The Lancet Neurology, 6*(2), 182-187.

Swenson, R. S. (2006). Review of clinical and functional neuroscience. *Dartmouth Medical School. Retrieved November*, 18, 2012.

Tabard-Fougere, A., Rose-Dulcina, K., Pittet, V., Dayer, R., Vuillerme, N., & Armand, S. (2018). EMG normalization method based on grade 3 of manual muscle testing: within- and between-day reliability of normalization tasks and application to gait analysis. *Gait & Posture, 60*. 6-12

Takeuchi, N., & Izumi, S. I. (2012). Maladaptive plasticity for motor recovery after stroke: mechanisms and approaches. *Neural plasticity*, 2012.

Teasell, R., McRae, M., Foley, N., & Bhardwaj, A. (2002). The incidence and consequences of falls in stroke patients during inpatient rehabilitation: factors associated with high risk. *Archives of Physical Medicine and Rehabilitation, 83*(3), 329-333.

Tesch, P. A., Dudley, G. A., Duvoisin, M. R., Hather, B. M., & Harris, R. T. (1990). Force and EMG signal patterns during repeated bouts of concentric or eccentric muscle actions. *Acta Physiologica Scandinavica, 138*(3), 263-271.

Thanvi, B., & Robinson, T. (2007). Complete occlusion of extracranial internal carotid artery: clinical features, pathophysiology, diagnosis and management. *Postgraduate Medical Journal, 83*(976), 95-99.

Thibaut, A., Chatelle, C., Ziegler, E., Bruno, M. A., Laureys, S., & Gosseries, O. (2013). Spasticity after stroke: physiology, assessment and treatment. *Brain injury, 27*(10), 1093-1105.

Thompson, H. S., & Ryan, A. (2009). The impact of stroke consequences on spousal relationships from the perspective of the person with stroke. *Journal of Clinical Nursing, 18*(12), 1803-1811.

Tilson, J. K., Sullivan, K. J., Cen, S. Y., Rose, D. K., Koradia, C. H., Azen, S. P., ... & Locomotor Experience Applied Post Stroke (LEAPS) Investigative Team. (2010). Meaningful gait speed improvement during the first 60 days poststroke: minimal clinically important difference. *Physical Therapy*, *90*(2), 196-208.

Tortora, G. J., & Derrickson, B. (2013). *Essentials of anatomy and physiology*. Wiley.

Trueblood, P. R., Walker, J. M., Perry, J., & Gronley, J. K. (1989). Pelvic exercise and gait in hemiplegia. *Physical Therapy*, *69*(1), 18-26.

Twitchell, T. E. (1951). The restoration of motor function following hemiplegia in man. *Brain, 74*(4), 443-480.

Tyson, S., & Connell, L. (2009). The psychometric properties and clinical utility of measures of walking and mobility in neurological conditions: a systematic review. *Clinical Rehabilitation*, *23*(11), 1018-1033.

Van Cutsem, M., Duchateau, J., & Hainaut, K. (1998). Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *The Journal of Physiology, 513*(1), 295-305.

van Gijn, J., & Rinkel, G. J. E. (2001). Subarachnoid haemorrhage: diagnosis, causes and management. *Brain, 124*(2), 249-278.

Van Vugt, J. P. P., & Van Dijk, J. G. (2001). A convenient method to reduce crosstalk in surface EMG. *Clinical Neurophysiology, 112*(4), 583-592.

Verma, R., Narayan, K., Sharma, P., & Garg, R.K. (2012). Understanding gait control in post stroke: implications for management. *Journal of Bodywork & Movement Therapies, 16,* 14-21.

Vinstrup, J., Calatayud, J., Jakobsen, M. D., Sundstrup, E., Jay, K., Brandt, M., ... & Andersen, L. L. (2017). Electromyographic comparison of conventional machine strength training versus bodyweight exercises in patients with chronic stroke. *Topics in Stroke Rehabilitation*, *24*(4), 242-249.

Vinstrup, J., Calatayud, J., Jakobsen, M. D., Sundstrup, E., Jay, K., Brandt, M., ... & Andersen, L. L. (2016). Electromyographic comparison of elastic resistance and machine exercises for high-intensity strength training in patients with chronic stroke. *Archives of Physical Medicine and Rehabilitation, 97*(3), 429-436.

Wagenaar, R. C., & Beek, W. J. (1992). Hemiplegic gait: a kinematic analysis using walking speed as a basis. *Journal of Biomechanics, 25*(9), 1007-1015.

Waters, R. L., Frazier, J. O. H. N., Garland, D. E., Jordan, C. & Perry, J. (1982). Electromyographic gait analysis before and after operative treatment for hemiplegic equinus and equinovarus deformity. The Journal of Bone and Joint Surgery, 64(2), 284-288.

Ward, A. B. (2012). A literature review of the pathophysiology and onset of post-stroke spasticity. *European Journal of Neurology*, *19*(1), 21-27.

Warren, M. L., & Ruppert, S. D. (2011). Ischemic Middle Cerebral Artery Stroke: A Case Study. Critical care nursing quarterly, 34(3), 218-226.

Waxman, S. G. (2010). *Clinical neuroanatomy*. McGraw Hill.

Wee, J. Y., Bagg, S. D., & Palepu, A. (1999). The Berg Balance Scale as a predictor of length of stay and discharge destination in an acute stroke rehabilitation setting. *Archives of Physical Medicine and Rehabilitation, 80*(4), 448-452.

Weintraub, D. B., & Zaghloul, K. A. (2013). The role of the subthalamic nucleus in cognition. *Reviews in the Neurosciences*, *24*(2), 125-138.

Williams, G., Galna, B., Morris, M. E., & Olver, J. (2010). Spatiotemporal deficits and kinematic classification of gait following a traumatic brain injury: a systematic review. *The Journal of Head Trauma Rehabilitation, 25*(5), 366-374.

Wist, S., Clivaz, J., & Sattelmayer, M. (2016). Muscle strengthening for hemiparesis after stroke: A meta-analysis. *Annals of Physical and Rehabilitation Medicine, 59*(2), 114-124.

Woolley, S. M. (2001). Characteristics of gait in hemiplegia. *Topics in Stroke Rehabilitation, 7*(4), 1-18.

Wortis, S. B., Marks, M., Hirschberg, G. G., & Nathanson, M. (1951). Gait analysis in hemiplegia. *Transactions of the American Neurological Association, 56*, 181-183.

Yavuzer, G., Öken, Ö., Elhan, A., & Stam, H. J. (2008). Repeatability of lower limb three-dimensional kinematics in patients with stroke. *Gait & Posture, 27*(1), 31-35.

Young, P. A., Young, P. H., & Tolbert, D. L. (2008). *Basic clinical neuroscience*. Lippincott Williams & Wilkins.

Yu, J., Xu, N., Zhao, Y., & Yu, J. (2018). Clinical importance of the anterior choroidal artery: a review of the literature. *International Journal of Medical Sciences, 15*(4), 368.

Zülch, K. J., Mennel, H. D., & Zimmermann, V. (1974). Intracranial hypertension. Handbook of clinical neurology, 16, 89-149.

Zwarts, M. J., Drost, G., & Stegeman, D. F. (2000). Recent progress in the diagnostic use of surface EMG for neurological diseases. *Journal of Electromyography and Kinesiology, 10*(5), 287-291.