CHARLES UNIVERSITY

FACULTY OF PHYSICAL EDUCATION AND SPORTS

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Effectivity of Combined Rhythmic Auditory Stimulation Rehabilitation Approach on Gait post Stroke

Master's thesis

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Declaration

I declare that this thesis is entirely my own. The theoretical information has been sourced using secondary methods of research, therefore the literature has been referenced at the end of this document according to APA sixth edition. As this thesis is a systematic review, the information obtained in the results section is similarly sourced from secondary research methods, thus the literature has been referenced according to APA sixth edition at the end of this document.

I declare no forms of plagiarism were intentionally made.

In Prague: May 2023 Author: Belinda Hlomayi

Acknowledgments

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Abstract

Background: this review is assessing the effectiveness of combing forms of rhythmic auditory stimulation (a form of neurologic music therapy) to commonly used physiotherapeutic methods in the treatment of gait for hemiplegic/paresis stroke patients.

Aim: to evaluate the extent in which Rhythmic Auditory Stimulation (RAS) combined therapy has a positive effect on gait for stroke patients, and whether RAS combined therapy is a more effective approach than conventional physiotherapeutic approaches.

Methods: Databases Cochrane Central Register of Controlled Trials, Pubmed and Science Direct were searched. All databases were searched using a publication year range from 2009-2022. Studies accepted were either Randomized Control Trials, Clinical Control Trails or Case Control Studies, evaluating RAS combined therapy versus conventional physiotherapeutic methods for Hemiplegic/paresis stroke patients. The outcome measures evaluated were gait and balance ability, according to spatiotemporal gait parameters and balance or lower extremity function assessments. Data was extracted according to PRISMA guidelines as well as with the help of a reference manager. The studies were analysed for risk of bias according to the PEDro Quality Scale by the author.

Result: a total of eight studies were analysed in this research with a total of 266 patients. RAS combined therapy proves to have a strong positive effect on hemiparesis stroke gait rehabilitation, as a total of 97.8% of the experimental groups‘ outcome measures from baseline had improved. RAS combined therapy has also proven to be a superior treatment option compared to conventional physiotherapeutic methods due to two factors: 1) the control groups having a total of 80.2% of improved outcome measures from baseline, indicate the experimental group to have a statistically significant higher outcome measure improvement from baseline. 2) From the 97.2% of improved experimental groups outcome measures from baseline, 62.2% showed greater significant improvement in comparison to the control groups outcome measures, while 0% from the 80.2% of improved control group outcome measures from baseline showed greater statistical significance to the experimental group. Therefore results indicated 61% of outcome measures measured post RAS combined therapy to be more effective in hemiparesis stroke gait rehabilitation in comparison to conventional physiotherapeutic methods.

Conclusion: RAS combined therapy is a very strongly effective rehabilitation approach in treating hemiparesis stroke gait pathologies and has proven to be a better treatment option than conventional therapeutic methods. However, the generalizability of the results are limited as the research analysed a small number of studies also consisting small study populations. Additionally, as all eight studies focused on chronic stroke, it is unreliable to conclude the findings to be true for acute and subacute stages of stroke.

Účinnost kombinovaného přístupu rytmické sluchové stimulace v rehabilitaci chůze u pacientů po cévní mozkové příhodě

Abstrakt

Východiska: práce je věnována posouzení účinnosti forem rytmické sluchové stimulace (forma neurologické muzikoterapie) k běžně používaným fyzioterapeutickým metodám v léčbě chůze u pacientů po cévní mozkové příhodě s hemiplegií.

Cíl: zhodnotit, do jaké míry má kombinovaná terapie rytmické sluchové stimulace pozitivní vliv na chůzi u pacientů po cévní mozkové příhodě a zda je tato kombinovaná terapie účinnějším přístupem než běžné, konvenční fyzioterapeutické přístupy.

Metody: Studie pro rešerši byly vyhledávány v databázích Cochrane Central Register of Controlled Trials, Pubmed a Science Direct. Pro zařazení studií bylo stanoveno období publikování v letech 2009-2022. Přijaté studie byly randomizované kontrolované studie, klinické kontrolované studie nebo případové kontrolované studie, hodnotící kombinovanou terapii rytmické sluchové stimulace oproti konvenčním fyzioterapeutickým metodám u pacientů s hemiplegií po cévní mozkové příhodě. Pro hodnocení efektu terapie byla použita chůze a schopnost rovnováhy dle časoprostorových parametrů chůze, hodnocení rovnováhy nebo funkce dolních končetin. Data byla extrahována dle PRISMA doporučených postupů a studie byly analyzovány vzhledem riziku zkreslení dle stupnice kvality PEDro.

Výsledky: v rámci tohoto výzkumu bylo analyzováno celkem osm studií s celkovým počtem 266 pacientů. Ukázalo se, že kombinovaná terapie rytmické sluchové stimulace má silný pozitivní vliv na rehabilitaci chůze u pacientů po cévní mozkové příhodě, protože celkem 97,8 % výsledků experimentálních skupin se zlepšilo oproti výchozímu stavu. Kombinovaná terapie rytmické sluchové stimulace se také ukázala jako lepší léčebná možnost ve srovnání s konvenčními fyzioterapeutickými metodami díky dvěma faktorům: 1) kontrolní skupiny, které zahrnovaly celkem 80,2 % zlepšených výsledků oproti výchozímu stavu ukazují, že experimentální skupina má statisticky signifikantně vyšší výsledek zlepšení oproti výchozím hodnotám. 2) z 97,2 % zlepšených výsledků experimentální skupiny od výchozího stavu, 62,2 % vykázalo větší významné zlepšení ve srovnání s výsledky kontrolní skupiny, zatímco 0 % z 80,2 % zlepšených výsledků kontrolní skupiny od výchozího stavu vykázalo větší statistickou významnost vůči experimentální skupině; tato skutečnost ukazuje, že kombinovaná terapie rytmické sluchové stimulace byla téměř o 61 % účinnější při rehabilitaci chůze pacientů po cévní mozkové příhodě, než u jiných terapií.

Závěr: Kombinovaná terapie rytmické sluchové stimulace je velmi účinným rehabilitačním přístupem při léčbě patologických stavů chůze u pacientů po cévní mozkové příhodě. Ukázalo se, že tato forma terapie je lepší léčebnou možností než konvenční terapeutické metody. Zobecnitelnost výsledků je však omezená, protože výzkum analyzoval malý počet studií, které rovněž obsahovaly malé skupiny probandů. Krom toho, všech osm zařazených studií se věnovalo pacientům v chronickém stadiu po prodělané cévní mozkové příhodě, nelze zjištění vztahovat také pro akutní a subakutní stadia cévní mozkové příhody.

Contents

1. INTRODUCTION

Stroke is a neurological pathology that is prevalent in our communities as the aging population rises, alongside normalisation of negative lifestyles such as obesity, alcoholism, smoking and sedentary lifestyle. Stroke leaves the patient with motoric and sensory impairments that varying in severity may or may not be fully restored. The recovery from chronic stroke or other chronic age-related bran diseases is approximately 80% of the economic burden excluding the acute treatment and care. *(Sihvonen, et al., 2017).* Therefore, this strain has led to the development of new cost effective treatment strategies that could either be included in conventional strategies such as Physiotherapy, Occupational and Speech therapy or be independent in use. One of these new strategies being music based therapy *(Sihvonen, et al., 2017).* The psychological influence of music or rhythm as well as its entrainment properties have proven to be effective in the treatment of functional abilities of patients struggling with Parkinson's disease, Cerebral Palsy as well as Stroke *(Thaut M. , 2015) (Pereira, et al., 2019) (OTR/L Denslow, 2021) (Xu, He, Shen, & Huang, 2022)*. Therefore this research has focused on determining the effectiveness of combining Rhythmic Auditory Stimulation stemming from Neurologic Music Therapy with conventional therapeutic methods in contrast to the sole use of conventional therapeutic methods for hemiparesis/plegic stroke gait rehabilitation. The results aim to determine if Rhythmic Auditory Stimulation combined therapy is more effective and therefore a rehabilitation approach worth pursuing over conventional physiotherapeutic methods for stroke gait pathologies.

2. THEORETICAL BACKGROUND

2.1. The CNS role in Production of Voluntary Movement

Voluntary movement is defined as an expression of thought through action: resulting from signals transmitted through a communication channel, purposefully linking the internal world of our minds to the physical world around us *(Schwartz, 2016).* The communication channel is the nervous system, which receives signals from the brain and transports them through the nervous network to the muscles resulting in the generation of displacement and forces, resulting in movement *(Schwartz, 2016).* As the internal environment affects the external environment change occurs: the resulting changes act to generate sensations that feed back to brain through the nervous network, therefore creating a closed loop of signals *(Schwartz, 2016).*

A successful voluntary action is produced by sequentially organised behaviours of the nervous system control in a hierarchical manner. A century ago an English neurologist John Hughlings-Jackson discovered the neocortex, brainstem and the spinal cord make up the nervous system hierarchy that orchestrates voluntary movement *(Kolb & Whishaw, 2009).* An example of this intricate action is picking up an object: according to *(Kolb & Whishaw, 2009),* the visual system firstly inspects the object, determining with part of its surface to grasp. This information in relayed from the visual cortex to the cortical motor regions, which then plan and initiate the movement, as they transfer instructions to the part of the spinal cord controlling the muscles of the arm and hand *(Kolb & Whishaw, 2009)*. When the surface is grasped, information from the sensory receptors in the fingers or hand travels to the spinal cord, and are transmitted to the sensory regions of the cortex responsible for touch. Lastly the sensory cortex informs the motor cortex that the object was grasped. Sub-regions such as the basal ganglia and the cerebellum assist in executing voluntary movements by producing the appropriate amount of force and regulating timing along with correcting movement errors respectively *(Kolb & Whishaw, 2009).*

Although the nervous system in humans is divided in a hierarchy, these different tiers do not work separately, rather they operate collectively. The higher regions are working through and influencing the actions of the lower ones. In order to produce a successful controlled movement, various parts of the nervous system engage: sensory control, planning and commanding centres of movement and action executors.

Using the reaching for a cup as an example of voluntary movement, we summarise how the hierarchical activation of different regions of the brain *(Kolb & Whishaw, 2009)*:

1. Location of target through visual information
2. Frontal-lobe motor areas plan the reach and command the movement
3. Spinal cord carries information to the hand
4. Motor neurons carry information to muscles of the hand and forearm
5. Sensory receptors on the fingers send message to the sensory cortex confirming the grasp of the cup
6. Spinal cord carries sensory information to the brain
7. Basal ganglia judge the grasp forces and cerebellum corrects movement errors
8. Sensory cortex receives the message confirming the grasp of the cup.

This chapter shall further analyse major components of the brain engaging in voluntary movement.

2.1.1. The Forebrain

The forebrain is the largest region of the mammalian brain *(Kolb & Whishaw, 2009)*. A voluntary action requiring complex movements or behaviours such as dancing or even visual arts require various components to be successful *(Kolb & Whishaw, 2009)*. Taking painting as an example the perception of what if appearing on the canvas and the brush stroke in your hand must be closely coordinated to have a desired outcome. Similarly, in couple dancing one must listen to the song and coordinate their moves in a synchronised manner to their partner quick enough to produce a desired outcome. In these complex movements at every moment decisions must be made and actions in different movement categories must be performed *(Kolb & Whishaw, 2009).* Individuals that choose categories efficiently and execute the movement effortlessly are recognised as professional or skilled artist or dancers.

The article 'The problem of serial order in behaviour' by *Karl Lashley in 1951* debunked the popular theory in the 1930s that stated controlled movement is achieved from feedback: we perform an action, wait for feedback on how successful the action was and then make the next move accordingly *(Rosenbaum, Cohen, Jax, Weis, & Van der Wel, 2007)*. Lashley argued that 'skilled movements such as piano playing occurred too quickly to rely on feedback of one movement shaping the next movement', rather he proposed that 'movements must be performed as motor sequences, with one movement module held in readiness, as an ongoing sequence is being completed' *(Rosenbaum, Cohen, Jax, Weis, & Van der Wel, 2007).* Therefore applying Lashley's concept, all complex behaviours such as painting or dancing require the selection and execution of multiple movement sequences: as one sequence is in action, the next is being prepared so it can follow the previous one smoothly *(Kolb & Whishaw, 2009).*

The preparation, and initiation of motor sequences are the responsibilities of each hemisphere of the frontal lobe. Each frontal lobe is comprised of three regions, anteriorly there is the prefrontal cortex, medially the premotor cortex and posteriorly the primary motor cortex *(Knierim, 2020).*

The prefrontal cortex – is the top of the movement preparation and initiation. It does not specify the price movements to be made, rather the goals toward which movements should be directed. The prefrontal cortex plans complex behaviours, examples being: deciding to get up at a certain time to be punctual at work, deciding to return a due library book or deciding whether an action is right or wrong and consequently whether it should be done at all. Injury to the prefrontal cortex impairs the individual's decision making *(MD Grujicic, 2022).*

The premotor cortex – receives instructions from the prefrontal cortex and from this produces complex movement sequences appropriate to the tasks. Damage to the premotor cortex results in these sequences being uncoordinated. An example from a research by C.Brinkman *(1984)* showed a monkey having to catch a snack from under the table it has to push through the hole on the table: a normal functioning premotor cortex successfully coordinates the two sequences of pushing the snack through the hole and catching it from under the table, with the goal of not dropping the snack. Meanwhile in a lesioned premotor cortex, the sequences are uncoordinated, the monkey can push the snack, and open the palm independently but fails to coordinate the movements resulting in the snack falling, therefore the goal being unsuccessful. Premotor cortex has mirror neurons, their function allows a subject to make, observe and represent movement sequences. They activate when the subject performs activities such as reaching for food or when the subject observes another person *(Physiopedia contributors, 2022).*

The primary motor cortex – specifies how the organised movement sequences from the premotor cortex are to be carried out, it is responsible for executing skilled movements *(Sullivan J. , 2019).* An example of the role the primary motor cortex plays is in picking up objects: we can use the power grasp which is ideal for large objects as well as objects requiring strength and power. In contrast we also use the pincer grip, which is ideal for picking up small objects as well as skilfully using these held objects. As the pincer grip demands more precision in comparison to the grasp, it makes it a more demanding movement for the primary motor cortex *(Olson & Colby, 2013)*. A lesion to the primary motor cortex leads to difficulty in performing precise or skilled movements of the hands, arms, or trunk. According to the experimental research ‘Brain Activation’ by *P.E Roland 1993* blood flow does not increase throughout the entire frontal lobe, rather is increases in the region active in the stage needed for planning and executing the voluntary movement.

In summary the frontal lobes plan, coordinate and execute voluntary movement in a hierarchical manner. The prefrontal cortex formulates the plan of action, it instructs the premotor cortex which then formulates appropriate movement sequences and the manner in which they are executed is the responsibility of the primary motor cortex.

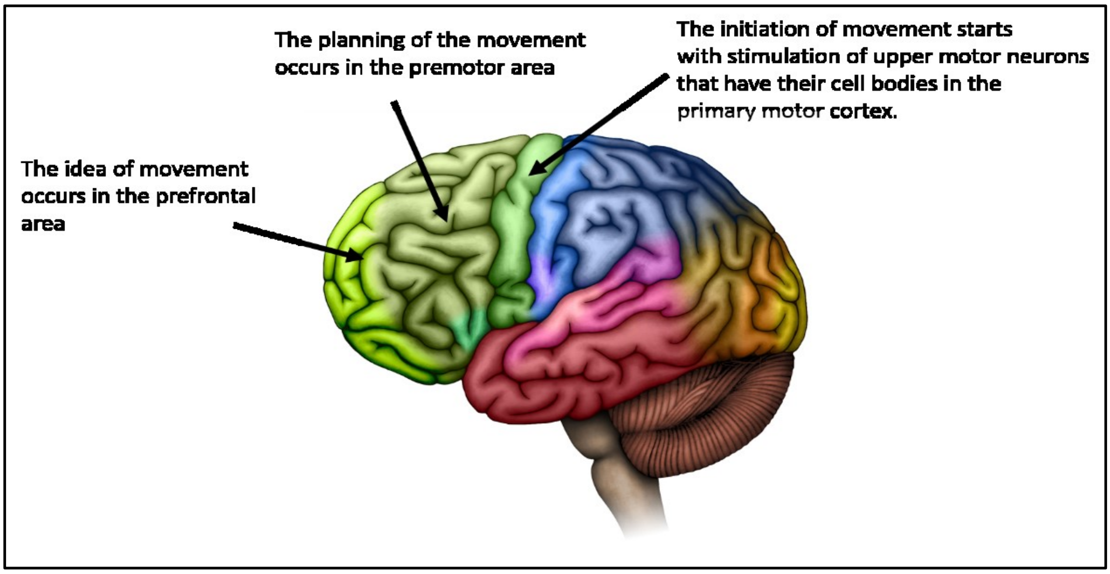


Figure 1: *Functions of the frontal lobe regions in voluntary movement. (University, 2014)*

2.1.2. The Motor Cortex and Voluntary Movement

The motor cortex as the name implies is responsible for initiating and coordinating voluntary movement in the body. It is located in the frontal lobe and is comprised of two regions: Primary motor cortex (PMC), and the Non-primary motor cortex (nPMC) *(Guy-Evans, 2021).* The nPMC is composed of the Premotor cortex (PC) and Supplementary motor area (SMC) *(OTR/L, Maher, 2020).* As mentioned above PMC decides how to execute skilled movements that have been planned as movement sequences by the PC. The SMC like the PMC critical in the execution of sequenced movements and the control of movement: it has the ability to make a decision to change to a different execution based on sensory input *(Guy-Evans, 2021).*

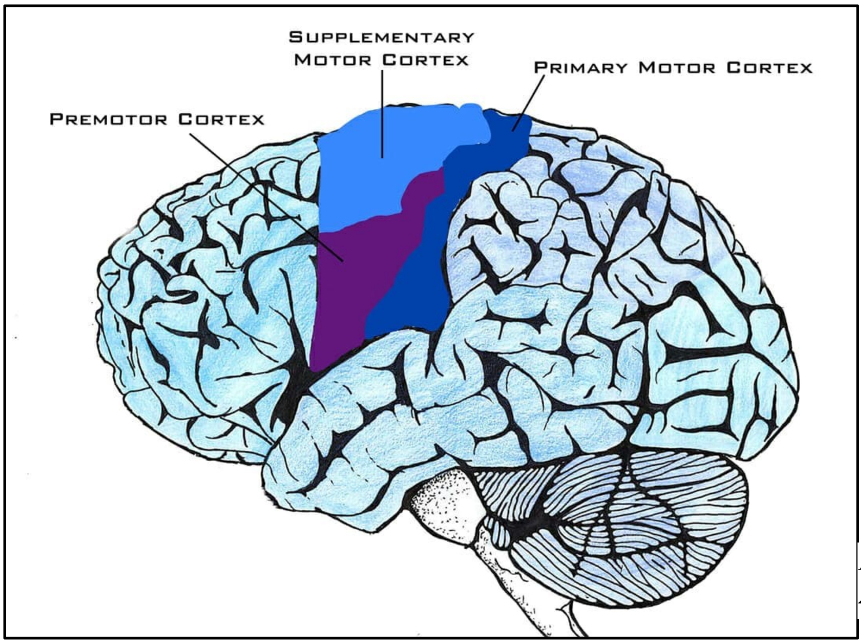


Figure 2: *The Motor Cortex (Sullivan J. , 2019)*

The Primary motor cortex works across the body's mid-line: muscular activation on the right side of the body is the result of signals sent from the left hemisphere of the primary motor cortex and vice-versa. Different parts of the body are controlled by different regions in the PMC and these regions are varying in degree of brain matter assigned to them: the greater the complexity of movement the greater the region of brain devoted to its activity. Gross movements require less brain activity in comparison finer movements *(OTR/L, Maher, 2020).*

To further understand the functions of the different regions of the motor cortex, the Primary Motor Cortex is located in the Precentral Gyrus that is further divided into the lateral and ventromedial groups. The lateral group controls movement of the fingers, hands and limbs while the ventromedial group is responsible for automatic and coordinated movement of the limbs such as posture and locomotion (*Psychology Info 2022*). Automatic and coordinated movement of the limbs are elicited by the Secondary Motor Cortices, the second main centre of movement. It is divided into three regions: the Posterior Parietal Cortex (PPC), the Premotor Cortex (PC) and Supplementary Motor Area (SMA). The SMA region arranges complex movements and coordinates two-handed movements, meanwhile the PC region has two responsibilities to mimic actions of others by comprehending and anticipating these actions and activates the sensory guidance of movement needed in actions associated with time and specific direction. Lastly the PPC creates motor commands as a result of visual input *(Psychology Info 2022).*

Penfield's Homunculus

The Homunculus is a map visualised as a distorted human like figure: it indicates the amount of cortical area dedicated to motor or somatosensory functions of each body part *(Catani, 2017).* Penfield created the homunculus by drawing a summary his findings on which region of the motor cortex is responsible for movement in a specific region of the body. A smaller homunculus is found in the supplementary motor cortex *(Catani, 2017).*

Due to the body's symmetry, the homunculus is found in the cortex of each hemisphere, and each controls movements on the opposite side of the body *(Catani, 2017).* The distinct feature of the Motoric Homunculus is the disproportionate sizes of the body parts in comparison actual human body: large lips, tongue, and hands especially the thumb, while the trunk, arms and legs are much smaller. The difference in these sizes are determined by how much of the motor cortex activates to produce movements in the region: the lips, tongue, hands and thumb require precise motor control and are therefore larger, meanwhile the trunk, arms and legs require less motor control and are therefore smaller *(Catani, 2017).*

2.1.3. Subcortical Structures

The two main centres of the brain involved in voluntary movement are also supported by three Subcortical areas of the brain *(Llyons, 2020):* the brainstem which is important for maintaining posture, standing upright and producing coordinated movements of the limbs the cerebellum and the basal ganglia *(Kolb & Whishaw, How Does the Nervous System Function?, 2009)* .

Reticular formation - located in the brainstem is a far reaching network of neurons extending from the spinal cord to the thalamus with connections to the medulla oblongata, midbrain, pons and diencephalon. This region is responsible for muscle tonus. It plays a role in voluntary movement by having various impacts on muscle activity such as:

- Coordinating the activity of respiratory centres controlling respiratory muscles
- Affecting the gamma and alpha motor neurons (Lower motor neurons of spinal cord and brain stem) it modifies reflex activity and muscle tone.
- Aids the vestibular apparatus during standing by preserving muscle tone in antigravity muscles.
- Has an effect on facial muscles. The reticular formation is located bilaterally allowing it to provide motor control to both side of the brain when a person laughs or smiles.

The Cerebellum - works to assist in postural control but most importantly it calculates complex motor muscle movements that are rapid and skilful *(Lyons, 2020)*. Not only is it a vital component in the human brain but it is highly important in voluntary movement, through movement regulation and balance control. It focuses on gait coordination, postural, muscle tone and voluntary muscle activity control. The Cerebellum is divided into three regions:

- Cortex of the vermis – coordinates the movements of the trunk, including the neck, shoulders, thorax, abdomen and hips.
- Intermediate zone of cerebellar hemispheres – controls the distal extremity muscles.
- Lateral areas – provides planning of sequential movements of the entire body along with involvement in the conscious of movement errors.

Basal Ganglia- according to *Carlson and Birkett (2017)* as cited by *(Llyons, 2020)* the Basal Ganglia assesses somatosensory information alongside the motor cortex, resulting in the motor cortex executing accurate movements. It adjusts and processes received impulses for the upcoming movement from the cerebral cortex, it sends the reviewed instructions to the thalamus, which then sends it back to the cortex. Lastly the assessed impulses are sent to the skeletal muscles through the tracts of the pyramidal motor system. The basal ganglia also mediates other higher cortical functions such as:

- Planning and modulation of movement
- Memory
- Eye movements
- Reward processing
- Motivation

2.1.4. The Cortical Spinal Tract and Motor Neurons

The different regions of the Central Nervous System (CNS) communicate through a bundle of nerve fibres known as the Cortical Spinal Tract, directly connecting the cerebral cortex to the spinal cord through the brainstem. As the name suggests, this pathway begins in the neocortex: specifically the motor cortex, premotor cortex and the sensory cortex, then terminates in the spinal cord.

On both hemispheres, majority of axons from the motor cortex descend to the ventral surface of the brainstem, whereby they merge forming bumps known as pyramids (hence corticospinal tracts are also known as pyramidal tracts) . At this region, the lateral axons descending from the right hemisphere crossover the midline to the left side of the spinal cord, while the ventral axons remain on the right; this is mirrored by the lateral and ventral axons descending from the left hemisphere, resulting in two tracts, one crossed and the other uncrossed entering each side of the spinal cord. The ventral and lateral tracts are represented by different regions of the cortical homunculus: muscle activation of limbs are digits are represented by the lateral axons, while muscle activation of torso are represented by ventral axons.

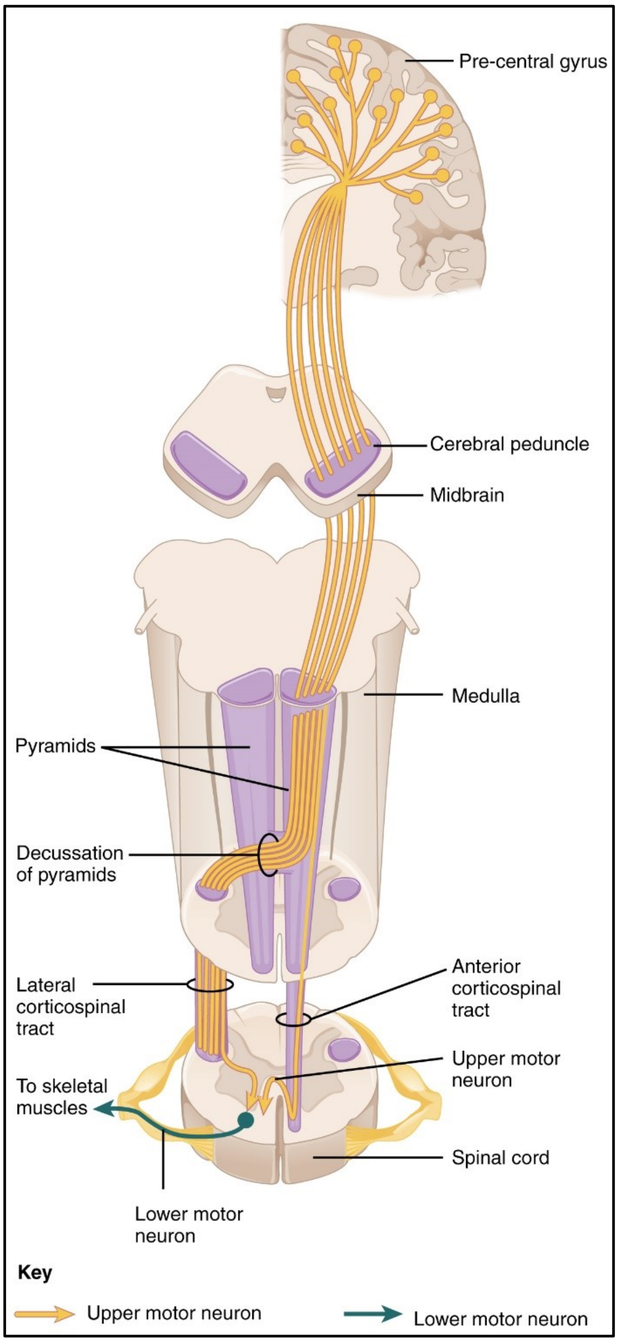


Figure 3: *The left Corticospinal Tract pathway (Physiopedia contributors , 2022)*

Motor Neurons (MN) are neuronal cells located in the CNS, controlling a variety of downstream targets. There are two main types of MN *(Physiopedia contributors , 2022) (Stifani, 2014):*

i. *Upper MN* originating from cerebral cortex.

ii. *Lower MN* originating from brainstem and spinal cord.

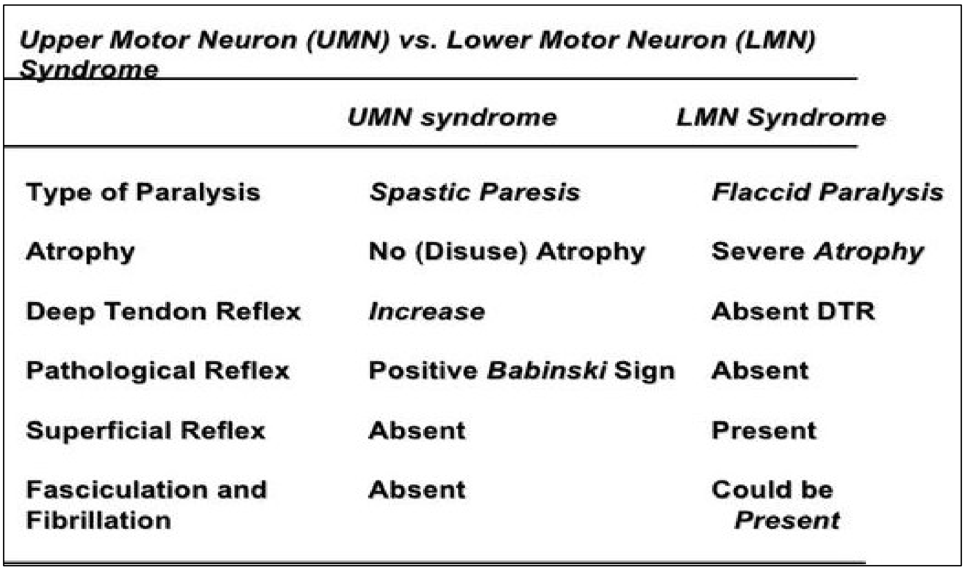
Spinal MN are an irreplaceable component of the neuronal circuitry sending commands to from the CNS to the effector muscles in periphery. They are located on the ventral horn of the spinal cord. They are also responsible for coordination and execution accuracy of voluntary movements: this is achieved by Spinal MN acquiring and retaining the identity of muscles they innervate, which is used in the sensory feedback loops that work to perfect movements *(Stifani, 2014).*

The Upper Motor Neuron (UMN) - cell bodies are generally concentrated in the premotor and primary motor regions (the motor strip) of the cerebral cortex and motor regions of the brain stem and they travel down to the spinal cord *(Physiopedia contributors , 2022)*. UMN have several ways to transmit electrical impulses leading to movement: those in the pyramidal tract are responsible for conscious movement, with their nerve impulses travelling from the motor strip to the spinal cord; meanwhile those in the extra-pyramindal tract, or any pathway outside the pyramidal are responsible for subconscious motor processes, such as balance or postural control. UMN are connected to Lower Motor Neurons (LMN) in the CNS through

Glutamatergic connections. Lesions of the UMN result in: uncontrolled movements, decreased sensitivity to superficial reflex stimulation and spasticity *(Stifani, 2014).*

The Lower Motor Neuron (LMN) – cell bodies are located in specific nuclei in the brainstem as well as the ventral horn of the spinal cord *(Stifani, 2014).* They transfer nerve impulses outsides the CNS from the UMN, interneurons and sensory neurons to effector cells, such as muscles and organs, using axonal extensions. Lower motor neurons are divided into three categories *(Stifani, 2014):*

- Brachial (special visceral) MN – innervate the muscles of the head and neck that stemming from the brachial arches. The brachial motor and sensory neurons together form the nuclei of the cranial nerves V, VII, IX, X and XI. They are located in the brainstem.
- General Visceral motor neurons – they act on both the sympathetic and parasympathetic functions of the autonomic nervous system, therefore directly involving them in the contractions of the heart, the muscles of the arteries and other viscera that are not consciously controlled.
- Somatic Motor neurons – are located in Rexed Lamina IX in brainstem and spinal cord and innervate skeletal muscles, resulting in movement. They are further divided into three categories:
    - *Alpha MN (aMN)* – the large aMN are the primary source of skeletal muscle contraction. The cell body can be located either in the brainstem or spinal cord: in the spinal cord they are found in the anterior horn hence the name ‘anterior horn cells’. From the anterior horn of the spinal cord, a single axon innervates many extra-fusal muscle fibres of a single muscle, creating a motor unit. The muscle fibres with in a muscle are nearly identical, permitting controlled and synchronous activation of the motor unit.
    - *Beta MN (bMN)* – although they are vaguely characterized, studies indicate they innervate both extra-fusal and intra-fusal muscle fibres.
    - *Gamma MN (gMN)* – they do not directly cause any motor function, rather they innervate muscle spindles and dictate their sensitivity in stretching. They participate in alpha-gamma coactivation, whereby their role is to fine-tune muscle contraction: a disruption in either alpha or gamma MN results in a disruption of muscle tone.



Upper Motor Neuron (UMN) vs. Lower Motor Neuron (LMN) Syndrome

	UMN syndrome	**LMN Syndrome**
Type of Paralysis	***Spastic Paresis***	***Flaccid Paralysis***
Atrophy	**No (Disuse) Atrophy**	**Severe *Atrophy***
Deep Tendon Reflex	***Increase***	**Absent DTR**
Pathological Reflex	**Positive *Babinski* Sign**	**Absent**
Superficial Reflex	**Absent**	**Present**
Fasciculation and Fibrillation	**Absent**	**Could be *Present***

***Table 1**: Differences in UMN and LMW lesions (Muley, 2017)*

Any damage or degeneration of the motor neuron results in signals from the brain failing to reach the effector muscle(s), resulting in impaired movement *(Physiopedia contributors , 2022).* Lesions in upper and lower motor neurons result in different clinical findings: lesions in UMN can occur in and between the cortex and the descending tracts, the lesion results in hyperreflexia, spasticity and positive pathological reflexes such as Babinski *(Stifani, 2014)(Physiopedia contributors , 2022)*. Meanwhile lesions in LMN can occur in the spinal cord, peripheral nerves, neuromuscular junction or muscles, the lesions result in hyperreflexia, flaccid paralysis and atrophy *(Stifani, 2014).*

2.1.5. The Central Nervous System Activity and Gait

Gait is considered an automatic process with the minimal involvement of higher-level cognitive input that promotes functional independence *(Mirelman, Shema, Maidan, & Hausdorff, 2018).* Literature additionally suggest that gait in challenging walking conditions requiring attention and skilled function demands ‘higher-levels’ of cognitive control *(Mirelman, Shema, Maidan, & Hausdorff, 2018)*. The Dorsal Pathway of Cognitive locomotor control and the Ventral Pathway for Emotional locomotor control are the two main locomotor pathways recruiting multiple brain regions for gait and postural control. Gait and postural control are controlled by muscles and the lower-level control which regulate timely activation of muscles *(Mirelman, Shema, Maidan, & Hausdorff, 2018).*

Physiological gait is dependent on specific networks in the brain: the networks are made up of the cortical and subcortical structures, which interact with each other and relay neuronal commands through the spinal cord to muscles *(Hamacher, Herold, Wiegel , Hamacher , & Schega, 2015).* Walking requires information processing, feedback processing and planning and commanding movements, which results in high brain activity for cognitive, sensory and motor areas respectively *(Hamacher, Herold, Wiegel , Hamacher , & Schega, 2015)*. When multitasking as you walk occurs, the prefrontal regions of the brain are active in order to ensure both tasks are successfully solved. The younger population requires less brain activity when walking in comparison to the aging population: therefore age and pathologies are factors influencing the activity of cortical and subcortical regions when walking *(Hamacher, Herold, Wiegel , Hamacher , & Schega, 2015).*

Maintenance of balance and gait therefore preventing falls is the responsibility of four neurologic components *(The Pacific Neuroscience Medical and Editorial Team, 2020):*

- *The Brain*: specifically the frontal lobes, basal ganglia and cerebellum conducts the motor program of walking as well as coordination. The motor program cohesively puts together alternation of flexion and extension of the lower extremity joints resulting in optimum stride length, stance, posture, arm-swing and gait speed.
- *Peripheral Nerves, Muscles and Spinal Cord*: responsible for providing strength and sensation to execute the walking program from the brain.
- *Vestibular System:* responsible for providing balance, by relaying information to the brain of the positioning of the inner ear in three dimensions. Vertigo is typically experienced when the vestibular system is not working.
- *Vision:* allows us to see the horizon and irregularities on the walking surface, poor vision is problematic for gait.

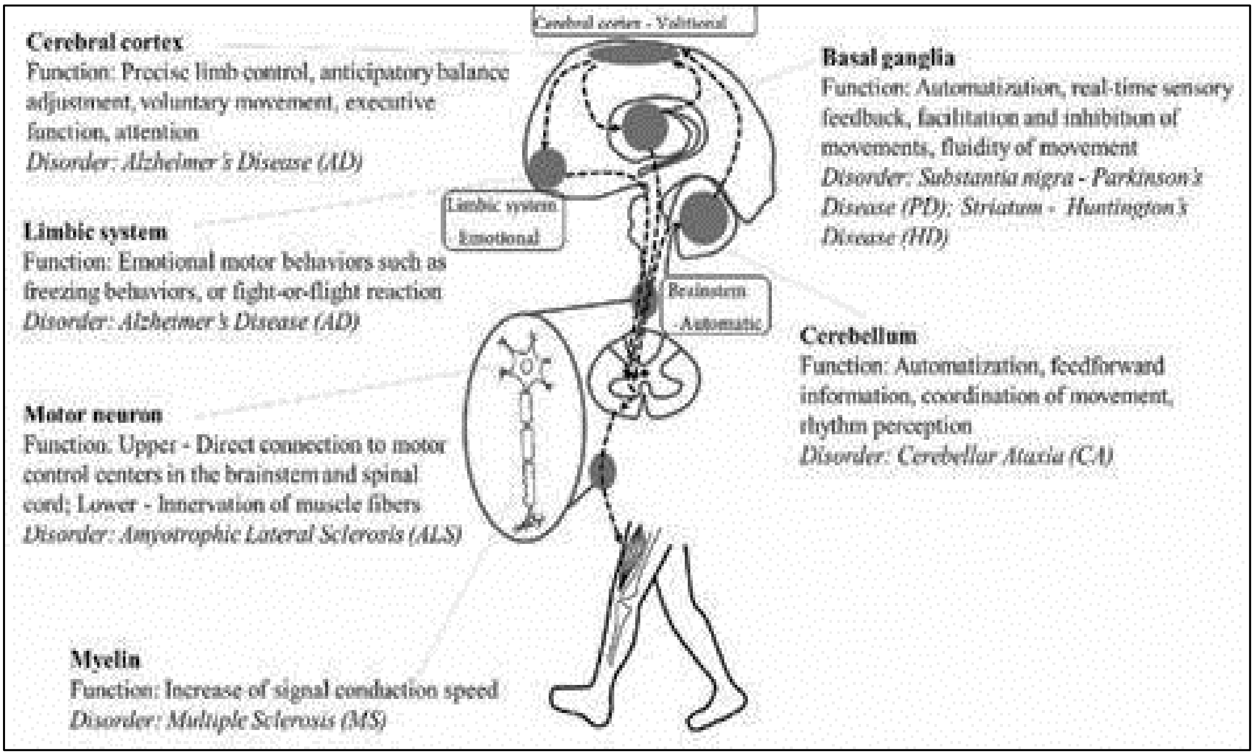


Figure 4: Schematic drawing of the neurological structures involved in gait.(Moon, Sung, An, & Hernandez, 2016)

2.2. Effects of Stroke on the CNS

Stroke is one of the popular causers of Hemiparesis or Hemiplegia, which are defined as mild weakness on one side of the body and severe to complete paralysis on one side of the body respectively *(Spinalcord.com Team, 2020)*. The weakness or paralysis is identified in the arms, hands, legs and face or a combination of these and can manifest at different degrees of loss of motor control and sensation. This paper will focus on motor control loss in hemiparesis/plegia resulting from a stroke attack.

Stroke is a result of compromised blood supply to the brain: it can either be ischemic, whereby there is an obstruction to an artery supplying blood to an area of the brain or haemorrhagic, when an artery in the brain bursts, resulting in internal bleeding *(Denslow, 2021)*. Stroke leads to changes in certain sensory, motoric and cognitive functions, depending on the affected region *(Denslow, 2021)*.

According to the study by *(Murphy & Werring, 2020)* stroke is one of the leading cause of mortality and acquired disability world-wide. Due to improvement of acute management of stroke, developed countries have successfully decreased stroke mortality *(Sarti, Rastenyte, Cepaitis, & Tuomilehto, 2000)*, but a third of victims are left with a level of impairments, popularly motoric impairments in upper extremities. Motoric impairments are the results of paresis, spasticity and poor spatiotemporal coordination, and their treatment not only relies of pharmaceuticals but strongly and nearly exclusively on rehabilitation techniques *(Li, 2017).*

The goals of stroke rehabilitation are to improve and maintain impaired function through restitution, substitution and compensation of function with the use of therapeutic interventions promoting adaptive learning *(Takeuchi & Izumi, 2013) (Wilbur, 2020)*. The results of therapy are dependent on the nervous system's ability to recognise its structure connections of functions in response to intrinsic and extrinsic stimuli. Greatest recovery of stroke is observed in the first few days or weeks but what guarantees recovery in the later stages and is used strategically by therapeutic interventions is neuroplasticity *(Moawad, 2021).* Neuroplasticity being the expression of growth-promoting genes promotes the remodelling of dendritic spine architecture, axonal sprouting and synaptogenesis: these developments are advantageous to therapeutic interventions for the establishment of new connections promoting learning-dependent spasticity through experience *(Health Jade Team 2, 2018).*

Training and enriched environments are the two main approaches therapeutic interventions take in stroke motoric rehabilitation *(Takeuchi & Izumi, 2013)*. When using the training approach, the patient is encouraged to actively engage in relearning of motor skills. The success of this approach is dependent on instruction and guidance from the therapist as well as their feedback and reinforcements *(Takeuchi & Izumi, 2013)*. On the other hand, the enriched environment approach aims to provide an interactive context that excites the physical, cognitive and social activities along with multimodal sensory processing *(Takeuchi & Izumi, 2013).* This approach encourages sensomotoric function as well as plasticity post stroke by engaging the patient in activities, having a positive influence on motivation and well-being, lastly it can be combined with other treatments to speed up motor recovery.

2.2.1.1. Cortical vs Subcortical Strokes

Stroke can occur in different regions of the brain, these regions are broadly categorized as either cortical or subcortical. Cortical strokes are those occurring in any of the four lobes of the cerebrum: frontal, parietal, temporal and occipital *(Denslow, 2021).* Strokes occurring in the lobes often result in the loss of higher levels of functioning. On the other hand, subcortical strokes are those occurring in structures lying deep within the brain, which include the: Diencephalon, Pituitary gland, limbic structures and the Basal ganglia *(Denslow, 2021).* Subcortical strokes are usually haemorrhagic as the arteries supplying blood to these regions are smaller and delicate, making them susceptive to high blood pressure *(Denslow, 2021)*.

The frontal lobe is the largest region of the brain comprised of two paired lobes, one on the left and the other on the right, and are collectively known as the left and right frontal cortex, taking two-thirds of the brain *(Maher, 2020)*. They play a huge role in expressing emotion, creating personalities and producing movement, as well as controlling high cognitive functions such as language, memory, problem solving and judgement *(Maher, 2020).* Stroke in the frontal lobe can target any of the functions it performs, hence the importance in identifying the hemisphere affected when planning a treatment. In the function of movement, the hemispheres of the frontal lobe activate the contralateral side of the body: stroke on the left hemisphere affects the right side of the body and vice versa. Due the frontal lobe dominating a large part of the brain, strokes in this region are more likely to occur in comparison to the subcortical structures. The most common symptoms of frontal lobe strokes are as follows *(Maher, 2020):*

- Hemiparesis/Hemiplegia
- Speech difficulties – mostly occur after a stroke on the left hemisphere, as it is the major language centre of the brain.
- Dysphagia
- Ataxia
- Incontinence
- Impaired spatial reasoning
- Vascular dementia
- Cognitive deficits
- Behaviour changes – such as irritability or impulsiveness
- Personality changes

The parietal lobe is found on both hemispheres of the brain and it functions to interpret sensory information and spatial awareness *(Maher, 2020)*. Strokes the effects of stroke in this region are strongly dependent on the hemisphere affected: each person has a dominant hemisphere is in comparison to the other *(Maher, 2020).* Studies have shown right handed people to have a more dominant left hemisphere and the opposite for left handed individuals. When the dominant side is affected by stroke, the following are expected *(Maher, 2020):*

- Agnosia
- Difficulty differentiating between left and right
- Agraphia – from motoric impairments or inability to spell
- Alexia
- Acalculia – usually a result of stroke on the left hemisphere
- Aphasia
- Proprioception disorders

On the other hand, the following are expected when stroke affects the non-dominant side:

- Hemineglect – usually affects the left side of the body as the right hemisphere is dominant in most.
- Poor spatial awareness
- Impaired sense of direction and visual memory
- Anosognosia

The temporal lobe is the second largest lobe of the brain and is responsible for memory, language and emotion. Common effects after stroke in this region are *(Brewer , 2020):*

- Poor memory – difficulty to learn and retain information, as well as affect past memories.
- Inability to recognise faces (prosopagnosia)
- Impaired speech (fluent/Wernicke's aphasia) – usually caused by stroke on the dominant hemisphere.
- Difficulty with depth perception or experience field cuts
- Trouble with sound
- Emotional and behavioural changes – caused by the damage of the amygdala located in the frontal lobe. After the stroke some patients present a more aggressive behaviour while others are more passive.

- Homonymous hemianopia
- Cortical blindness
- Central vision loss
- Visual hallucinations
- Prosopagnosia
- Visual agnosia
- Alexia without agraphia

The occipital lobe processes visual input from the eyes, therefore in the occurrence of a stroke in this region visual impairments are the primary deficits, these include *(Denslow , 2021):*

The following symptoms are also typical for occipital lobe strokes:

- Facial drooping on one side
- Arm weakness mainly on one side
- Slurred speech

Less typical symptoms include:

- Tingling/numbness
- Light-headedness/ vertigo
- Severe headache/migraine

The brainstem is made up of midbrain, pons and medulla oblongata: collectively it controls basic body functions such as breathing, heart rate and consciousness *(Maher, 2020).* A stroke can occur at any region of the brainstem and in some cases strokes that injure the brainstem can also affect the cerebellum or other surrounding areas *(Maher, 2020).* Brainstem strokes can be difficult to diagnose as the symptoms are atypical, examples being vertigo and nausea. According to *(Maher, 2020)* Stroke in the brainstem affects breathing, heart rate and consciousness, leading to the following secondary effects:

- Coma
- Locked in syndrome
- Difficulty breathing
- Dysphagia
- Vision problems
- Ataxia
- Wallenberg’s syndrome
- Loss of sensation

According to research there is a 3% chance of a cerebellar stroke occurring. The cerebellum is essential in the control and coordination of voluntary movements, as well as maintaining balance and posture, motor learning and some aspects of language *(Maher, 2020).* Due to majority of the cerebellum controlling the motor system, a stroke often results in motor control and posture impairments. Secondary effects of the stroke in this region are as follows *(Maher, 2020):*

- Acute cerebellar ataxia
- Loss of coordination and balance
- Vertigo
- Nausea and vomiting
- Impaired memory
- Difficulty with proprioception
- Speech problems
- Cerebellar cognitive affective syndrome

The thalamus is found in the subcortical regions of the brain, and it is responsible for our memory, emotions, sleep-wake cycle, processing sensory input, sensorimotor control and executive functions *(Denslow, 2021)*. The thalamus relays 98% of the sensory input within the body therefore after stroke in the thalamus the processing and transmission of sensory information is mostly affected. Other impairments include *(Denslow, 2021):*

- Impaired sensation
- Sleep disturbances
- Amnesia
- Changes in attention
- Speech difficulties
- Hemispatial neglect
- Vision impairments
- Difficulties with balance
- Central post-stroke pain

The Basal ganglia is another subcortical structure, which controls emotions, voluntary muscle control, cognitive function and procedural memory and learning (Maher, Basal Ganglia Stroke: Understanding the Effects & Recovery Process, 2020). When a stroke occurs in this region, any of the functions of the basal ganglia are affected, such as *(Maher, Basal Ganglia Stroke: Understanding the Effects & Recovery Process, 2020):*

- Motor impairments
- Changes in sensation
- Emotional blunting
- Post-stroke depression
- Loss of spontaneous speech

Internal capsultes are V-shaped structured located deep in the brain with motor, sensory and cognitive fibers run through the internal capsules as they travel between the cerebral cortex and brainstem *(Denslow, Understanding Internal Capsule Stroke: Symptoms & Recovery Process, 2021)*. The internal capsule is found on both hemispheres of the brain, therefore damage on the right side of the hemisphere results on impairment on the left side of the body and vice-versa *(Denslow, Understanding Internal Capsule Stroke: Symptoms & Recovery Process, 2021)*. Typical effects after stroke in the internal capsule are *(Denslow, Understanding Internal Capsule Stroke: Symptoms & Recovery Process, 2021):*

- Pure motor hemiplegia
- Facial weakness
- Cognitive impairments
- Hearing impairments
- Visual impairments
- Sensory loss

2.2.2. Effects of stroke on Motor Cortex

The study 'TMS measures of motor cortex function after stroke: A meta-analysis' - describes what occurs in the motor cortex post stroke by using a Transcranial Magnetic Stimulation assessing and comparing corticomotor excitability, intracortical function and interhemispheric interactions in the affected and unaffected hemispheres of the brain. The results concluded that the affected hemisphere of the brain primarily faces neurophysiological changes after stroke. The Primary Motor Cortex (PMC) on the affected side exhibits lower excitability levels in comparison to the unaffected side and PMC in healthy patients in acute and chronic stage of stroke. The Intracortical Function is assessed measuring short interval intracortical inhibition: the SICI presented lower in the affected hemisphere in comparison to the unaffected hemisphere and the healthy control group only in acute stages of stroke *(McDonnelll & Stinear, 2017)*. It is important to note that the unaffected hemisphere of the brain in stroke patient works in the same way as in a healthy patient (*McDonnelll & Stinear, 2017)*. According to the research done for 'TMS measures of motor cortex function after stroke: A meta-analysis', there was a low number of acceptable researches that were evaluated were within the research criteria, that managed to give clinically acceptable outcomes for assessing changes in the interhemispheric interactions.

However the study by Frias, et al., *(2018*) studied the changes in the both the motoric and sensory hemispheres post stroke, as they understood that impairment in the sensory hemisphere significantly affects motoric functions or the stroke outcome for the patient. Their results demonstrated that after stroke there is a disruption of interhemispheric resting state-functional connectivity between the primary sensory cortex as well as the primary motor cortex. Comparing these results with the control group that demonstrated symmetrical resting state–functional connectivity in both primary motor and sensory cortices, therefore it concludes that bilateral and symmetrical connectivity between hemispheres is crucial in achieving physiological motor performance.

2.2.3. Stroke Impact on Gait

Commonly, hemiplegic stroke patients due to motor paralysis experience a spastic gait pattern: the paralysis and spasticity lead to decreased motor control and altered range of motion in the joints *(Gait and Balance Academy , 2021)*. Pathologies in gait negatively affect activities of daily living, consequently decreasing the quality of life of patients. Depending on severity, stroke patients could fail to load the affected leg due to motor paralysis, negatively impacting the walking ability *(Pau, et al., 2020)*. Motor paralysis is a result of an Upper Motor Neuron Lesion which impairs muscle contraction balance, resulting in muscle coordination impairment (Pau, et al., 2020). Additionally muscular strength is decreased by the reduction of maximal voluntary force. Patients suffering from hemiplegia usually obtain a drop foot due to weakness or reduced control of the tibialis anterior, resulting in an absence of the heel strike phase in gait *(Pau, et al., 2020).*

Furthermore heel strike phase can be absent as a result of spasticity of calf muscles *(Gait and Balance Academy , 2021).* The absence of heel strike or dorsiflexion lead to a foot slap or toe-heel gait pattern. Due to lack of control of quadriceps muscles, knee hyperextension is observed during the initial loading phase *(Gait and Balance Academy , 2021).* Overall muscle weakness can result in an increase of flexion in knee and hip joints during the mid-stance phase. On the other hand, weakness in calves potentially cause poor heel rise timing leading to hyperextension in the knee. If the patient is struggling with knee and ankle-planar flexion, there is an insufficient toe off during the pre-swing phase *(Gait and Balance Academy , 2021).* Poor knee and ankle dorsiflexion limits foot clearance in initial and mid-swing phases; additionally in terminal swing, reduced range of motion in the knee and ankle dorsiflexion prevents the foot from being properly positioned for appropriate foot contact *(Gait and Balance Academy , 2021).*

In summary, hemiplegia frequently results in difficulties during foot clearance in swing phase, stability during stance phase and upholding energy efficient gait patterns *(Gait and Balance Academy , 2021)*. Patients struggling with foot clearance and stability have a higher risk of falls, while pathological joint kinematics lead to joint damage. Impaired motor functions along with cognitive factors and emotions increase the risk for falls post stroke. The frequency of falls consequently develops a fear of falling in patients leading them to avoiding activities as they lack confidence, leading to the development of anxiety.

As pathologies in gait arise post stroke, the patient tends to create compensatory patterns in order for them to maintain a level of function. Limitations with foot clearance caused by decreased range of motion in hip and knee flexion along with dorsiflexion of ankle results in the common compensatory pattern of circumduction coupled with hip-hiking *(Gait and Balance Academy , 2021)*. Circumduction cause hip abduction which moves the foot laterally, while hip-hiking causes an elevated pelvis on the affected side resulting in a larger pelvic rotation in the frontal plane *(Gait and Balance Academy , 2021)*. Hemiplegia/paresis manifests instability during the gait stance phase on that side: compensating for the instability, patients tend to reduce the time spent in the unilateral stance phase on the affected side *(Gait and Balance Academy , 2021)*.

There are various changes in gait that can be observed due to hemiplegia/paresis, therefore it is necessary to quantify the most common characteristics. Patients typically walk with decreased speed, along with asymmetrical and decreased step length, decreased stance and duration of single leg support on the affected side and changes in joint kinematics *(Gait and Balance Academy , 2021)*. Listing the characteristics helps to determine the most suitable treatment option to improve gait, prevent joint damage and reduce fall risk.

Rehabilitation post hemiplegic stroke aims to bring back the patient as close to their condition pre-stroke as possible. Examples of treatment are as follows: bracing and assistive devices are used to compensate for loss of strength and range of motion *(Gait and Balance Academy , 2021)*. Orthotics such as ankle-foot orthotic aims to prevent excessive plantar flexion of the ankle improving foot contact *(Gait and Balance Academy , 2021)*. Stance stability can be achieved through walking devices such as canes, and walkers along with upper body strength. Patients suffering from spasticity are helped with injections such as Botulinum toxin while functional electrical stimulation is used as an encouragement to promote voluntary muscle activation. Physical exercise is used to improve overall function. Other limitations promoting gait deviations are improved by gait training and robot-assisted training *(Gait and Balance Academy , 2021)*.

2.3. Music in Motoric Rehabilitation

The neural substrates of musical functions in the human brain have been explored extensively in the last two decades *(Thaut & McIntosh, Neurologic Music Therapy in Stroke Rehabilitation, 2014).* Research continues to reveal music to be a powerful complex auditory stimulus, with the capability to engage the brain aiming to retrain neural and behavioural functions that are applicable to non-musical functional aspects of therapy and/or medicine *(Thaut & McIntosh, Neurologic Music Therapy in Stroke Rehabilitation, 2014).* These outcomes have been achieved through the study of rhythm perception and production as they are the most valuable structural element in the language of music *(Thaut & McIntosh, Neurologic Music Therapy in Stroke Rehabilitation, 2014).*

Due to neuroscience research, the use of music in therapy has shifted from customarily aiming to influence an emotional response, facilitate relationship building and improving overall health which can be summarized as '*social science and interpretive models'* to *'neuroscience and perceptual'* models *(Thaut & McIntosh, Neurologic Music Therapy in Stroke Rehabilitation, 2014).* The '*neuroscience and perceptual'* models study the ways in which musical structures and patterns engage the brain in ways that can be transited and generalized into non-musical therapeutic learning and training: the non-musical therapeutic outcomes are the result of music's capability to stimulate affective, cognitive and sensorimotor processes in the brain *(Thaut & McIntosh, Neurologic Music Therapy in Stroke Rehabilitation, 2014).* The shift in concepts of the use of music in therapy has lead the development of Neurologic Music Therapy (NMT): NMT aims to retrain brain function through cues obtained from our capability to perceive auditory structures and patterns in music *(Thaut & McIntosh, Neurologic Music Therapy in Stroke Rehabilitation, 2014).*

Additionally recent research has emerging evidence of music therapy and/or other music or rhythm integrating methods significantly improving symptoms of neurological and non-neurological disorders *(Devlin, Alshaikh, & Pantelyat, 2019).* Music has the non-invasive potential to improve behavioural, motor and psychological functions in patients with neurological disorders, it can be used in the following ways *(Daniel, Koumans, & Ganti, Impact of Music Therapy on Gait After Stroke, 2021):*

- Used as catalyst to regain freedom of movement in people with Parkinson's *(de Bruin, et al., 2010).*

- Used for speech fluency after stroke *(Schlaug, Marchina, & Norton, 2008)*
- Reduces mood symptoms such as: increased agitation *(Baird & Samson, 2015)*
- Recollection of memories in people with dementia. *(Baird & Samson, 2015)*

According to MacDonald et.al 2012's study as cited in *(Brancatisano, Baird, & Thompson, 2020),* music is used as therapeutic tool to impact health and well-being due to the following general properties:

- Easily accessible therapeutic tool
- Induces physical activity which is fundamental for neurorehabilitation
- It can be a form of non-linguistic communication
- Music has the capacity to impact behaviour, emotion, cognition and identity: the ability of music to elicit movement and change emotions are relevant for neurorehabilitation *(Altenmuller & Schlaug, 2013).*

Therefore, music is capable of engaging, provoking emotions, being personal, promoting social activities, being persuasive and encouraging synchronisation of movement and speech: these attributes of music have concrete benefits that are interdependent and overlapping, making it a valuable and unique tool for therapeutic purposes *(Brancatisano, Baird, & Thompson, 2020).* Music based therapy can occur either actively (playing instruments, clapping, singing and dancing) or passively (listening) or both. Therapy sessions can occur either in groups or individually *(Brancatisano, Baird, & Thompson, 2020).*

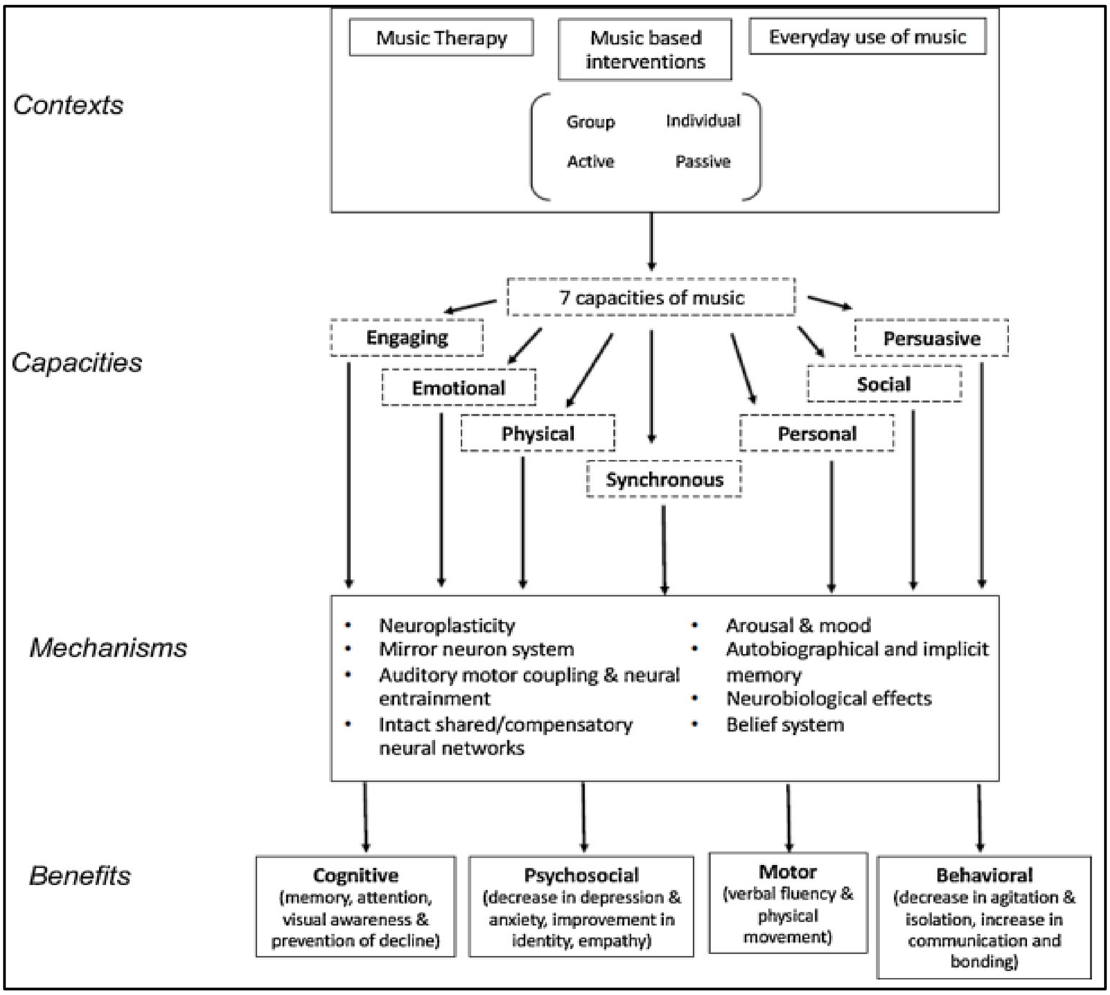


Figure 5: *Showing Therapeutic Music Capacities Model (TMCM) (Brancatisano, Baird, & Thompson, 2020)*

2.3.1. Capacities of Music Influencing Stroke Recovery

This section clarifies the ways in which the capacities of music are advantageous in the treatment of stroke.

Engagement of Music:

Music is engaging to the brain from either a neurological or psychological aspect *(Brancatisano, Baird, & Thompson, 2020).* Neurologically active and passive forms of music activate or engage breadth and depth of cognitive functions such as: attention, learning, memory, emotion, auditory scene analysis, planning and expectation as well as behavioural and psychological functions such as motor responses, breathing and heart rate *(Brancatisano, Baird, & Thompson, 2020).* The activation of these cognitive functions are a reflection of the ability of music to have a wide-spread activation of brain regions: cortical regions, deep mid and hind subcortical regions and cerebellum *(Zatorre & Salimpoor, 2013).*

Psychologically, music engagement references to the tendency of music capturing attention: musical activities are far more immersive in comparison to other activities *(Brancatisano, Baird, & Thompson, 2020)*. Music has combinations of time varying features that our brains constantly have to track, perceive and categorise. The varying features include harmony, tempo, timbre, meter phrasing, consonance, dissonance and dynamics: their processing allows music to capture attention more powerfully than other sensory stimuli *(Brancatisano, Baird, & Thompson, 2020).*

According to *Peretz and Zatorre's 2005* study as cited in *(Brancatisano, Baird, & Thompson, 2020)* music is capable of engaging multiple regions of the brain simultaneously, giving it a multisensory nature thus making it a beneficial form of environmental enrichment. One of the regions stimulated by music is the Grey Matter, which processes information from sensory organs towards its centres for regulation and control of our intellectual processes as well as skills such as: emotion, sight, hearing, speech, self-control, decision making, memory and motor skills *(Sarkamo, et al., 2014)*. A study by Gaser and Schlaug *(2003)* comparing grey matter volume in the primary, pre-motor, somatosensory areas and cerebellum between musicians with different expertise, concluded: Grey Matter is highest in professional musicians, followed by amateur musicians and lastly non-musicians: the changes in Grey Matter volume were discovered to persist later in life as older practicing musicians have larger volume of grey matter in left inferior frontal gyrus in comparison to non-musicians of the same age. Structural and brain differences are also specific to the instrument being played: musicians playing string instruments have larger somatosensory representations of fingers in comparison to drummers *(Pantev, Engelien, Candia, & Elbert, 2006)*.

Neuroplasticity in the brain is a result of long term effects of music engagement post injury or when learning and experiencing something new: the neuroplasticity changes from music engagement benefit auditory (Kraus & Chandrasekaran, 2010) and motor functions *(Skoe & Kraus, 2012).* The study by Schlaug et al., *(2006)* investigating the functional and structural brain differences between young musicians and non-musicians concluded young musicians to have performed better than non-musicians on a number of cognitive tasks assessing: abstract reasoning, auditory, vocabulary, mathematical and motor functions.

In a study by Bugos, et.al. *(2007)* on the benefits of music therapy in the brain towards the elderly population taking piano lessons in comparison to those not: the results concluded in music therapy improving working memory, speed, and motor skills in the population learning to play piano. Stroke is a prevailing threat in the elderly community and music based therapy has therapeutic benefits as music engagement leads to increased arousal and mood. The positive reaction of music to arousal and mood has cascading benefits towards cognitive function, resulting in greater neural activity and therefore greater potential for neuroplasticity changes with lasting benefits *(Brancatisano, Baird, & Thompson, 2020).*

Physicality of Music:

It is undeniable that music has an impelling effect on spontaneous movement: the stimulation felt when listen to music results in spontaneous motions ranging from a little as foot tapping to grandiose movements like dance *(Brancatisano, Baird, & Thompson, 2020).* Scholars have discovered that movement is an inherent component of music as listening to rhythmical music automatically activates motoric regions of the brain, even when no movement is physically generated *(Brancatisano, Baird, & Thompson, 2020).*

Research in rehabilitative medicine has discovered physical exercise to be beneficial in prevention as well as treatment for age related cognitive decline and most importantly neurological impairments *(Brancatisano, Baird, & Thompson, 2020).* Physical exercise increases 'brain reserve' and its structural integrity: through challenging the bodily systems, exertion, and increase in oxygenation, mechanisms of neuropasticity are altered, specifically those in relation to memory *(Brancatisano, Baird, & Thompson, 2020).* Although the benefits of physical exercise are evident, older adults feel reluctant to it, therefore music is pair with exercise program, making the process more engaging and positive. Studies conducted by Verghese et al., *(2003)* and Verghese*, (2006)* proved that in a neurologically healthy population, dance provided greater prevention against cognitive and physical decline in comparison to purely physical exercise. This study focused on the risk of developing Dementia concluded that adults regularly engaging in dance are less likely to develop Dementia in comparison to those rarely or never dancing: it is further stated that dance compared to other activities such as swimming, cycling and walking, is the most effective in lowering the risk of Dementia.

Music-physical exercise has been further proven to be therapeutic for patients suffering from movement disorders such as Parkinson's disease (PD), as it has improved balance and functional mobility greater than exercise alone *(Hackney, Kantorovich, Levin , & Earhart, 2007).* PD patients have in regained flow of movement, as improvements in balance, gait walking distance and mobility are achieved through dance interventions. Dance interventions for PD patients have simultaneously improved the psychological challenges experienced by this population: dance has alleviated feelings of anger, fatigue and mood disturbances *(Lewis, Anett, Davenport, Hali, & Lovatt, 2014).*

Furthermore the Rhythmicity of music stimulates movement through intact neural networks such as the supplementary motor area, premotor cortex and cerebellum *(Brancatisano, Baird, & Thompson, 2020).* Lastly, Participating in active music-based treatments particularly in groups enhances the physical capacity of music: stimulating mechanisms of auditory motor coupling, synchronization of movement and supports the engagement of intact shared neural networks *(Brancatisano, Baird, & Thompson, 2020).* This enhancement results in improvement in motor function and brain health for both neurologically challenged and healthy individuals.

Synchronicity of Music:

Rhythm along with melody are elements of music that promote synchronization through singing or moving, which results in fluid or fluent motor functions *(Brancatisano, Baird, & Thompson, 2020).* A number of studies have proven that several cortical and sub-cortical regions involved in timing, inclusive of the cerebellum, basal ganglia, parietal cortex, prefrontal cortex, premotor cortex and supplementary motor area are activated by rhythmic synchronization *(Brancatisano, Baird, & Thompson, 2020).* Neural entrainment defined as the repetitive neural firing coinciding with temporally predictable events such as musical rhythm is strongly associated with the instinctive human action of synchronising body movements to an external beat *(Doelling & Poeppel, 2015).* Listening and synchronising body movements to music elicits neural entrainment: the entrainment can continue without further input from the external rhythmic source, which then allows the individual to predict when the next musical beat will occur, providing a steady timing cue allowing the brain to plan ahead *(Brancatisano, Baird, & Thompson, 2020).*

Personal characteristics of music:

The quality of life of people suffering from neurologic disorders may be improved through listening to personally-preferred music as it recruits the limbic and reward centres of the brain *(Brancatisano, Baird, & Thompson, 2020)*: Sung and Chang *(2005)* confirmed this as they concluded that family members often report marked changes in mood, physical ability and verbal responses. For stroke patients the loss of motor function and impaired speech impacts their physical and social identities, leading to the possible development of depression and/or anxiety *(Brancatisano, Baird, & Thompson, 2020).* According to *Sarkomo, et.al., (2008)* listening to preferred music in the first six months after stroke reduced depressive symptoms. Forsblom, et al., *(2009)* from interviews with stroke patients concluded: patients listening to interventions in the early post stroke period reported that music induced a positive mood, state of calmness, relaxation and improved sleep, lastly 75% of patients reported that personalised music contributed positively to their recovery.

Lastly music is persuasive:

Across cultures, music has been part of practices and rituals associated with healing *(Gouk, 2016).* The persuasive nature of music makes it a useful tool for building optimism in patients towards the treatment program and according to the Health Belief Model the positivity augments therapeutic benefits *(Brancatisano, Baird, & Thompson, 2020).* Consequently, by believing in the treatment, patients are more eager to participate in treatments. In music therapy, music is used not only to distract the patient form pain and anxiety, but to also boost the patients' belief in their ability to control their healing *(Moreno, 1988).*

2.3.2. Neurologic Music Therapy

According to The Academy of Neurologic Music Therapy (NMT) at Colorado State University, Neurologic Music Therapy is ‘a research based therapeutic application of music to cognitive, sensory and motoric function due to neurologic diseases of the human nervous system *(Coast Music Therapy, 2013).* Its treatment techniques are based on the scientific knowledge in music perception and production and their effects on non-musical brain and behaviour functions.

Rhythm has the potential to build new connection in the brain called neuropathways, which leads to improving the brain functions, resulting in a more productive and functional life *(Oliver, 2021)*. These changes are possible due to rhythm and music simultaneously affecting multiple areas the brain on a subconscious level *(Oliver, 2021)*. NMT uses various treatment approaches, which are used selectively for a specific therapeutic goal such as improvement of motoric function. For this goal, Rhythmic Auditory Stimulation, Patterned Sensory Enhancement and Therapeutic Instrumental Music Performance are the appropriate approaches to use *(Oliver, 2021).*

Rhythmic Auditory Stimulation:

Rhythmic Auditory Stimulation (RAS) is defined as a therapeutic application of pulsed rhythmic or musical stimulation in order to improve gait or gait related aspects of movement *(Mainka, Wissel, Voller, & Evers, 2018)*. It does this by acoustic rhythms produced by metronomes or previously selected music, which then signal cadence during walking enabling the patient to synchronize their footsteps with the rhythm or stimulus heard *(Physiopedia Contributors, 2020).* Successful synchronisation results in: increased step length, cadence and symmetry as well as improvement of functional walking ability manifested by increasing gait speed and therefore produces faster walking and longer strides.

An increase in accuracy of the central motor impulse results in an increase of impulse force of the nerve over which the command is given when the highest auditory signalling is given *(Physiopedia Contributors, 2020).* This allows coordination between the agonizing and antagonizing muscles as the skeletal muscles are regulated by the central nervous system. RAS provides the possibility to train the coordination of axial and proximal movements by motor commands as it activates the motor neuronal spinal nuclei through the reticulospinal pathway *(Physiopedia Contributors, 2020)*. Rhythmic Auditory Stimulation has a feedback stimulus in gait that works in the following way: increases the excitation in the subcortical nuclei that adjusts the balance with the bilateral movement of the trunk and proximal muscles, resulting in reactive motor coordination *(Physiopedia Contributors, 2020).*

Gait has the ability to adjust to acoustic stimulus and this is defined as auditory motor coordination *(Physiopedia Contributors, 2020)*. It is essential for physical therapists to know the auditory motor coordination of a patient as it helps them to modify the metronome, aiming to achieve the most optimal coupling between gait and rhythm: this helps to obtain better results in the modification of gait parameters through acoustic rhythmic stimulation *(Physiopedia Contributors, 2020).* A study by Roerdink, et.al., *(2011)* concluded that if the rhythm of the metronome is slower than the rate the patient can maintain, the patient then anticipates the rhythm with their footsteps. In the case the frequency of metronome is closer to the patient's preferred rate, the time it takes the patient to synchronise their footsteps with the rhythm will be shorter *(Physiopedia Contributors, 2020)*. The decrease in time it takes to synchronise footsteps to the rhythm the better the auditory motor coordination of the patient, therefore the farther the frequency of the metronome from the patient's cadence the greater number of steps the patient requires to synchronise to the bea*t (Physiopedia Contributors, 2020).*

The efficiency of acoustic rhythms in symmetry, fluidity and gait adaptability are greater when auditory motor coordination is better, which is achievable by having stimulus frequency closer to patient's preferred rate *(Physiopedia Contributors, 2020).* RAS uses three different percentages of auditory cueing, 90,100 and 110: a study by *Yu, et.al., (2015)* indicated using 110% of patient's cadence is the best frequency to improve stride length, cadence and gait speed, due to this signal frequency increasing accuracy of central motor impulses and consequently the impulse force of the nerve over which command is issued.

2.3.3. Rhythmic Entrainment

Studies in behaviour/brain/psychology demonstrated that humans characteristically respond to external rhythms with synchronization. In the early 1900's, Thaut and fellow colleagues established the use of entrainment for therapeutic purposes *(Thaut M. , 2015).* To 'entrain' defined by the Oxford Languages Dictionary is 'rhythm or something that varies rhythmically gradually causes another to fall into synchrony with it: can be observed physically from pendulum clocks and biological systems from fire flies *(Thaut M. , 2015).* In the early 1990s, they also concluded that the periodicity of auditory rhythmic patterns are capable of entraining movement patterns in patients with movement disorders. Studies on physiological, kinematic and behavioural movements further proved that not only do entrainments change timing of movement, but also improve spatial and force parameters *(Thaut M. , 2015)*. Optimal motor planning and execution heavily rely on anticipatory rhythmic templates, which are critical coordinative constraints in the brain: this strongly suggests rhythm to be a successful stimulus for therapeutic purposes *(Thaut M. , 2015)*. During entrainment two movement oscillators of different periods (frequencies) entrain or synchronise into a common period: during an auditory entrainment, the motor period synchronises to the auditory rhythm period. It is necessary to identify that entrainment is not defined/identified by phase (beat), rather it is defined by period (frequency) *(Thaut & Kenyon, 2003).*

2.3.4. Auditory System and Music Activation

In the mid-1990s motor control research demonstrated a new perspective of the role music in therapy: these studies concluded that rhythmic entrainment of motor function positively influence movement recovery for stroke patients *(Thaut & McIntosh, 2014)*. According to crucial researches by Paltsev and Elner in 1967 and Rossignol and Melvill Jones in 1976 as cited by Thaut and Mclntosh *(2014)*, there are complex physiological interactions between the auditory and motor system. These studies illustrated how the auditory motor pathways such as the reticulospinal connections are capable of influencing the excitability threshold of motor neurons, resulting in a priming effect on the segmental motor system through the auditory input *(Thaut & McIntosh, 2014)*. The priming of the segmental motor system transforms into a timing effect that functionally facilitates muscle activation patterns during auditory rhythmic cuing *(Thaut & McIntosh, 2014).*

The auditory system is faster and with greater precision in comparison to the visual and tactile systems: it has a high intelligence of detecting temporal patterns in auditory signals with concise precision and speed. Additionally the auditory system is equipped to detect and construct rhythmic sound patterns: this ability of the auditory system to observe timing links it to the motor system. Studies by Thaut et al. *(1998) (1998)* Illustrated the capability of upper extremities to entrain to rhythmic stimulus and maintain the acquired frequency, as subtle tempo changes appear, the entrainment is maintained as they are not consciously perceived. In the last 20 years it has been discovered that rhythmic entrainment in human movement is achievable and therefore useful in treating motoric functions of movement disorders *(Thaut M. , 2015)*. This is supported by the discovery by *Felix et al 2011* as cited *by (Thaut M. , 2015)* stating that the auditory system has richly distributed fibre connections to motor centres from the spinal cord, the brainstem, subcortical and cortical levels.

2.3.5. Clinical Applications of Entrainment

A 2014 study by Thaut and Hoemberg revealed multiple treatment techniques in NMT utilize entrainment concepts in sensorimotor, cognitive and speech/language training *(Thaut M. , 2015).* Rhythm entrainment is considered one of the most important underlying mechanisms for the successful application of rhythmic-musical stimuli in motor rehabilitation for movement disorders such as stroke, Parkinson's disease, traumatic brain injury and cerebral palsy *(Thaut M. , 2015).*

Studies have shown entrainment processes such as auditory rhythm and music have an effect on the human motor system and therefore useful in improving functional control of movement for patients with motoric dysfunctions such as stroke. For stroke patients entrainment has shown positive effects for those with gait pathologies as a result of hemiparesis: it has improved gait velocity, stride length, cadence and stride symmetry and muscle activation.

The study of rhythmic motor circuits in the brain made known that rhythm processing and auditory-motor interactions occur in neural networks that are widely distributed with a hierarchical organization: the network extends from the brainstem and spinal levels to the cerebellar, basal ganglia and cortical loops *(Konoike , et al., 2012)*. Auditory rhythm r music triggers the firing of auditory neurons, which then entrain the firing patterns of motor neurons, consequently driving the motor system into different frequency levels. This entrainment process if further supported by two mechanisms:

i. Priming of the motor system into a state of readiness to move by auditory stimulation.
ii. Regarded as the more specific aspect of entrainment referring to changes in motor planning and execution. Rhythmic stimuli create stable anticipatory time scales or templates.

Rhythm improves movement quality as it provides anticipatory time cues: anticipation is a critical component in perfecting movement quality, its cues allow the brain to plan ahead and be ready *(Thaut M. , 2015)*. For the brain to further improve movement quality through anticipation, foresight of the duration of the cue period is required *(Thaut M. , 2015)*. Time cueing through period entrainment generally aids patients suffering from motor control in space, time and force, additionally auditory rhythm changes the spatial kinematic and dynamic force measures of muscle activation. *Thaut (2015)* highlighted that time cuing through period entrainment is helpful with overall motor control in space, time and force due to the rhythmic cues' ability to give the brain a time constraint: in simpler terms, time cues fix the duration of movement *(Thaut & McIntosh, 2014)*. Foreknowledge of the duration of the movement period changes the calculations of motor planning for the brain *(Thaut M. , 2015)*. Naturally the brain has an internal time keeper fixating movement time: when an external rhythmic interval is added to fixate movement time, the brain's internal time keeper acquires an externally triggered time keeper with a precise reference interval which presents time information to the brain at any stage of movement *(Thaut M. , 2015) (Thaut & McIntosh, 2014)*. The presentation of time information at any stage of movement allows the brain to know at any point of the movement how much time has elapsed and how much is left, resulting in better mapping and scaling of optimal velocity and acceleration parameters across the movement interval, which creates a template *(Thaut M. , 2015).* The matching of the movement to the given template by the brain results in an optimal motor control: there are changes in movement speed, along with smoother and less variable movement trajectories and muscle recruitment *(Thaut M. , 2015)*. Therefore 'rhythm not only influences movement timing (time as the central coordinative unit of motor control) but also modulates patterns of muscle activation and control of movement in space' *(Thaut M. , Kenyon, Schauer, & Mclntosh, 1999).*Understanding the mechanism of entrainment highlights the unimportance of synchronising the patient's movement exactly to the beat; rather it is important to entrain to the rhythmic period as it contains critical information to optimise motor planning and execution *(Thaut M. , 2015)*.

3. METHODOLOGY

Purpose of study: to study the effectiveness of rhythm auditory stimulation combination therapy in the rehabilitation of lower extremity voluntary motor functions, with the focus on gait performance. The following research questions are explored:

1. To what extent RAS has a positive effect on the gait of hemiparesis stroke patients.
2. The effectiveness of this therapeutic approach in comparison to conventional therapeutic methods.

This systematic review was conducted with reference to the guidelines outlined by the PRISMA statement. Data sources where mainly retrieved from three academic databases [Cochrane, Science Direct, PubMed].

Studies were screened according to the inclusion/exclusion criteria:

Inclusion Criteria	**Exclusion Criteria**
Studies published 2009-2022	Studies published later than 2009
Randomised Control Trials/Clinical Control Trials	Case studies or Reports and Systematic Reviews/Meta-analysis
Studies evaluating RAS/RAC/MC/RAE/AC in stroke gait rehabilitation vs conventional therapy	Studies evaluating other forms of NMT besides RAS/RAC/MC/RAE/AC
Stroke patients with hemiparesis, regardless of lesion site, time since onset.	Monoplegia and Quadriplegia strokes
Studies evaluating spaciotemporal gait parameters: gait velocity/cadence/stride length/ stride symmetry/stride time/single/double limb support duration and postural stability assessed by Berge balance scale, fugl meyer lower body assessment and time up and go test.	Studies with < 3 on PEDro quality scale (assessing quality of study) Unpublished/’grey’ literature
Language – English	

The studies were first searched for using the following keyword searchers: rhythmic Auditory Stimulation (RAS) and gait/stroke, Rhythmic Auditory Cueing(RAC) and gait/stroke, Metronome Cueing(MC) and gait/stroke, Rhythmic Auditory Entrainment(RAE) and gait/stroke, Acoustic Cueing(AC) and gait/stroke lastly Neurologic Music Therapy(NMT) and gait/stroke. Studies were assessed and excluded by access, titles, abstracts, duplicates, and relevancy. This was followed by retrieval of potentially relevant articles in full text which were assessed and eliminated in accordance to the inclusion criteria until the final studies were obtained.

4. RESULTS

Based on the keywords searched with filters of studies from 2009-2022 and research articles, trials and reports, a total of 2314 studies were identified from three database (Cochrane, Pubmed and Science Direct). With the assistance of Zotero Reference Manager, 813 duplicate records, and 260 ineligible records were removed, remaining with 1241 records for screening. Furthermore 906 records were excluded by title or abstract as they had no significance in this research. A further 204 reports were not retrieved due to lack of access to the full text, and the remaining potentially eligible 134 full-text reports were further screened according to the inclusion criteria, therefore concluding with a total of 8 eligible studies to answer the research questions. The research process is summarized by the flow diagram below according to PRISMA guidelines:

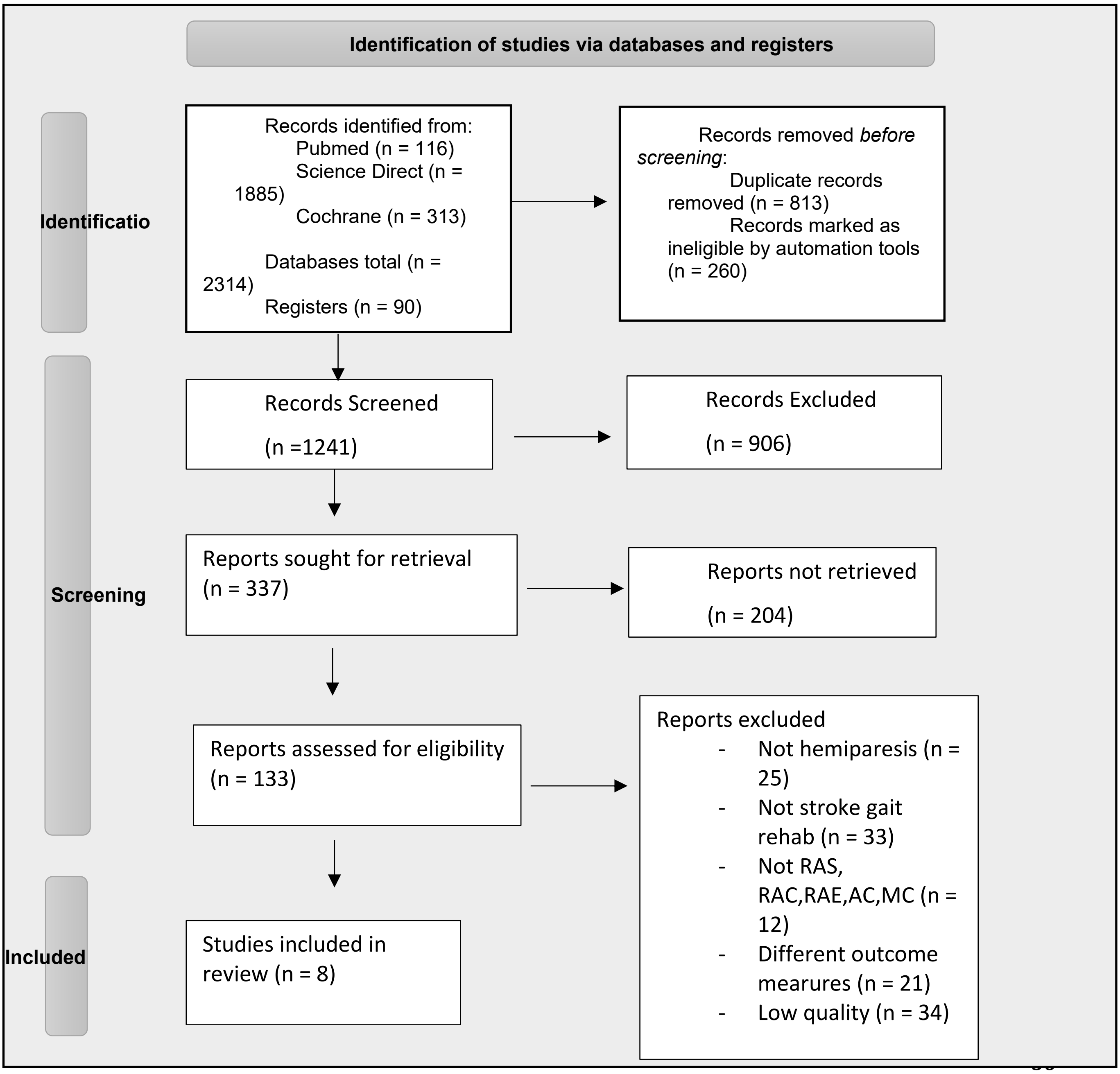


Figure 6*: PRISMA flow chart for the inclusion of studies.*

STUDY	**SAMPLE SIZE**	**STUDY GROUP**	**CONTROL GROUP**	**OUTCOME MEASURES**
1.Gait Training with Bilateral Rhythmic Auditory Stimulation in Stroke Patients: Randomised Control Trial *(Lee, Lee, & Song, 2018)*	45 participants Study group [n=23] Control group [n=22 – 1in final analysis]	Gait training with bilateral rhythmic auditory stimulation (GBTR) + conventional therapy: 30mins a day, 5 days a week for 6 week period.	Gait training without RAS + conventional therapy: 30mins a day, 5 days a week for 6 week period.	Gait symmetry on step time, Gait symmetry on step length, Gait Ability, Balance ability, Lower extremity function
2. Effect of Rhythm of Music Therapy on gait in patients with stroke. *(MB Pan, et al., 2021)*	60 participants Study group [n=30] Control group [n=30]	Music therapy + conventional drug therapy + rehabilitation training + walking training: 6 days a week (Sunday rest day) for 4 weeks	Conventional drug therapy + rehabilitation training and walking training: 6 days a week (Sunday rest day) for 4 weeks	Gait ability (stride length, cadence and maximum velocity, step length), Balance ability, Lower limb motor function and Stroke rehabilitation treatment satisfaction questionnaire.
3. Effects of Gait training with rhythmic auditory stimulation on gait ability in stroke patients. *(Song & Ryu, 2016)*	40 participants Study group [n=20] Control group [n=20]	Gait training with RAS for 30mins 5 times a week for 4 weeks + neurodevelopmental therapy for 30mins 5 times a week for 4 weeks.	Gait training with a supervisor for 30mins 5 times a week for 4 weeks + neurodevelopmental therapy for 30mins 5 times a week for 4 weeks.	Gait ability (cadence, Step length, speed), Balance (for functional gait ability)
4. Effects of a Music-Based Rhythmic Auditory Stimulation on Gait and Balance in Subacute Stroke. *(Gonzalez-Hoelling, Bertran-Noguer, Reig-Garcia, & Suner-Soler, 2021)*	53 participants Study group [n=28] Control group [n=27]	RAS for 90min 3 times a week + 2hrs conventional physiotherapy Mon-Fri and 1hr on Sat. Participants begun intervention at hospital admission till discharge	2hrs conventional physiotherapy Mon-Fri and 1hr on Sat. Participants begun intervention at hospital admission till discharge	Primary outcome measures: Standing and Dynamic balance, Walking patterns, Fall risk, Gait speed. Secondary outcome measures: trunk control, Functional independence measure and Active Daily living.
5. Walking with rhythmic auditory stimulation in chronic patients after stroke: A pilot randomized controlled trial. *(Elsner, Scholer, Kon, & Mehrholz, 2020)*	12 participants Study group [n=6] Control group [n=6]	Overground gait training + RAS for 30min 3 times a week for 4 weeks	Overground gait training without RAS for 30min 3 times a week for 4 weeks	Primary outcomes: walking velocity and capacity. Secondary outcomes: Balance ability and Step length.
6. Effects of Multi-Directional Step-Up Training with Rhythmic Auditory Stimulation on Gait and Balance Ability in Stroke Patients. *(Choi & Kim, 2021)*	16 participants Study group [n=8] Control group [n=8]	RAS + multidirectional step-up training for 20min + 10min warm-up including: posture alignment and weight bearing training. Sessions were 3 times/week for 4 weeks.	20min Multidirectional step-up training no RAS + 10min warm-up training including posture alignment and weight bearing training. Sessions were 3 times/week for 4 weeks.	Gait ability (walking speed and functional gait evaluation), dynamic standing balance and static standing balance (velocity AVG, Path length, Area 95%).

7. Intensive gait training with rhythmic auditory stimulation in individuals with chronic hemiparesis stroke: a pilot randomized controlled study. *(Cha, Kim, Hwang, & Chung, 2014)*	20 participants Study group [n=10] Control group [n=10]	Intensive gait training + RAS 30min/day, 5 days/week for 6 weeks.	Intensive gait training no RAS for 30min/day, 5 days/week for 6 weeks.	Balance ability, Gait ability (gait velocity, cadence, stride length (affected and non-affected side) and Double stance (affected side and non-affected side)). Specific quality of life scale and
8. Home-Based Auditory Stimulation Training for Gait Rehabilitation of Chronic Stroke Patients. *(PT,PhD Kim & PT,PhD Oh, 2012)*	20 participants Study group [n=10] Control group [n=10]	Overground gait training + metronome beat for 10 mins 3 times a week for 6 weeks	Overground training for 10mins 3 times a week for 6 weeks.	Gait ability (stride length, single support time and walking velocity of paretic side)

Table 2*: Listed summary of Sample size, Interventions and Outcome measures of each study investigated. A total of 266 participants were evaluated.*

Study **1-8**	**Group**	**Age (mean ± sd) (Years)**	**Stroke Duration (mean of months)**	**Lesion Type (infarct/haemorrhage)**	**Paretic side (left/right)**
(Lee, Lee, & Song, 2018) *[45]*	Experimental	56 ± 9.39	14.22 ± 5.79	19/4	15/8
	Control	54.92 ± 6.65	14.29 + 5.16	18/3	13/8
(MB Pan, et al., 2021) *[60]*	Experimental	61.12 ± 7.49	8.39 ± 2.09	16/14	14/16
	Control	62.02 ± 7.51	8.45 ± 2.11	14/16	18/12
(Song & Ryu, 2016) *[40]*	Experimental	57.10 ± 7.8	12.30 ± 3.4	-	12/8
	Control	60.10 ± 6.8	14.75 ± 6		11/9
(Gonzalez-Hoelling, Bertran-Noguer, Reig-Garcia, & Suner-Soler, 2021) *[55]*	Experimental	65.7 ± 12.7	10.46 ± 4.09	17/9	9/17
	Control	62.2 ± 8.9	10.07 ± 4.27	18/9	7/20
(Elsner, Scholer, Kon, & Mehrholz, 2020) *[12]*	Experimental	68.7 ± 11	34.7 ± 20.1	6 ischemic	6 left
	Control	65.3 ± 7.5	99.2 ± 88.5	6 ischemic	6 left
(Choi & Kim, 2021) *[16]*	Experimental	49.80 ± 8.77	-	-	-
	Control	58.50 ± 15.58			
(Cha, Kim, Hwang, & Chung, 2014) *[20]*	Experimental	59.8 ± 11.7	14.5 ± 5.5	-	9/1
	Control	63.0 ± 14.1	14.7 ± 5.4		9/1
(PT,PhD Kim & PT,PhD Oh, 2012) *[20]*	Experimental	65.2 ± 6.8	15.8 ± 2.3	7/3	4/6
	Control	64.5 ± 8.1	15.3 ± 3.0	7/3	4/6

Table 3: *Summary of average of, duration since stroke, side of lesion in the brain, type of lesion and side of body affected.*

Study	**Duration of sessions and length of study**
1	30 min/day for 6 weeks
2	60min/ 3x/day for 4 weeks
3	30min, 5x/week for 4 weeks
4	90min, 3x/week until discharge
5	30min, 3x/week for 4 weeks
6	30min, 3x/week for 4 weeks
7	30min, 5x/week for 6 weeks
8	10min, 3x/week for 6 weeks

Table 4*: showing the duration of exercises implemented and the length of the research experiment for each study reviewed.*

Collectively the outcome measures assessed by the studies were Gait Ability and Balance ability: gait ability was assessed either simply as ‘gait ability or its spatio-temporal components (temporal- velocity, cadence, step time, double support time, single support time and spatial- gait symmetry, stride length, step length and waking capacity). On the other-hand, balance ability and gait ability were also determined by measurements of lower extremity function, trunk control, functional gait ability and functional independence. The researches measures outcome measures using the following assessments:

Gait Ability	Gait analyser/free step gait analyser software, 10meter Walk Test, Functional gait evaluation, Rs Scan System with 2m long plate, 6min walk test, Gaitite.
Balance and Gait Ability	Berg Balance Scale, Time Up&Go Test, The Tinette Test, Balancia Software, Fugl Meyer lower extremity assessment, functional independent measure, Measures of ADL.

The first study *(Gait Training with Bilateral Rhythmic Auditory Stimulation in Stroke Patients: A Randomized Controlled Trial, 2018)* was assessor blind, and the participants were randomly allocated to the experimental or control group. The auditory stimulation was produced at an increased rate of 10% for the paretic side and 5% for the non-paretic side rather than walking at a comfortable speed: this was set as the researchers followed the notion of subjects improving gait velocity and symmetry when waking at a faster acoustic cue as proven by other studies. Warm up was conducted before the training which allowed patients to familiarize to the RAS and reducing leg spasticity. Bluetooth headphone were used to listen to the cue in order to prevent any external environment disturbance. The control group received rehabilitation programs consisting of therapeutic exercise, occupational therapy and electrical stimulation therapy.

The second study, *Effect of Rhythm of Music Therapy on gait in patients with stroke* (2021), had no blinding towards assessors, therapists or subjects. The subjects were allocated to either the intervention or control group at random. Patients from both study groups were administered the same drug therapy along with physical rehabilitation and routine waking training. As the practice was performed 3 times a day, in the first therapy the metronome was used to coordinate with the patient's walking velocity, while in the second therapy music with familiar melody for patients, according to the walking velocity obtained from the first therapy, to help patients control their walking rhythm with the playing rhythm as the indicator signal: simultaneously patients were required to perform walking training according to the playing music rhythm. During the third therapy, the walking velocity was measured by the metronome, and the result was used in the next walking training as the basic walking speed of the next music therapy. Patients from both groups received the following regular rehabilitation therapy: proprioceptive neuromuscular facilitation, neuromuscular electrical stimulation, traction, balance function training, as well as hip joint, trunk muscle, pelvis, knee joint control training and dorsiflexion induction training, and lastly benign limb position placement and control, face washing, tooth brushing and other daily activity training.

The third study*, Effects of Gait training with rhythmic auditory stimulation on gait ability in stroke patients (2016).* did not disclose whether or not any form of blinding was done. The subjects were allocated to either the intervention or control group at random. Both the experimental and control groups underwent 30min of neurodevelopmental therapy for the length of the experiment along with the gait training provided for each group.

The fourth study, *Effects of a Music-Based Rhythmic Auditory Stimulation on Gait and Balance in Subacute Stroke* (2021) was an evaluation-blinded, quasi-experimental trial with a historical control group. The subjects were allocated to either the intervention or control group at random. The intervention group underwent 15min of general body warming before the music based RAS exercises conducted with a metronome and another 15min of cool down/relaxation exercises after the RAS exercise. On Monday and Friday the RAS exercises were based on the Ronnie Gardiner Method which focuses on Neuroplasticity principles, motor learning and postural control. On the other-hand Wednesday RAS rehabilitation was based on walking training with music overlaid with a metronome according to the clinical protocol of M.H Thaut, which focuses on anterior, lateral, tandem and posterior walking, as well as military march, walking on toes and then on heels through progressive variations and increase of rhythm speed. The music used was from past and present music genres, with a marked pulse, ¼ or 6/8 rhythm and variations of beats/minute. Both groups underwent the conventional physiotherapy consisting of: therapeutic exercises in combination with walking training. The therapeutic exercises were based on proprioceptive neuromuscular facilitation, trunk dissociation, motor control and strengthening exercises. Patients with severe hemiplegia and sensorimotor impairments practiced sitting and standing balance and sit-to-stand in the parallel walking bar and as their physical function improved they progressed to dynamic standing balance and gait training with assistive devices.

The fifth study, *Walking with rhythmic auditory stimulation in chronic patients after stroke (2020)* was an assessor blind study. The subjects were allocated to either the intervention or control group at random. Both groups had the same over-ground gait training three times per week for four weeks lasting thirty minutes each: it begins with walking at a self-selected walking speed for ten minutes, followed by walking with increment speed increases up to 15% in 5% steps for ten minutes. After each increase in velocity the therapist assessed the patient's gait pattern, if the gait pattern deteriorated significantly increasing gait instability the speed was reduced by 5% and not increased further for session. This was followed by step combination exercises with or without a step platform with alternating stepping of the legs such as: stepping forward/backward, tapping one leg on the step platform or step and back, placing one leg with weight shift on the step platform or on a step and back, tapping with one foot in step position, tapping with one foot while sitting, walking on the spot and side stepping with and without a handrail. The intervention group went through the training above with the support of RAS in the form of uniform MP3 music of classical wandering songs with a clearly accentuated beat at an appropriate pace using headphones. The therapist did not instruct the patients to walk or move according to the beat but should only listen to the music as well as correct the patients gait pattern in regards to its quality. Patients were allowed to take breaks at their request for no more than half of the exercise time.

The sixth study, *Effects of Multi-Directional Step-Up Training with Rhythmic Auditory Stimulation on Gait and Balance Ability in Stroke Patients* (2021) did not specify if there was any blinding of assessors or patients. The subjects were allocated to either the intervention or control group at random. Both the intervention and control group underwent multidirectional step-up training and in intervention group it was accompanied by RAS. The RAS was applied by a metronome application on a smartphone. Additionally both patient groups underwent 10 minutes of warm up training including posture alignment and weight-bearing training. Prior to the experiment the beats per minute comfortable for each patient were calculated and was increased during training by 5-10% each week as the as the patients skill level increased. Patients took breaks to minimise the risk of falls if they felt dizziness or fatigue.

The seventh study, *Intensive gait training with rhythmic auditory stimulation in individuals with chronic hemiparesis stroke: a pilot randomized controlled study (2014)* did not specify if there was any binding of assessors or patients. The subjects were allocated to either the intervention or control group at random. Both groups received general physical therapy which include Bobath approach and proprioceptive neuromuscular facilitation. For gait training in the RAS group a metronome along with specifically prepared music tapes were used. For preparation of music a synthesizer key-board, MIDI cue-base musical instrument digital interface program and a KM player 3.3 was used to control the rhythmic tempo in each participant, while the metronome was played over the beat of the music in order to enhance the rhythm perception for the patient. The metronome was set up so that it matched directly with the participants step pattern. The music was the patient's preference of either country or pop music. In the third and fifth weeks the rhythm frequency was increased by 5%.

The eighth study, *Home-Based Auditory Stimulation Training for Gait Rehabilitation of Chronic Stroke Patients Home-Based Auditory Stimulation Training for Gait Rehabilitation of Chronic Stroke Patients (2012)* did not specify if any blinding took place in the study. The subjects were allocated to either the intervention or control group at random. Patients from both groups were undergoing rehabilitation at home and were strictly not doing any other exercises besides over-ground gait training: the experimental group performed over-ground training accompanied by RAS using a metronome cue which begun at 20 cues per minute every two minutes or kept at a constant cueing.

Studies two, three, four, six and seven where conducted in hospitals, meanwhile the first and fifth study were conducted in outpatient clinics and lastly the eighth study was conducted at the subjects' homes.

4.1. Results from each study

Study One *(Gait Training with Bilateral Rhythmic Auditory Stimulation in Stroke Patients: A Randomized Controlled Trial, 2018)*:

Measured gait symmetry, gait ability, balance ability and lower extremity function. Gait symmetry was calculated by the data collected by the gait analyser software, the Timed Up and go test (TUG) and the Berge Balance scale (BBS) each measure the balance ability of patients and lastly the Fugl-Meyer Assessment (FMA) was used to assess lower extremity function. The statistical analysis were performed using the SPSS Version 19.0 with statistical significance of *p-value<0.05.* The results are as follows:

Variables	**GBTR group**				**Control group**		
	Pre-Test	Post-Test	Change score		Pre-Test	Post-Test	Change score
Gait Symmetry on step time							
SI (%)	0.03 ± 0.03	0.02 ± 0.03	−0.01 ± 0.01 *†		0.02 ± 0.02	0.02 ± 0.01	0.00 ± 0.01
GA (score)	5.18 ± 5.77	4.07 ± 5.29	−1.11 ± 1.33 *†		3.53 ± 2.75	3.56 ± 1.73	0.03 ± 1.50
SR (ratio)	1.14 ± 0.14	1.11 ± 0.13	−0.03 ± 0.03 *†		1.09 ± 0.07	1.09 ± 0.04	0.00 ± 0.04
Gait Symmetry on step length							
SI (%)	0.02 ± 0.02	0.01 ± 0.02	0.01 ± 0.01		0.02 ± 0.02	0.02 ± 0.02	0.00 ± 0.00
GA (score)	2.72 ± 3.92	2.29 ± 4.09	−0.43 ± 1.71		3.96 ± 3.03	3.83 ± 2.75	−0.14 ± 0.48
SR (ratio)	0.98 ± 0.11	0.99 ± 0.11	0.01 ± 0.04		0.98 ± 0.11	0.98 ± 0.10	0.00 ± 0.01
Gait Ability							
Velocity (m/m)	50.01 ± 12.49	52.15 ± 13.23	2.14 ± 2.02 *†		48.50 ± 10.20	48.88 ± 10.19	0.38 ± 0.85 *
Cadence (steps/min)	97.10 ± 22.97	99.32 ± 23.89	2.23 ± 2.43 *†		96.05 ± 16.31	97.03± 16.82	0.98 ± 1.32 *
Balance Ability							
TUG (sec)	25.68 ± 2.96	25.21 ± 2.91	−0.47 ± 0.64 *		26.68 ± 4.08	26.38 ± 4.13	−0.30 ± 0.61 *
BBS (score)	42.57 ± 4.78	43.70 ± 5.00	1.13 ± 1.49 *		41.58 ± 5.21	42.08 ± 4.96	.50 ± 0.83 *
Lower Extremity Function							
FMA (score)	13.89 ± 4.76	14.76 ± 5.08	0.87 ± 1.52 *		13.75 ± 2.88	14.08 ± 2.87	0.33 ± 0.56

Table 5: *Outcome results of study 1. Values are expressed as mean ± standard deviation. SI = Symmetry Index, GA = Gait Asymmetry, SR = Symmetry Ratio, TUG = Timed Up and Go Test, BBS = Berg Balance Scale, FMA = Fugl–Meyer Assessment. *means significant difference within group.*
† means significant difference between group.

The results showed Gait Symmetry on step time was significantly improved in the intervention group relative to the pre-test values, additionally the magnitude of the decreases in gait symmetry on step time was significantly greater in the intervention group in comparison to the control group. On the other hand gait symmetry on step length did not significantly improve in both groups.

Gait ability on velocity and cadence in both groups significantly improved relative to their pre-test values, however the intervention group presented with significantly greater improvement in comparison to the control group in velocity and cadence.

Both groups showed significant improvement in the TUG test and BBS with no significant difference between groups, meanwhile the FMA results showed significant difference between the post-test and pre-test results of the intervention group compared to the control group but no significant difference between the intervention and control group.

Step time symmetry improved while step length symmetry showed no improvement possibly due to auditory stimulation being produced from standard of step time: step time used in this research is a form of temporal data depending on movement of lower extremity during waking therefore making it insufficient in changing step length as it is spatial index. Performing gait at a controlled speed contributed to gait speed improvement.

Limitations in this study are as follows *(2018):*

- Difficulty in improving gait symmetry of spatial parameters using only step time.
- Small sample size

Study Two *(Effect of Rhythm of Music Therapy on Gait in Patients with Stroke, 2021):*

Measured walking ability, lower extremity motor function and balance ability before the therapy at the second week of therapy and at the end of therapy. Walking ability data was assessed using the Free-Step Gait Analyser which calculates: maximum velocity, difference in step length between affected and non-affected side, the cadence and patient's stride length. The lower extremity motor function was assessed using the lower extremity motor part of the Fugl-Meyer Assessment, which included 6 items with 34 points in total. The Balance ability of the lower limbs was evaluated using the Berg Balance Scale, which included 14 items each with a score of 0-4 and a total score of 56 points. Statistical analysis was performed using SPSS 20.0 software and $p<0.05$ was considered statistically significant. The results are as follows:

Outcome Measure	**Groups**	**Before treatment**	**2nd week during treatment**	**At the end of treatment**
Stride length (cm)	Study group	19.255 ± 2.14	25.17 ± 2.11^{a}	29.36 ± 2.44^{a}
	Control group	19.31 ± 2.21	22.14 ± 1.65^{a}	25.44 ± 1.36^{a}
	t	0.107	6.196	7.686
	p	0.915	<0.001	<0.001
Stride frequency/Cadence	Study group	59.45 ± 2.69	65.12 ± 2.69^{a}	71.01 ± 2.99^{a}
	Control group	60.12 ± 2.88	63.12 ± 2.55^{a}	66.45 ± 3.01^{a}
	t	0.893	2.955	5.887
	p	0.376	0.005	<0.001
Maximum walking speed (m/s)	Study group	31.36 ± 2.32	38.45 ± 2.36^{a}	43.01 ± 2.54^{a}
	Control group	31.47 ± 2.41	35.14 ± 2.21^{a}	38.14 ± 2.69^{a}
	t	0.18	5.607	5.729
	p	0.858	<0.001	<0.001
Step size (cm)	Study group	8.59 ± 2.46	6.01 ± 1.67^{a}	5.22 ± 1.24^{a}
	Control group	8.61 ± 2.55	7.01 ± 2.14^{a}	6.16 ± 1.31^{a}
	t	0.031	2.018	2.854
	p	0.975	0.048	0.006
FMA (scores)	Study group	17.35 ± 3.69	24.45 ± 4.12^{a}	28.21 ± 24.65^{a}
	Control group	18.01 ± 3.87	21.02 ± 4.09^{a}	24.12 ± 5.14^{a}
	t	0.676	3.236	3.232
	p	0.502	0.002	0.002
BBS (scores\)	Study group	22.06 ± 2.17	32.46 ± 3.12^{a}	42.47 ± 6.51^{a}
	Control group	22.25 ± 2.23	26.14 ± 3.27^{a}	36.12 ± 7.14^{a}
	t	0.335	7.659	3.600
	p	0.739	<0.001	<0.001

***Table 6**: Outcome measurements of study two. a- represents outcomes with statistical significance within the groups. data expressed as mean standard deviation.*

The table above shows for Walking Ability that the Stride Length, Cadence and Maximum Velocity of patients were higher in the intervention group in comparison to the control group at the second week and final assessments, and the difference in step length between the affected and unaffected limb was significantly lower in the study group relative to the control group. Each of the differences presented with statistical significance. These results were assumed to be the result of:

- Regularity patient's motor response promoted by external music rhythm signals resulting in improved motor function.
- chronaxie signal of the human auditory system can accurately and quickly enter into the motion indication signal when music plays for patients with regular rhythm allows patients to obtain a clear signal prompt under the rhythm's beat instruction therefore allowing them to walk orderly under fixed rhythm, which results in better balance control.
- Familiarity with music allowed grasping of the rhythm to an extent, which helps control muscle movement process time.

The Fugl-Meyer Score in both the second week and final assessments was higher in the intervention group than the control group: the difference between groups was statistically significant.

Lastly the Berg-Balance Scale scores in the intervention group at the second week and final assessment was higher in comparison to the control group with a statistically significant difference.

Limitations in this study are as follows *(2021):*

- No blinding method – bias risk
- Single centre clinical study therefore small sample size
- Specific mechanisms are still unclear therefore more research is needed

Study Three *(Effects of gait training with rhythmic auditory stimulation on gait ability in stroke patients, 2016):*

Measured gait ability and functional gait ability. A 10-meter walking test (10MWT) was used to measure speed, cadence and step length, and the Dynamic Gait Index (DGI) was used to test balance for functional gait ability with the highest achievable score being 24. The results in this study were statistically analysed using SPS 12.0 KO with statistical significance of p<0.05: the results are as follows:

	RASG Group			**GTG Group**	
Outcome	Before	After		Before	After
Cadence (step/min)	75.6 ± 6.4	102.5 ± 6.2*[a]		78.6 ± 3.4	92.2 ± 4.3*
Step Length (cm)	53.7 ± 5.4	59.6 ± 4.5*[a]		52.3 ± 5.7	56.5 ± 6.7*
10MWT(m/sec)	22.7 ± 2.2	16.7 ± 8.9*[a]		18.9 ± 2.1	14.3 ± 9.3*
DIG(Score)	12.3 ± 4.5	20.7 ± 7.9*[a]		13.4 ± 5.2	17.6 ± 2. 4*

***Table** 7: Outcome measures of study three.*Significant difference compared with before therapy at <0.05. [a] Significant difference in gains between the two groups at <0.05.Values are shown as the mean ± standard deviation.*

The results from the table above show that both the intervention group (Rhythmic Auditory Stimulation Gait training group) and the control group (Gait Training Group) had significant improvements in gait abilities in the final assessments in comparison to the baseline measures. The intervention group further demonstrated all outcome measures to have shown statistically significant greater improvement in comparison to the control group.

Limitations in this study are as follows (2016):

- Small sample size

Study Four *(Effects of a Music-Based Rhythmic Auditory Stimulation on Gait and Balance in Subacute Stroke, 2021):*

Primary outcome measures were standing balance, gait and fall risk, gait speed and walking ability. Dynamic and static balance and walking patterns were evaluated by The Tinetti test (there are 9 balance score categories and 10 gait score categories, scores ranging from 0-28 with higher scores representing better gait, balance and lower risk fall), and the Timed Up&Go test (time >20s a fall risk is assumed). Gait speed was calculated by 10meter walk test. Secondary outcome measures included trunk control, assistive devices and functional independence measure and the Barthel Index. Trunk control was 0 if the patient had no assistive device, 1 for cane or crutch, 2 for walker use and 3 for wheelchair. Functional Independence Measure (FIM) is scored in 18 categories (from 0 to 126) and each item is rated on a 7-point scale. The focus is on motor and cognitive function independence with higher scores. Barthel Index (scored from 0 to 100) is a reliable index for measuring activities of daily living, with higher scores indicating greater independence. Data was analysed using SPSS Statistics version 17.9, in all test, significance was set at $p<0.05$. The results are as follows:

Baseline				Discharge		
Outcome	**Control Group**	**Music-based RAS Group**	**p-value**	**Control Group**	**Music-based RAS Group**	**P-Value**
Tinetti Score(max score=28)	9.8 ± 7.5 9 (3–16)	8.3 ± 6.8 8 (1–14)	0.389	24.1 ± 4.3 26 (21–27)	23.1 ± 5.8 24.5 (22–27)	0.593
Timed Up and Go (s)	16.5 ± 4.8 16.4 (12.7–20.4)	20.5 ± 11.9 17.1 (3.6–24.3)	0.79	12.6 ± 10.8 10.4 (6.6–13.4)	14.0 ± 6.1 12.4 (10.1–16.0)	0.058
Gait Speed (m/s)	0.1 ± 0.2 0.0 (0)	0.1 ± 0.2 0.0 (0)	0.314	0.5 ± 0.2 0.5 (0.3–0.6)	0.6 ± 0.3 0.6 (0.4–0.9)	0.314
FAC (max score=6)	1.2 ± 0.6 1 (1–1)	0.4 ± 0.7 0 (0–0.7)	0.142	3.7 ± 1.2 4 (3–5)	3.8 ± 1.1 4 (3–4)	0.696
FIM (max score=126)	87.9 ± 17.2 86 (78–97)	85.5 ± 19.6 88 (72.7–98)	0.99	119 ± 9.2 122 (120–124)	120.0 ± 6.9 121 (120–124)	0.638
NIHSS (max score=42)	5.1 ± 3.0 4 (3–7)	5.6 ± 3.5 5 (3–8)	0.622	1.6 ± 1.8 1 (0–2.5)	0.7 ± 2.2 2.5 (1–3)	0.036
Barthel Index (max score=100)	42.2 ± 14.7 45 (30–55)	48.1 ± 21.7 45 (35–63.7)	0.254	92.6 ± 10.3 95 (90–100)	91.1 ± 13.7 92.5 (90–100)	0.646

Table 8*: Outcome measures from study 6.No differences are found (p value > 0.05) by the Chi-square test between groups at baseline or discharge. Values are presented as mean ± standard deviation, or median (interquartile range).*

The table results show both patient groups to have improved by discharge but without significant differences between the music-based RAS group and the control group for the primary outcomes at discharge. Therefore from simply analysing the outcome measure at baseline and at discharge, music-based RAS in combination with conventional physiotherapy yields positive results for people with stroke.

As mentioned in the study, both groups in this study received 7-11 hours of therapy while in previous studies control groups received 3-5 hours, which possibly yielded better results from this form of therapy compared to previous studies.

Limitations in this study are as follows *(2021*):

- Lack of precision of the Tinetti Test in measuring gait parameters

- Limited gains in the experimental group/RAS group may be due to some of the patients inability to tolerate extra therapy sessions as they are 21 days post stroke onset
- Due to 80% of patients failing to walk at baseline in each group resulted in failure to evaluate accurately TUG test and Tinetti score at baseline
- Small sample size
- Use of historical, non-parallel control group, as well as lack of randomised group assignment which limits the robustness of results
- severity of affected side hemiparesis/hemiplegia and muscle strength were not taken into much consideration in this study
- The number of music-based rhythmic auditory stimulation sessions in the music-based RAS group was not determined by the researcher. The days of stay and intervention sessions depended on the achievement of therapeutic objectives as assessed by the rehabilitation hospital
- The intervention was not individualized, which was consider as both a limitation and a strength. Participants in a walking phase were together with non-walkers, making it difficult to find the right level of challenge. However, social relationships and motivation were established between the participants in the music-based RAS group, consistent with some literature

Study five *(Walking with rhythmic auditory stimulation in chronic patients after stroke: A pilot randomized controlled trial, 2020):*

The primary outcome measures were walking velocity and capacity and secondary outcome measures are the balance and step length. Walking velocity was measured using the 10-m walk test, while walking capacity was measured using the 6-min walk test. Balance was measured by the Berg-Balance Scale, and step length was calculated by counting steps during the 10-m walk test and using the step counts according to published formulas and recommendations. In this study step length was used as a surrogate marker for quality of walking. Data was analysed using SAS/STAT 9 and statistical assumptions were tested with the implemented functions. Due to a small sample size used, nonparametric tests such as the Mann-Whitney U test were used for comparison between baseline/pre-test measures and differences between groups. Global alpha level was set at 0.05. The results are as follows:

	Baseline		**Post-Intervention (4 weeks) T1-T2**			**Follow-up (12 weeks) T1-T3**		
Outcome	RAS-Group	GT Group	RAS-Group	GT Group	p-value	RAS-Group	GT Group	p-value
Walking speed (m/s) *median(IQR)*	0.42 (0.45)	1.04 (1.02)	0.05 (0.1)	0.12 (0.3)	0.298	0.09 (0.1)	0.10 (0.3)	0.45
Walking capacity (m) *median (IQR)*	111.5 (123)	379 (371)	13.6 (14)	41 (79)	0.297	14.0 (23)	48.5 (65)	0.18
Balance (points) *median (IQR)*	39 (20)	54.5 (7)	4.0 (4)	1.0 (3)	0.146	5.0 (5)	1.0 (1)	0.080
Step length (cm) *median (IQR)*	34.0 (20)	59.5 (40)	6.3 (12)	5.5 (9)	1.0	3.3 (9)	5.5 (9)	0.800

***Table 9**: Outcome measure from study 5. T1: baseline; T2, at the end of intervention period; T3, at follow-up (T1-T2/3 means the change between these measurement points).*

For primary outcomes the table indicates patients from both groups significantly improved from baseline until the end of the intervention in walking velocity and walking capacity, however the improvements for walking velocity and capacity did not significantly differ between groups (p = 0.298) and (p = 0.297) respectively. Significant improvement of walking velocity and capacity are observed between baseline and follow up measures but no statistically significant improvement of walking velocity (p = 0.45) and capacity (p = 180) are observed between groups.

For secondary outcomes the table indicates significant improvements of balance and stride length between baseline measurements and end of intervention measurements as well as follow up measurements. On the other-hand the improvements of these two parameters are not statistically different between both groups at both the end of intervention and follow up.

Limitations in this study are as follows (2020):

- Small sample size was the main limitation
- Compared to other studies patients were more chronic
- Duration of study was only 4 weeks while similar studies occurred for 6 weeks
- Therapy was administered 3 times a week while similar studies occurred 5 times a week

Study Six *(Effects of Multi-Directional Step-Up Training with Rhythmic Auditory Stimulation on Gait and Balance Ability in Stroke Patients, 2021):*

The outcome measures were gait ability and dynamic and static balance ability. The gait ability was assessed by the functional gait evaluation (FGA) and the 10-meter walking test (10mWT), while dynamic standing balance ability was assessed by the Berg Balance Scale (BBS) and static standing balance ability was assessed by Balancia software. Balancia software measures the average sway velocity average (velocity AVG), the total sway path length (path length) and the 95% sway area (area 95%). Data analysis collected in this study was done by the SPSS version 25 statistical program and normality was tested by the Kolmogorov-Smirnov test. All statistical significance levels were set to $p<0.05$, t-test was used for comparison of changes between pre and post-test in each group. The results are as follows:

Pre-homogeneity Test for Dependent Variables

Outcome	**Experimental Group**		**Control Group**		**t**	**P**
FGA (score)	12.37 7.48[a]	±	18.50 8.25	±	1.56	0.14
10mWT (sec)	18.35 11.06	±	17.81 12.41	±	0.09	0.93
BBS (score)	44.88 6.40	±	47.13 8.15	±	.61	0.55
Velocity AVG (cm/s)	2.40 0.46	±	3.19 0.82	±	2.37	0.44
Path Length (cm)	23.99 4.62	±	27.25 3.88	±	1.52	13.6
Area 95% (cm^2)	1.39 1.20	±	2.13 1.40		1.14	13.7

Table 10: *pre-test outcome measures of intervention and control group. t = comparison of means of the two groups*

After the interventions, FGA score for the experimental group significantly increased from 12.37 ± 7.48 to 25.62 ± 4.24 and the score in the control group also significantly increased from 18.50 ± 8.25 to 23.32 ± 4.59 after the training. The difference in the amount of change between the two groups was 8.5 ± 1.03, with a higher score in the experimental group (step-up training with RAS) but with no statistically significant difference between the two groups. Balance ability was also measured before and after the interventions in both groups: the experimental group showed a significant improvement from 44.88 ± 6.40 to 51.00 ± 3.70 and the control group also showed a significant improvement from 47.13 ± 12.41 to 48.75 ± 8.45. The difference in the amount of change between the two groups was 4.5 ± 2.78, the score improvement was significantly greater in the experimental group.

Comparison of the static standing balance ability measurements within the groups: pre and post intervention

Outcome	**Groups**	**Pre-intervention**	**Post-intervention**	**t**	**p**
Velocity AVG (cm/s)	Experimental	2.40 ± 0.46[a]	1.37 ± 0.28	6.36	0.05
	Control	3.18 ± 0.82	2.77 ± 0.52	1.91	0.09
Path Length (cm)	Experimental	23.99 ± 4.62	14.95 ± 3.28	11.13	0.00*
	Control	27.24 ± 5.14	24.22 ± 5.14	2.42	0.05
Area 95% (cm)	Experimental	1.38 ± 1.20	0.51 ± 0.31	2.75	0.05
	Control	2.13 ± 1.39	1.97 ± 1.34	2.53	0.05

Table 11: *Outcome measures of study 6 from the Balancia balance assessment software. [a] mean ± SD, *p<0.05.*

Comparison of ⊿(mean difference) in the static standing balance ability measurements between the groups

Outcome	Experimental Group	Control Group	t	p
⊿Velocity AVG. (cm/s)	1.02±0.45[a]	0.4±0.60	2.29	0.00*
⊿Path length (cm)	9.03±2.30	3.02±3.53	4.03	0.00*
⊿Area 95% (cm^2)	0.87±0.90	0.16±0.18	2.17	0.05

Table 12: *Outcome measure of study 6 of the Balancia balance assessment software. [a]mean ± SD, *p<0.05*

From table 9, the amount of change in Velocity in AVG, Path length and Area 95% showed statistically significant reduction in both group after training however a table 3 shows a significantly greater degree of decrease in the experimental group compared to the control group.

Limitations in this study are as follows *(2021)*:

- Experiment was only 4 weeks long therefore difficult to conclude on long term effects.

Study seven *(Intensive gait training with rhythmic auditory stimulation in individuals with chronic hemiparetic stroke: a pilot randomized controlled study, 2014):*

The outcome measures assessed were balance ability, gait velocity, cadence, stride length, double support. Balance ability was assessed by the Berge Balance Scale (BBS) while the rest of the spatiotemporal parameters were assessed by the GAITite. Statistical analysis was done by SPSS 12.0 with a significant level of p<0.05, t-test was used for comparison of changes between pre and post-test in each group. The results are as follows:

Outcome measures	**RAS Training Group**		**Control Group**		**t**	**p**
	Pre-test	**Post-test**	**Pre-test**	**Post-test**		
BBS (score)	43.5 ± 8.2	48.6 ± 7.7	41.9 ± 6.9	43.6 ± 7.0	4.919	<0.001
Gait velocity (cm/s)	37.4 ± 19.7	60.7 ± 27.8	37.9 ± 18.3	42.0 ± 18.5	2.710	0.0024
Cadence (steps/min)	71.0 ± 18.2	87.2 ± 23.3	72.5 ± 22.8	76.8 ± 25.3	2.312	0.040
Stride Length (cm)						
Affected side	61.3 ± 17.3	79.8 ± 18.3	60.9 ± 14.9	65.0 ± 15.1	2.797	0.018
Less affected side	60.9 ± 16.9	75.6 ± 22.9	60.4 ± 14.6	64.8 ± 15.7	1.666	0.126
Double stance period (% cycle)						
Affected side	44.8 ± 13.5	32.6 ± 10.1	40.1 ± 14.1	39.2 ± 11.8	3.474	0.005
Less affected side	45.3 ± 14.7	32.8 ± 10.4	39.1 ± 13.5	36.9 ± 9.6	1.166	0.259

Table 13: *Study 7 Pre and Post- tests results of clinical measures. Value= Mean ± Standard Deviation.*

The results in the table above indicate scores on the BBS to have had significant improvement after training in both the RAS training group and the control group and the spatiotemporal parameters showed significant improvement in the intervention group after gait training. Comparison of outcome measures between the two groups showed gait velocity, cadence, stride length on the affected side and double support period on the affected side to be significantly improved in greater amount in the RAS training group than in the control group after training. Meanwhile stride length and double support period on the less affected side showed no significant difference between the two groups after training. Lastly BBS score showed to have significantly greater improvements in the RAS training group in comparison to the control group.

Limitation in this study are as follows *(2014)*:

- Small sample size – fail to generalize the results
- No brain imaging tools were used for measurement: however music could have produced some changes in the brain.

Study eight *(Home-Based Auditory Sttimulation Training for Gait Rehabilitation of Chronic Stroke Patients, 2012):*

The outcome measures were gait ability which analysed stride length, single support time and walking velocity of paretic sides. These measures were calculated by the Rs scan system with a 2m long plate, which calculates spatial and temporal coordinates by region while subjects are walking on the plate. The spatial and temporal value were collected 3 times for each conditions the mean values and standard deviations were used for analysis. The single-support time asymmetry ratio and the stride length asymmetry ratio were used to quantify the extent of spatial and temporal asymmetry of the gait pattern: the greater the ratio, the greater the asymmetry 0 indicating perfect symmetry. SPSS version 12.0 was used for data analysis, paired t-tests was used to test within group differences between before and after the experiment. Statistical significance level was p = 0.05. The results are as follows:

Gait Parameters		**Intervention Group**	**Control Group**
Affected side Stride Length (cm)*	Pre	69.9 ± 8.9$^{\alpha}$	68.2 ± 7.2
	Post	92.1 ± 3.2*	71.7 ± 6.0
Non affected side Stride Length (cm)*	Pre	65.1 ± 5.9	69.9 ± 10.4
	Post	89.9 ± 2.4*	68.4 ± 5.8
Stride Length Ratio*	Pre	0.1 ± 0.1	0.1 ± 0.1
	Post	0.0 ± 0.0*	0.1 ± 0.1
Affected side single support time (m/s)*	Pre	373.0 ± 43.5	349.1 ± 70.9
	Post	942.0 ± 87.0*	549.0 ± 98.9*
Non affected side single support time (m/s)*	Pre	843.0 ± 53.6	830.6 ± 62.5
	Post	1005.0 ± 96.7*	849.0 ± 98.9
Single support time ratio*	Pre	0.6 ± 0.1	0.6 ± 0.1
	Post	0.1 ± 0.1*	0.4 ± 0.0*
Gait Velocity (km/h)*	Pre	2.3 ± 0.5	2.2 ± 0.4
	Post	3.7 ± 0.5*	2.9 ± 0.3*

Table 14: *Outcome measure results of study 8. $^{\alpha}$ Mean ± Standard Deviation, * $p<0.05$*

The results show that the affected side single support time, affected side single support time ratio, and gait velocity of both groups after the training were significantly improved when compared with their corresponding values before training or intervention. Affected side stride length, non-affected side stride length, stride length ratio of the intervention group after the training were significantly different from their corresponding value before the training. Comparing the spatial-temporal gait parameters and symmetry ratios between the intervention and control group after the training shows a significant difference in affected stride length and non-affected stride length, stride length ratio as well as affected single support time and non-affected single support time, single support time ratio and in gait velocity.

Therefore from the outcome of results one can conclude that walking performance of the auditory stimulation training group after the experiment was statistically significantly better than that of the control group, as the comparison between groups shows that affected side stride length and non-affected side stride length, stride length ratio as well as the affected single support time, non-affected side single support time, single support time ratio and gait velocity after auditory stimulation training improved more in the experimental/intervention group than control group.

Limitations of this study are as follows *(2012*):

- Lack of randomization and relatively small number of subjects

Success of Outcome Measures within groups and comparing groups for Each Study

Study	*Number of Outcome Measures*	*SS Improvement from baseline within group*		*SS difference of group comparison*		*No SS Improvement*	
1	*5*	*Intervention*	4	*Intervention*	2	*Intervention*	1
		Control	*2*	*Control*	-	*Control*	*3*
2	*6*	*Intervention*	*6*	*Intervention*	*6*	*Intervention*	-
		Control	*6*	*Control*	-	*Control*	-
3	*4*	*Intervention*	*4*	*Intervention*	*4*	*Intervention*	-
		Control	*4*	*Control*	-	*Control*	-
4	*7*	*Intervention*	*7*	*Intervention*	-	*Intervention*	-
		Control	*7*	*Control*	-	*Control*	-
5	*4*	*Intervention*	*4*	*Intervention*	-	*Intervention*	-
		Control	*4*	*Control*	-	*Control*	-
6	*3*	*Intervention*	*3*	*Intervention*	*2*	*Intervention*	-
		Control	*3*	*Control*	-	*Control*	-
7	*5*	*Intervention*	*5*	*Intervention*	*5*	*Intervention*	-
		Control	*5*	*Control*	-	*Control*	-
8	*7*	*Intervention*	*7*	*Intervention*	*7*	*Intervention*	-
		Control	*3*	*Control*	-	*Control*	*4*

***Table 15**: Summary of outcome measures results from all studies, comparing results within and between intervention and control group SS = statistically significant results.*

Total percentage of outcome measures in each group from each study with or without significant improvement vs group baseline or group comparison

	Outcome measures [om]					
Study (n = om)	**No SS Improvement vs Baseline [CG]**	**No SS Improvement vs Baseline [EG]**	**SS Improvement vs Baseline [CG]**	**SS Improvement vs Baseline [EG]**	**SS greater Improvement vs Experimental [CG]**	**SS greater Improvement vs Control group [EG]**
1 (5)	3/5	1/5	2/5	4/5	0/5	2/5
2 (6)	0/6	0/6	6/6	6/6	0/6	6/6
3 (4)	0/4	0/4	4/4	4/4	0/4	4/4
4 (7)	0/7	0/7	7/7	7/7	0/7	0/7
5 (4)	0/4	0/4	4/4	4/4	0/4	0/4
6 (6)	0/6	0/6	6/6	6/6	0/6	4/6
7 (7)	0/7	0/7	5/7	7/7	0/7	5/7
8 (7)	4/7	0/7	3/7	7/7	0/7	7/7
total	***7/46***	***1/46***	***37/46***	***45/46***	***0/46***	***28/46***
Total (%)	***15.2***	***2.2***	***80.4***	***97.8***	***0***	***60.9***

Table 16: *Number of outcome measures in each study showing the number of outcome measures for the tested intervention that either showed no statistically significant (SS) improvement from baseline/showed SS improvement from baseline/showed SS improved in comparison to control group. Number of om (n=om).*

Table 15 displays a summary of all eight studies outcome results divided into three categories in both the experimental and control groups: number of outcome measures in each group that showed statistically significant improvement from baseline within the groups, number of outcome measures that showed statistically significant difference when comparing the experimental group to the control group and lastly the number of outcome measures that showed no statistical improvement from the baseline in each group. Six out of eight studies show the intervention group to have yielded better outcome measures in comparison to control group. On the other hand two studies show no statistically significant improvement for one outcome measure in the intervention group and seven outcome measures in the control groups (three in study one and four in study eight).

Table 16 summarises each intervention's outcome measure statistical significant success in the improvement of gait parameters for the experimental group and control group in comparison to the baseline measurements and each other. The results in Table 16 indicate each study's control and experimental groups to have had statistically significant success in improving gait parameters from baseline measurements with 80.4% and 97.8% respectively. The results also indicate experimental groups to have had greater statistically significant improved results in gait parameters in comparison to control groups by 60.9%. The control groups presented with seven (15.2%) of the outcome measures not showing significant improvement, while one (2.2%) outcome measure in the experimental group.

Study	No. of OM greater improvement vs CG	No. of OM improved vs Baseline
1	2	4
2	6	6
3	4	4
4	0	7
5	0	4
6	4	6
7	5	7
8	7	7
Total	**28**	**45**
Percentage (%)	**62.2**	

Table 17: *The percentage of outcome measures in the experimental groups that have a statistically significant difference of improvement compared CG.*

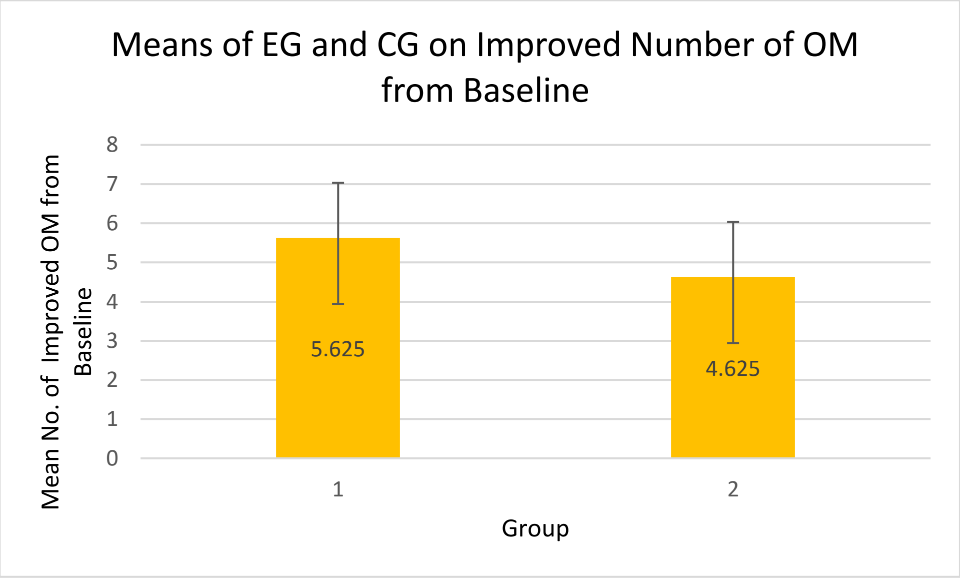


Figure 8*: Graph showing mean and standard deviations of number of outcome measures improved from baseline in experimental and control groups.*

Study	**Number of Imporved OM(EG)**	**Number of Improved OM(CG)**
1	4	2
2	6	6
3	4	4
4	7	7
5	4	4
6	6	6
7	7	5
8	7	3
Mean	**5.625**	**4.625**
Stdev	**1.40788595**	**1.68501802**
Ttest	**0.21858702**	

Table 18: *Comparing mean values of the number of improved outcome measures from baseline from the eight studies between the experimental and control groups.*

The calculated T-test being less than p = 0.05 indicates there to be a statistically significant difference of means between the experimental and control groups: meaning the experimental groups had a significantly higher number of outcome measures improved after interventions when comparing to baseline results.

	1		2		3		4		5		6		7		8	
	EG	CG	EG	CG	EG	CG	EG	CG	EG	CG	EG	CG	EG	CG	EG	CG
Gait symmetry on step time	x o	n														
Gait symmetry on step length	n	n														
Velocity/Speed	x o	o	x o	o	x o	o	o	o	o	o			x o	o	x o	o
Cadence	x o	o	x o	o	x o	o							x o	o		
Balance ability	o	o	x o	o					o	o	x o	o	x o	o		
Lower extremity motor function	o	n	x o	o												
Stride length			x o	o									x o	o	x[3] o[3]	n[3]
Step length			x o	o	x o	o			o	o						
Standing dynamic balance							o	o								
Standing static balance							o	o			x o	o				
Fall risk					x o	o	o	o								
Trunk control							o	o								
Functional independence measure							o	o								
Active Daily living							o	o								
Waking capacity									o	o						
Postural Stability											o	o				
Single support time															x[3] o[3]	n[1] o[2]
Double Stance period													x o	o		

Table 19*: Shows all outcome measures assessed across all studies. x – Outcome measures with statistically significant difference in results between groups, showing that group to have more effective results. o – Outcome measures with statistically significant improvement compared to baseline results. n – Outcome measures with no statistically significant improvement from baseline. [–] Number of assessed sub- measures for the tested outcome measure.*

Gait symmetry on step time is assessed by one study - shows significant improvement in the experimental group and no significant improvement in the control group but the difference between groups is significant and in favour of the experimental group.

Gait symmetry on step length is assessed by one study - in both groups no significant improvements were found.

Velocity/speed were both assessed across seven studies - all studies indicate significant improvement in both groups, while five additionally present significant difference of results between the groups, in favour of the experimental groups.

Cadence was assessed across four studies - all studies indicate significant improvement in both groups as well as significant difference of results between the groups in favour of the experimental groups.

Balance ability was assessed across five studies – all studies indicate significant improvement in both groups, however three of the studies showed there to be a significant difference of results between the groups, in favour of the experimental group.

Lower extremity motor function was assessed across two studies – both studies show significant improvement in the experimental groups, however the control group had significant improvement in one group. Only one study proved significant difference of results between the groups in favour of the experimental group.

Step length was assessed across three studies – all studies indicate significant improvement in both groups, however two studies indicate significant difference of results between the groups, in favour of the experimental groups.

Stride length was assessed across three studies – a three studies indicate significant improvement in the experimental group, while two studies indicate significant improvement in the control group and one study indicated no significant improvement in the control group. All three studies indicate significant difference of results between the groups, in favour of the experimental groups.

Standing dynamic balance was assessed by one study – the study indicates significant improvement of results in both the experimental and control groups.

Standing static balance was assessed across two studies – both studies indicate significant improvement in both groups and one study indicates significant difference of results between the groups, in favour of the experimental groups.

Fall risk was assessed across two studies – both studies indicate significant improvement in both groups and one study indicates significant difference f results between the groups, in favour of the experimental group.

Trunk control was assessed by one study – the results indicates a significant improvement in both groups.

Functional independence measure was assessed by one study – the study indicates significant improvement of the outcome measure in both the experimental and control groups.

Active daily living was assessed by one study - the study indicates significant improvement of the outcome measure in both the experimental and control groups.

Walking capacity was assessed by one study - the study indicates significant improvement of the outcome measure in both the experimental and control groups.

Postural stability was assessed by one study - the study indicates significant improvement of the outcome measure in both the experimental and control groups.

Single support time was assessed by one study – the study evaluated this outcome measure in three sub-tests: in the experimental group all three sub-tests had significant improvement and only two sub-tests in the control group as the third sub-test had no significant improvement. All three sub-tests indicated significant difference between the groups in favour of the experimental group.

Double stance period was assessed by one study - the study indicates significant improvement of the outcome measure in both the experimental and control groups. The study indicates a significant difference between results between the groups, in favour of the experimental group.

5. DISCUSSION

The purpose of this systematic review was evaluate the effectiveness of Rhythmic Auditory Stimulation (RAS) combined therapy approach on gait post stroke in comparison to conventional therapy methods. Therefore this research objectively tries to answer the following questions:

1) Does RAS have a positive effect on the gait of hemi-paretic stroke patients
2) How effective or successful is this therapeutic approach in comparison to Conventional Therapeutic Approaches.

The data suggests that Neurologic Music Therapy through Rhythmic Auditory Stimulation and/or Metronome Cueing has a positive rehabilitative effect on the gait of stroke patients suffering from hemiplegic/paresis. This rehabilitation approach is more effective than Conventional Therapy (CT) used to treat hemiplegic/paresis stroke gait; with most relevant improvement observed in gait cadence, velocity, step length and balance ability.

This review has proved RAS combined therapy approach to have a positive effect on gait for hemi-paretic stroke patients as the result indicated 97.8% of the total outcome measures examined from each study showed statistically significant improvement in the RAS groups, when compared to the groups' baseline results *(Lee, Lee, & Song, 2018) (MB Pan, et al., 2021) (Song & Ryu, 2016) (Gonzalez-Hoelling, Bertran-Noguer, Reig-Garcia, & Suner-Soler, 2021) (Elsner, Scholer, Kon, & Mehrholz, 2020) (Choi & Kim, 2021) (Cha, Kim, Hwang, & Chung, 2014) (PT,PhD Kim & PT,PhD Oh, 2012).* The control and experimental groups having 80.4% and 97.8% respectively in statistically significant outcome measures improved in comparison to baseline results within the group, proves that both RAS and CT cause positive effect on the gait of hemi-paretic stroke patients, however the RAS group has a significantly higher percentage of positive outcome measures as the calculated t-value was 0.2 (p=0.5), suggesting it to be the better treatment option *(Lee, Lee, & Song, 2018) (MB Pan, et al., 2021) (Song & Ryu, 2016) (Gonzalez-Hoelling, Bertran-Noguer, Reig-Garcia, & Suner-Soler, 2021) (Elsner, Scholer, Kon, & Mehrholz, 2020) (Choi & Kim, 2021) (Cha, Kim, Hwang, & Chung, 2014) (PT,PhD Kim & PT,PhD Oh, 2012).* The results additionally indicate RAS therapy approaches in comparison to CT approaches to be more effective: as a total of 60.9% of final outcome measures from the experimental (RAS combine therapy) groups have statically significant improvement difference between the RAS and CT groups, in favour of the experimental group *(Lee, Lee, & Song, 2018) (MB Pan, et al., 2021) (Song & Ryu, 2016) (Choi & Kim, 2021) (Cha,* *Kim, Hwang, & Chung, 2014) (PT,PhD Kim & PT,PhD Oh, 2012)*. Additionally, the results also show that from 97.8% of improved outcome measures from baseline within the group, 62.2% of these outcomes are better improved by RAS in comparison to CT methods, as 0% of outcome measures improved better with CT than RAS from the 80.4% that improved from baseline within the group. Therefore this study concludes that RAS combined therapy is 60.9% superior in obtaining better gait than Conventional Therapy, proving it to be the better treatment option for gait rehabilitation for hemiparesis/plegic stroke patient if available.

The outcome measures reviewed across all eight studies *(Lee, Lee, & Song, 2018) (MB Pan, et al., 2021) (Song & Ryu, 2016) (Gonzalez-Hoelling, Bertran-Noguer, Reig-Garcia, & Suner-Soler, 2021) (Elsner, Scholer, Kon, & Mehrholz, 2020) (Choi & Kim, 2021) (Cha, Kim, Hwang, & Chung, 2014) (PT,PhD Kim & PT,PhD Oh, 2012),* proved to have influenced a significant positive effect on gait for stroke affected patients, with the exception of 'gait symmetry on step length' as the effect was calculated to not have statistically significant improvement *(Lee, Lee, & Song, 2018).* The following spatio-temporal parameters have been assessed in three or more studies and yielded better results in the experimental groups in comparison to the control groups in two or more studies: velocity/speed, cadence, stride length and step length. Balance ability similarly indicated better results in the experimental groups in comparison to the control groups. Lastly the following gait parameters have been assessed in one or two studies and yielded better results in the experimental groups in comparison to the control groups in a study gait symmetry on step time, lower extremity motor function, static standing balance, fall risk, single support time and double stance period. However, despite having positive results, the parameters assessed in a maximum of two studies result in conclusions derived from them being ungeneralizable. However it is evident and more reliable from the results that RAS is more effective in improving speed/velocity, cadence, stride length, step length and balance for hemiplegic stroke patients.

From all eight studies assessed, the fourth study *(Gonzalez-Hoelling, Bertran-Noguer, Reig-Garcia, & Suner-Soler, 2021)* and fifth study *(Elsner, Scholer, Kon, & Mehrholz, 2020)* are the only researches indicating no difference between RAS and CT in effectiveness of gait treatment, as they do not displaying contrast in any outcome measure results when comparing the experimental and control groups. This could possibly be influenced by the research methodology. The fourth study *(Gonzalez-Hoelling, Bertran-Noguer, Reig-Garcia, & Suner-Soler, 2021)* being a quasi-experimental study using a historical control group gives it potential limitation in the following as explained by *(Pandis & Cobourne, 2013)*, affecting the accuracy of outcome results:

- Randomization – possibility of a lack of baseline similarity hindering separation of the effect of the intervention from possible presence of confounding effects. Current patients maybe better responders to the treatment resulting in overestimation of treatment effects.
- Blinding – although this study was evaluation-blinded, lack of blinding can result in attrition, detection, and performance bias. Participants of the current study may receive favoured monitoring and care paralleled to the historical control group. There is an increased likelihood of methodological differences in assessing outcomes as well as bias recording in favour of the new therapy. Patient exclusion due unforeseeable circumstances may differ between the two experiments.
- Difference in diagnostic or outcome assessment methodology – it is reasonably assumed that overtime better diagnostic and outcome assessment methods are developed, possibly resulting in differences in patient selection and outcome assessment between current patients and historical controls as known as selection and detection bias respectively.
- Time trends – outcomes may change with time for reasons which may be unpredictable.

Additionally the fourth study's *(Gonzalez-Hoelling, Bertran-Noguer, Reig-Garcia, & Suner-Soler, 2021)* outcome measures may not have displayed differences between the two groups due to the researcher not determining the number of therapy sessions: instead the number of sessions were determined by the achievement of the therapeutic objectives as assessed by the rehabilitation hospital. Not having the number of sessions controlled, or the beginning and end of an experiment (controlled variable), makes it difficult to interpret the accuracy of results (cause and effect reliability) *(Betts, 2022).* Unlike the other studies in this research, study four assessed patients in the subacute phase of the stroke: this was viewed as a possible limitation to results in the intervention group as the intensity of the program was possibly too overwhelming for the patients, therefore possibly affecting the accuracy of outcome results. Additionally as the patients were in subacute stroke phase more than 80% in each group could not walk at baseline measurements, resulting in difficulty to measure the Timed-up&Go and the Tinetti scores, therefore reducing accuracy in measuring the improvement of balance.

While the fifth study *(Elsner, Scholer, Kon, & Mehrholz, 2020)* only had twelve participants in total, split into the experimental or control groups, equally and at random, one could suggest that the results are unreliable as a small sample size reduces the confidence level of the study, consequently increasing the margin of error. If researchers are involuntarily constrained to a small sample size they are settling for less conclusive results. The strength of a study is also its ability to avoid Type II errors in an experiment, small sample sizes increase the chances of this error skewing the results, therefore decreasing the power of the study. The fifth study *(Elsner, Scholer, Kon, & Mehrholz, 2020)* has attempted to avoid this possibility by providing a sample size calculation, which resulted in a minimum of 12 participants to reject the null hypothesis. The study additionally measured the tested outcomes with tests of excellent reliability. However even with the attempts to create reliable results the small sample size was predicted to not normally distribute the data, hence the Mann-Whitney U-test was used to compare baseline measures and difference between groups as it is one of the most powerful non-parametric test: it has good probability of providing statistically significant results when alternative hypothesis applies *(Nachar, 2008)*. Therefore the results likely to reliable in this study due to the measures taken but the small sample size is still limiting.

The first study *(Lee, Lee, & Song, 2018)* and the eighth study *(PT,PhD Kim & PT,PhD Oh, 2012)* studies were the only ones to present with outcome measure results with no statistical significance in improvement in comparison to the baseline results: these results could be the outcome of poor methodology such as weak testing tools, differences in participants between groups or common error in measurements. The first study *(Lee, Lee, & Song, 2018)* had step length symmetry in both the control and experimental groups, while step time symmetry and lower extremity function only in the control group lacked statistical significance. The groups did not have any significant differences to possibly affect the outcome and there was assessor blinding and randomization of patient group allocation preventing bias and possibility of skewing results of the outcome measures. Step length symmetry and step time symmetry were measured using the OPTOGait Photoelectric Cell System, which according to a study by *Bernal et al (2016),* provides reliable measurements for most spatial-temporal gait parameters, with the exception of acceleration and progressive step time. It can be trusted to measure effects of different interventions over different testing session and/or measuring differences between participant groups in research. The research by *Lee et al (2014*), further indicates the OPTOGait system to have strong concurrent validity and test-retest reliability, rendering it useful for assessing gait spatio-temporal parameters for stroke patients. This research preferred to use treadmill training to over-ground training as it allows a continuous measurement of gait parameters, additionally intervention effects could be compared under equal conditions by the constant walking speed pre and post-test.. Therefore the first study the use of OPTOGait to measure gait spatio-temporal parameters further provided reliability in results, however, as the patients were tested in over-ground training limited accuracy in measurement of step length and step time were a possibility. The OPTOgait was proved reliable in a test with young participants as subjects *(Bernal, Becerro-de-Bengoa-Vallejo, & Losa-Iglesias, 2016)*, the first study *(Lee, Lee, & Song, 2018)* however had middle participants as subjects, which creates the question if this measuring tool is still ideal for this population. Another limiting factor to changing step length was the use of auditory stimulation based on step time: step length being a spatial parameter would benefit from training methods based on spatial data rather than temporal data.

In the first study *(Lee, Lee, & Song, 2018)* lower extremity function was assessed using the Fugl-Meyer Assessment. According to a study by *Hernandez et al. (2021)*, this assessment tool presented with excellent intra-and-inter-rater reliability at item and summed scored level as well as reliability on repeated measures. Other studies such as the one by *Sullivan et al. (2011),* reinforce this measuring tool to be valid and reliable in the measurement of post stroke motor impairment severity, thus concluding the results obtained in the first study on lower extremity function to be accurate or reliable.

The eighth study *(PT,PhD Kim & PT,PhD Oh, 2012)* showed no significant improvement in stride length and single support time in the control group when comparing baseline results to the final results: the two groups were similar in characteristics, random allocation was used to place patients in the groups and the only factor that differed in interventions was the presence of auditory stimulation in the experimental group. The RS-scan system is a foot-scan platform used to analyse spatial and temporal coordinates by region as patient walks on a 2m long plate, was used to assess stride length: the study by *Xu et al (2017)* concluded this measuring tool to be repeatable and therefore a valuable tool in assessment of planter pressure distribution. Additionally a study by *Xu et al (2017)*, assessing the reliability of the Foot-scan Platform System with and without top-layer protocols in measuring plantar pressure, concluded that both protocols produced a moderate to good level of intra-and intersession reliability; however when comparing the two protocols, the one without top-layer presented with better reliability. Stride length is directly proportional to peak pressure and maximum mean pressure in the foot, thus the reliability and repeatability of loading or pressure parameters using the Footscan system indicate stride length results obtained to also be reliable *(Dr.Shinde, Dr.Wang, Dr.Abboud, &*

Dr.Cochrane, 2014). This proves that results obtained for the control group in study eight, for the stride length outcome measure for the control group, are increased in outcome accuracy.

According to *Annino et.al, (2019)* studies have suggested RAS to have beneficial effects on Neurological disorders with stroke being among them. RAS has been discovered to be capable of entraining motor responses due to the fascinating connection between the auditory and motor systems from the sensorimotor connectivity *(Thaut, Mclntosh, & Hoemberg, 2015)*. The auditory system is efficient in detecting temporal patterns in auditory signals with precision and speed unlike the visual and tactile systems *(Thaut, Mclntosh, & Hoemberg, 2015)*; gait has temporal attributes, these temporal gait parameters, can be influenced by external rhythmic sounds through entrainment, with the use of metronome cues or selected music. The second significant mechanism of entrainment and its link to gait is explained by how it influences motor planning and execution, by the external rhythmic stimuli creating a stable anticipatory motor time scale or motor template: this improves movement quality as anticipation is a critical component in movement *(Annino, Alshram, & Mercuri, 2019*) *(Thaut, Mclntosh, & Hoemberg, 2015)*. Successful movement anticipation relies on premonition of the cue period duration. The results in this systematic review have proved the positive effectiveness and influence rhythmic stimulation has on temporal parameters of gait. The results obtained from this research were in support of the results attained by the systematic review by *(Daniel, Koumans, & Ganti, 2021),* presenting an overall conclusion that music supported therapy can be beneficial in improving gait and ambulation, enhancing cognitive and motor function in the life of hemiplegic/paretic stroke patients. Similarly the systematic review by *(Ghai & Ghai , 2019)* concluded there to be positive effects of rhythmic auditory cueing to enhance gait performance and dynamic postural stability post-stroke: spatiotemporal gait parameters were enhanced mostly in gait velocity, stride length and cadence, similarly dynamic postural stability in improved.

As mentioned above, the auditory system affects the motoric system through entrainment in this case from external influence, which then mirrors its efforts in the change of the patients temporal gait parameters. However, gait is simultaneously composed of spatial parameters: due to auditory system superbly functioning to detect temporal patterns which work on a vibrational level *(Thaut, Mclntosh, & Hoemberg, 2015)*, one might question how then spatial parameters are then possibly influenced by the auditory system. The first mechanism of entrainment explains that the auditory stimulation primes the motor system to a state of readiness to move, facilitating the motor response quality *(Annino, Alshram, & Mercuri, 2019)*: additionally period entrainment (two movement oscillators of different periods synchronise to a common period: motor period entraining to an auditory rhythm period) explains why auditory rhythm also changes the spatial kinematic and dynamic force measures of muscle activation *(Thaut, Mclntosh, & Hoemberg, 2015)*. Having foreknowledge of the duration of movement periods alters calculations of everything in the brain for motor planning: the auditory stimulation is assisting the internal brain time keeper as an externally triggered timekeeper, with a precise reference interval and continuous time reference *(Thaut, Mclntosh, & Hoemberg, 2015)*. The brain's efforts in matching the movement to the produced template influenced by the external stimulus results not only in the change of speed but also smoother and less variable movement trajectories and muscle recruitment, thereby moderating patterns of muscle activation and control of movement in space *(Thaut, Mclntosh, & Hoemberg, 2015)*. With the effect RAS has had on the temporal and spatial variables of gait, it can be concluded in agreement with previous studies that, it is effective in optimizing all aspects of gait motor control.

Stroke is classified as one of the leading causes of death world-wide, however when survived, it brings challenges to one's life not only physically but also financially *(WHO Contributors, 2020) (Patel et al., 2017)*. Therefore it is extremely necessary to find a treatment method that is highly effective, leading patients to a fast recovery, and consequently financial relief. Loss of gait functionality is very detrimental and limiting thus it tends to be a big focus in hemiparesis/plegic recovery, hence the focus of this study on gait rehabilitation post stroke. Previous studies have focused solely on effects of RAS on stroke gait and confirmed RAS to be a beneficial treatment for stroke gait recovery, however very few studies have compared outcomes obtained by RAS to other treatment options. To explore the extent of effectiveness of RAS, this systematic review compared this treatment method to conventionally used stroke treatment methods aiming to see if RAS potentially the new advisable approach or substitute to the common to gait training approach for stroke patients. The results in this study have not only proved RAS to be a beneficial treatment, but have further indicated RAS to be a better treatment option as it yields more beneficial results in comparison conventional treatments.

Limitations of study

The generalizability of the results is limited by the study analysing a small number of clinical trials which also consist of small study populations. Additionally the reliability of the outcome measure results and consequently the conclusion of this research is compromised by five of the studies either not having or unaware of blinding for assessors, subjects and/or therapists and one study being a quasi-experimental study with a historic control group.

Majority of the studies were conducted over a four week period, which can be questioned if it is long enough to see change in stroke patients reliable enough to compare between interventions. All of the studies are presenting with chronic stroke patients, which allows for the results to be true for chronic stroke patients, however as it was not specified in the research question, the effectiveness of RAS combined therapy for acute or subacute patients is still unknown.

6. CONCLUSION

The aim of this thesis has proved Rhythmic Auditory Stimulation combined therapy to positively impact gait for hemiparesis stroke more than conventional therapy methods as improvement in gait spatio-temporal parameters, balance and lower extremity functions are observed. However further research with a larger population is needed to generalise the results and insight on Rhythmic Auditory Stimulation combined therapy effects on acute and subacute stroke patients is needed to conclude the extent of effectiveness of Rhythmic Auditory Stimulation combined therapy for the hemiparesis stroke population.

6.1. Suggestions for Future Research

Future studies should aim to review randomised clinical control trials as it improves the quality of work. Additionally larger pooled trials and number of reviewed studies are required to produce a more reliable and informed generalisation of results.

Due to this review not specifying on stage of stroke, to further explore the effectiveness of Rhythmic Auditory Stimulation combined therapy versus Conventional Therapy it is necessary to extensively evaluate its influence on acute and subacute subjects.

To further determine the effectiveness of Neurologic Music therapy in contrast to conventional therapy, it is advisable for future the study to have the intervention solely treated by a form of Neurologic Music therapy (such as Rhythmic Auditory Stimulation and Metronome Cueing), giving a clear indication of the extent of impact Neurologic Music Therapy approaches have in stroke gait rehabilitation, due to the elimination of possible influence from conventional therapeutic approaches. This will allow a better comparison of the two treatment approaches.

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