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PHASE-DEPENDENT MODULATION OF MUSCLE ACTIVATION EVOKED BY SUPERFICIAL RADIAL NERVE STIMULATION DURING WALKING IN HUMANS

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PHASE-DEPENDENT MODULATION OF MUSCLE ACTIVATION EVOKED BY SUPERFICIAL RADIAL NERVE STIMULATION DURING WALKING IN HUMANS

by

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Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Kinesiology

The University of Texas at Austin

December 2021

Acknowledgements

I would like to express my gratitude to the wonderful people who have assisted me in the completion of this thesis for their unrelenting support and encouragement.

I wish to acknowledge the efforts of my thesis supervisor, Dr. Lawrence Abraham, for his untiring guidance, valuable suggestions and constant encouragement throughout the study. . He not only gave me valuable advice regarding designing the study, designing the experiment set-up, data analysis techniques and writing the thesis, but also helped me hands-on in the lab with hardware issues and overcoming technical challenges. His timely guidance, critical suggestions and constant encouragement have been of immense help in the successful completion of this work.

I wish to acknowledge my Academic Advisor and co-supervisor, Dr. Jody Jensen, for sharing her extensive knowledge, time, insight, and resources. Her experience was of immense help, not only in the technical matters but also in developing interpersonal skills. Most importantly, she made me learn to think as a researcher and analyst. Her constant motivation and consultation helped me thrive as a professional.

I wish to acknowledge the efforts of Dr. James Sulzer, who generously provided his equipment and technical support countless times. In addition, he not only helped me with thesis related matters but also provided me with an excellent opportunity to work with him and develop software skills.

It would be unfair if I failed to acknowledge the participants who volunteered their time and put their best efforts during the study. This work also would not have been possible without the resources of the department, my fellow colleagues, support of the

faculty members; constant backing of Dr. Hao-Yuan Hsiao, critical evaluation of Dr. Lisa Griffin and the great coordination of Dr. Mandy McClintock.

Lastly, I would like to acknowledge the immense support provided by my friend Soubir Kumar, who not only provided me with all the necessary tech support and information, but actively volunteered to help me with data collection and analysis as a Research Assistant. I would also like to acknowledge Brianna Villalba for her tireless assistance in the beginning of data collection as a Research Assistant.

Abstract

Phase-dependent modulation of muscle activation evoked by superficial radial nerve stimulation during walking in humans

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The University of Texas at Austin, 2021

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Abstract: Researchers have been trying to develop an understanding of the complex neural mechanisms involved in controlling and regulating the coordination of numerous muscles during locomotion. Many sensory inputs received by the central nervous system from cutaneous and muscle receptors during movement that might help adjust to varying demands of the environment during the movement have been examined. It has been established that some nerve fibers involved in the control of locomotion interconnect the cervical and lumbar segments of the spinal cord, and that stimulation of upper limb nerves can alter the activation in lower limb motor pools. This study analyzed specific details of muscle activation responses in eight lower limb muscles evoked by superficial radial nerve stimulation in the right upper limb during several static postures and walking. Eighteen healthy volunteer adult participants with no documented neurological impairment or musculoskeletal injuries (ages 18-35) were recruited for the study. After determining the maximum isometric voluntary contraction (MVC) for each muscle being studied, muscle activation responses to brief nerve stimulation at random

intervals during sustained contraction of 30% MVC, six static postures representing the different phases of the step cycle, and continuous walking were analyzed. The target level of ~30% MVC was selected to present a suitable baseline for observing both inhibition and excitation. This study specifically aimed to assess whether differences in reflexive muscle activation in response to electrical stimulation during different static postures were in some ways task-dependent and/or phase-dependent during locomotion. To assess that, muscle activation responses during the six static postures were compared with muscle activation responses during comparable phases of walking on a treadmill. The results from the study indicated the presence and nature of inter-limb reflexes in healthy individuals. Findings from this study may help understand further position-dependency and phase dependency of such reflexes in humans.

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Chapter 1: Introduction

According to The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2016, neurological disorders are the second leading cause of death after heart disease in the USA and worldwide, with 9.1 million deaths and 16.5% of global deaths, respectively [1]. In addition, neurological disorders are the leading cause of severe disability resulting in physical impairments that greatly compromise the quality of life. The GBD estimated 276 million disability-adjusted life-years (DALYs) by age and sex in 195 countries, and 11.6% of global DALYs [1]. The high prevalence of neurological disorders place heavy demands on society and the health care system for persistent efforts in the field of rehabilitation to improve the quality of life of people living with a disability.

Clinically, individuals with neurological disorders, such as stroke and spinal cord injury, often show reduced leg muscle activity [2-3] and altered spatiotemporal characteristics during walking [4]. Such spatial and temporal changes may occur because of compensatory strategies adopted by either the non-affected leg or the affected leg [5], which can significantly affect walking function [6]. Over the years, neural rehabilitation has developed various approaches and advanced techniques that promote recovery of function and mobility [7]. Yet, statistically, not many such patients achieve the walking level necessary to resume all daily activities. Furthermore, it is unclear how effective these approaches are or whether one is more effective than the other [8][9]. Evidence suggests that such approaches and techniques involve restoring the impaired functional neural mechanism [7][8][9].

Physiologically, the nervous system controls the coordination of numerous muscles to regulate desired walking speeds through different control strategies,

generating and regulating changes in the pattern to adapt to changing circumstances during walking [10]. The sites of pattern generation in the brain and spinal cord receive integrated multi-sensory input from vision, somatosensory, and vestibular sources consequent to the movement to adjust to varying demands of the environment [10]. Sensory signals from visual and vestibular sources are integrated and processed by the central nervous system to maintain postural control and stability [11], and the somatosensory inputs from the periphery result in spinal reflexes that are considered to play a vital role in the muscular activity and coordination during locomotion [12][13]. It has been established that some nerve fibers involved in the control of locomotion interconnect the cervical and lumbar segments of the spinal cord, and stimulation of upper limb nerves can alter the activation in lower limb motor pools [11-13]. These inter-limb reflexive responses have been suggested to affect the coordination of the movement of the upper and lower limbs during locomotion [14-16]. Pearson further explained the role of sensory feedback for movement patterns as assistance in shaping the pattern to control phase transitions and to maintain the ongoing responses [17]. Yet, some studies have failed to find such inter-limb connections in neurologically intact humans, but only in people who have suffered a spinal cord injury (SCI) [17].

Experimentally, multi-sensory input received by the brain from cutaneous and muscle receptors during the movement has been examined. Variability in sensorimotor control mechanisms related to movement has been well-documented in animals [14-18]. In humans, a few studies have demonstrated the presence of interlimb reflexes in neurologically intact humans by examining H-reflex modulation [20]. Kearney and Chan demonstrated inter-limb reflexes after activation of both cutaneous and muscle afferents from the foot and leg [21-22]. Additionally, different rhythmic movements such as walking, running, arm cycling and leg cycling have demonstrated similar variability in

muscle activation response patterns, and phase-specific modulation of these inter-limb reflexive responses has also been suggested by a few studies. [21-24] [26-27]. In other words, these reflexive responses are known to be influenced by both active and passive changes in limb postures, even if the stimulus is held constant. On the other hand, very few studies have shown the phylogenetic evidence of central pattern generators in non-human primates and the functions that reflexes might serve during natural and purposive behaviors such as walking have remained unclear.

Therefore, there is uncertainty remaining concerning the presence and modulation of inter-limb reflexes in neurologically intact humans. For decades, researchers have been trying to decode the complex neural mechanisms contributing to the coordination and regulation of rhythmic movement in humans. It is critical to study further the role of somatosensory feedback in the regulation of neural pathways involved in movement control. This type of inter-limb reflex response has been studied previously by electrical stimulation of cutaneous nerves [21-23]. Careful control of the magnitude of the sensory input allows interpretation of changes observed in the magnitude of the effects (muscle activation) throughout the limbs. EMG modulation curves are obtained by averaging many sweeps of EMG data time-locked to a stimulus. They represent the integrated net neural response and are a direct measure of patterned motor output.

This study was designed to observe specific details of the reflexive muscle activation responses in lower limb muscles elicited by an electrical stimulus applied to a cutaneous nerve in one of the upper limbs in healthy humans. In this study, these responses were evoked by electrical stimulation to a cutaneous branch of the radial nerve, the superficial radial nerve in the right upper limb. The study examined reflexive muscle activation responses during sustained contraction at 30% of the muscle activation level

during maximum voluntary contractions (MVC), static postures representing the different phases of the step cycle, and walking.

The study specifically assessed whether differences in reflexive muscle activation in response to electrical stimulation during different static postures and during continuous locomotion were position-dependent and/or phase-dependent during phases of locomotion [21-24] [26-27]. To observe position and phase dependency of the reflex modulation, which could inform our understanding of the nature of interneuronal activation networks subserving locomotion, the muscle activation responses during the static postures were compared with muscle activation responses during the same positions while walking on a treadmill. It has been suggested these pathways are important in normal locomotion and may need to be strongly activated for effective rehabilitation and regaining walking ability following neurological injuries such as stroke and SCI [25].

Chapter 2: Methods

2.1 Participants:

Twenty healthy volunteer adult participants (ages 18-35, 9 female and 11 male) with no documented neurological impairment or musculoskeletal injuries, were recruited. They reported that they never had a medical diagnosis and/or treatment of neurological disability, injury, or neurological complications in their body. All participants reported that they were not following any prescription or over-the-counter medications known to affect the central nervous system (CNS depressants, CNS stimulants, hallucinogens, Phencyclidine [PCP] and its analogs, narcotic analgesics, inhalants, marijuana, or any allergy medications). A questionnaire was given related to these issues at the beginning of each session, and the participant was excluded if he or she answered 'Yes' to any of the questions. Two participants, one male and one female, were disqualified once it was discovered that they had a disqualifying chronic injury.

2.2 Protocol:

Participants visited the Movement and Cognitive Rehabilitation Science Lab (BEL 530) for two sessions, each lasting for about two hours. There was a rest interval of at least 24 hours between these two sessions. During session one, participants performed trials to determine maximum isometric voluntary contractions (MVCs) for each muscle being studied and Task 1. Task 2 and Task 3 were performed during session two. Cutaneous reflexes were evoked by stimulating the superficial radial nerve at the right wrist during all three tasks. The tasks are described as follows:

2.2.1 MVC Trials (seated): Participants were seated comfortably on an adjustable chair with the knee joints flexed to approximately 90 degrees for all trials. The adjustable chair includes several sturdy bars, which were used to attach a chain with a padded strap on the other end to wrap around the lower leg, to provide resistance when participants performed MVCs of the vastus lateralis muscle on both sides of the body. For the tibialis anterior, gastrocnemius medialis and biceps femoris muscles, the participants placed the foot in a brace with straps that prevented leg and foot movements while the participants remained seated in the chair. Muscle activation during maximum voluntary isometric contractions of each selected muscle was recorded individually using surface electromyography (EMG). For each of the eight selected muscles, participants performed four trials, each of 10 seconds duration. During the first trial the muscle activity while the participant was in a resting position was recorded. The remaining trials included the maximum voluntary contraction of a different selected muscle of the eight muscles. The resting trials along with the MVC trials were used to set target EMG levels for each muscle during static postures testing in the seated position. The resting trials were required to create a mathematical baseline for the MVC trials to calculate the 30% target value of the MVC trials in LabVIEW software. The maximum EMG activation values were also used to normalize subsequently recorded EMG values to allow comparison across all participants. Participants were asked to rest briefly (around 10 seconds) between the trials to minimize fatigue.

2.2.2 Task 1 (seated): Participants then performed in separate trials a focused contraction at ~30% of the MVC muscle activation recorded for each muscle while seated as they were during the MVC trials and viewing a display of the EMG signal on a desktop screen to aid in maintaining the target constant activation level [23]. Each 30% of MVC muscle activation level was determined by a custom LabVIEW program described previously. Participants received a 2ms electrical stimulus at irregular intervals, averaging once every 3sec, during all these experimental trials [23]. Participants performed 8 experimental trials, one for each muscle being studied. The muscles were tested in random order across all participants. Data for 50 stimuli were collected for each selected muscle [23]. Participants had to hold the contraction for a total of 4min to allow collection of data for 50 stimuli. Participants also performed 2 to 3 short practice test trials of about 10sec for each muscle separately to practice maintaining a sustained focused contraction before the control trials. The duration for each recorded trial to obtain control data was 20sec. No electrical stimuli were delivered during the control trials. The target level of ~30% of the maximum EMG was selected to present a suitable baseline for observing both reflex inhibition and excitation and to reduce the likelihood of fatigue [23]. Participants completed 8 test trials for Task 1 with 1min of rest or more between trials to mitigate fatigue. If a participant was not able to sustain a focused contraction level for a total of 4min, the participant was asked to rest briefly, as often as needed, in between attempts to complete a total of at least 4min of data collection while minimizing the effects of fatigue on the data. If multiple attempts were required, the data were

collected for a somewhat longer total duration (more than 4min), since the first and last few seconds in each attempt were not considered usable.

2.2.3 Task 2 (mimicked postures of step cycle): The participants were also tested holding six static postures, in which the arms and legs were held in positions mimicking those observed at different points in the walking step cycle [26]. The participants held these postures on a platform with a force plate under each foot (Bertec recording system, LA). The ground reaction force (GRF) data recorded by the force plates ensured the participants were bearing 25%, 50% and 75% of body weight for early stance, midstance, and late stance postures for each leg when it was in front of the other leg in the double support stance phases. Participants received instructions to hold and maintain the full body postures according to the real time GRF data observed by the experimenter for each stance phase. Kinematic data were recorded with a Vicon system to show static body postures. The EMG data were recorded simultaneously from all the selected limb muscles while the participants received the electrical stimulus at varying intervals (to avoid anticipation) of approximately once every three seconds [26]. The data for 50 stimuli were collected for each posture. Participants held each posture for a total of about 4 minutes to collect data for 50 stimuli, as well as to sample muscle activation levels without stimuli. Participants were asked to rest briefly as often as needed between attempts to complete the total time required for data collection in each posture while minimizing fatigue. A sheet of cardboard held by a tripod beside the participant was provided to provide a constant tactile stimulation on the dorsal aspect of the left hand to

help maintain stable postures. If the postures could only be held for short periods, the data collection duration would have had to be much longer, since the first and last 5sec in each trial were not considered usable. Most of the participants completed 6 test trials, one for each posture, with 1 minute of rest between trials to mitigate fatigue. There were a few participants who performed only four postures, when it was observed that the participants were not able to maintain some of the postures for even a very short duration and were getting tired in the process.

2.2.4 Task 3 (walking): All the participants walked on a treadmill at a speed of 3 km/hr (1.86 miles/hr). Each participant walked on the treadmill for 20 minutes. EMG data were recorded simultaneously from all the selected limb muscles, and the participants received an electrical stimulus at pseudorandom intervals, ranging from 3-4sec.

2.3 Terminology:

The term inter-limb reflex is used to describe reflex responses in muscles located in limbs other than the limb that is stimulated. Participants always received the electrical stimulus on the right upper limb. Muscles are described as 'ipsilateral' when they are present on the same side of the body as the site of the electrical stimulus, whereas the term 'contralateral' is used for the opposite side muscles with respect to the site of the electrical stimulus.

2.4 General apparatus and Setup:

2.4.1 Electrical Stimulation: The superficial radial nerve (SRN), a cutaneous branch of the radial nerve, was stimulated with bipolar stimulation electrodes (two 0.5 cm diameter Ag-AgCl electrodes 2.0 cm apart). The electrodes were attached with tape on the dorsolateral portion of the right forearm just proximal to the radial head, where the SRN is closest to the skin surface. The appropriate location and intensity of the stimulus was determined by probing with a stimulating wand to evoke radiating paresthesia in the innervation area of the SRN as guided by CDC. This value of intensity is referred to as a radiating threshold. The participant reported the sensation of shooting pulse in their thumb and first finger and this feeling was deemed to indicate an accurate stimulation for the target nerve. The intensity of the stimulus was kept strong enough to evoke a reflex response but not be deemed painful by the participants. Previous studies have used a variety of radiating threshold values to evoke inter-limb reflex responses [23][26][27]. An isolated constant current (model DS7A digitimer) stimulator connected with a Stimulus Isolation Unit, was used to deliver trains of five rectangular pulses of 1ms duration delivered at a frequency of 300Hz. The stimulator was connected to a motion capture system (Vicon Oxford Metrics, UK) to synchronize the onset of each electrical stimulus with the motion and EMG data. The Stimulation Isolation Unit delivered the electrical stimuli through bipolar stimulation electrodes. With respect to the data being collected, participants received the electrical stimuli at pseudorandom 2.5-3.5sec intervals, during the three tasks to avoid stimulus anticipation.

2.4.2 Electromyography: After lightly scrubbing and cleaning the shaved skin with alcohol, disposable bipolar surface EMG electrodes (H69-P, Jason-Kandell LTP, CA) were placed on the skin over the 8 selected muscles of the lower limbs. Recordings from

four muscles from the lower limbs on each side were made to record the muscle contractions and reflexive responses with a Delsys Trigno wireless EMG system (Natick, MA). The lower limb muscles from which recordings were made were the tibialis anterior (TA), gastrocnemius medialis (GM), vastus lateralis (VL) and long head of biceps femoris (BF) of both legs. The EMG data were collected at 2000 Hz and were amplified, full-wave-rectified and bandpass-filtered at 30-300 Hz.

2.4.3 Kinematic data and step cycle detection: Step cycle parameters and kinematic body position and motion data were obtained with a Vicon nine-camera motion-capture system, using the Vicon Full Body Plug-In-Gait and Vicon Nexus software at a sampling rate of 120Hz. Force plate data (Bertec recording system, LA) integrated with the Vicon data motion capture data, provided real time data to observe the movement patterns during walking and the accuracy and consistency of the static postures representing six phases of double support during walking. Twenty-two reflective markers were attached to target locations on the participants according to the Full Body Plug-In-Gait Model used for motion capture. The target locations were the lateral epicondyle of the elbow joint, medial, and lateral aspects of the wrist joint, shaft of the forearm, shaft of the arm, sternum, xiphoid process, shoulder joint, 7th cervical vertebra, 10th thoracic vertebra, scapula, front and back of the head, anterior superior iliac spine, posterior superior iliac spine, mid-thigh, lateral epicondyle of the knee, shank, ankle joint, 2nd metatarsophalangeal joint, and Achilles tendon on both sides of the body.

2.5 Measurement:

We measured EMG amplitude to observe the intensity of the reflex muscle activation responses throughout the different tasks, as well as whether the responses were excitatory or inhibitory. Reflex response times (the time from each electrical stimulus to peak response amplitude) were calculated to categorize the responses into early, middle, and late latency responses, which provided information about the length and complexity of the neural pathways and connections involved.

2.6 Data acquisition and analysis:

The data collected for each task were visually inspected and then analyzed using an interactive custom-written software program offline (MATLAB, The MathWorks, Natick, MA) on a computer. The process included the following steps-

- For each task and condition, the EMG data from 100 ms before the onset of each electrical stimulus till 250 ms after the onset of the electrical stimulus were separated. These data trials were termed "sweeps".
- Sweeps from all data trials for each task were averaged, rectified and bandpass filtered.
- The EMG data from each posture without stimulation were averaged and the standard deviation (SD) calculated as a control standard.
- Based on the mean and standard deviation of the EMG data with no reflex response, a reflex response was considered significant if it lasted more than 5 ms, exceeded ± 2 SD in amplitude, and was centered about the mean EMG level of the data without electrical stimulation.

- For Task 2 and Task 3, detection of the foot ground reaction force (GRF) was determined with the force plate data. These points were used to ensure that participants maintained the six static standing postures, and to determine step cycle phases during walking.
- From walking data, six groups of sweeps/traces were extracted for analysis that represented activity during 25%, 50% and 75% of body weight on the lead foot, when each leg (left and right) was placed in front during double support periods, like the six Task 2 static postures. These sweeps represented different phases of the double support portions of the step cycle during walking.
- Mean and standard deviation (SD) of the non-stimulated EMG data were calculated for each phase of the step cycle.
- The calculated means of the stimulated EMG data were used to produce the stimulus-evoked EMG data for each selected phase of the step cycle..
- Reflex amplitude was considered significant and included in the analysis if it differed from a 2-SD band centered on the mean calculated from the no-stimulation (control) EMG data and had a duration of at least 5ms.

Reflex amplitudes were normalized to the maximum background EMG recorded from the respective tasks without stimulation for each muscle except for Task 1. Reflex amplitudes were normalized with MVC data for Task 1.

The data for MVC trials and Task 1 (seated trials) were collected from 18 participants. 15 of these participants also performed Task 2 (standing posture trials) and

Task 3 (walking trials). Not all 15 participants performed the six standing postures for Task 2. The standing postures were studied in a random order assigned to the participants in even numbers i.e. either early stance on each leg in front, and/or mid-stance on each leg in front and/or late stance on each leg in front. A total of 11 participants performed early stance postures, 13 performed late stance postures, and 10 participants performed mid-stance postures. During data analysis, it was noticed that data for Task 1 from three of the participants were technically affected and could not be used. Also, one participant's data for task 3, for early stance with right leg in front, and another participant's data for late stance with right leg in front during Task 3 were technically affected, and hence were not part of further analyses.

Chapter 3: Results

All participants showed inter-limb reflex responses in at least one muscle for all tasks at different times after a stimulus occurred. To quantify the amplitude of each reflex response, a 10 ms window centered around the maxima or minima of each response was calculated for each latency. On rare occasions, more than one significant inter-limb reflex was observed. In such observations, only the first reflex response was considered in further analysis. The time elapsed from a stimulus to a significant reflex response was termed latency. No muscle activity was analyzed during the first 50 milliseconds after the stimulus occurred, to avoid considering a stimulus artifact. The latency to the peak of the evoked response was used to separate the reflex latencies into three epochs: early, middle, and late responses. The early, middle and late latency responses were <70ms, 70-120ms, >120ms, respectively. It should be noted that these epochs were set based upon visual inspection of the superimposed (averaged) data for each participant and condition, and thus reflect the observed pattern of the responses. All the results from each task were plotted and are discussed further below.

Task 1: Graphs for each selected muscle include data from 16 right and left TA, 16 right and left GM, 16 right and left VL, and 15 right and left BF. In all muscles, excitatory and inhibitory responses were noted when present. 74 muscles, out of 126 muscles, showed either an excitatory or inhibitory response. 55 muscles showed inhibitory responses and 19 excitatory responses were observed out of 74 muscles, while 52 muscles showed no

response. In most of the muscles, inhibitory responses predominated during Task 1 except for LGM. Table 1 includes the number of excitatory and inhibitory responses observed for each muscle across all participants. Table 2 includes the latency of the responses observed across all participants, and these data have also been plotted in Figures 1-8.

Task 2: Graphs for early and late stance standing postures include the reflex responses observed at different latencies from 12 participants, and 14 participants for mid late stance standing posture for each selected muscle. In some muscles both excitatory and inhibitory responses were observed, while in most remaining muscles either excitatory or inhibitory response occurred.

For early stance with the right leg in front, 15 muscles showed an inhibitory response, and 34 muscles showed an excitatory response, whereas no response occurred in 47 muscles out of the total of 96 muscles included. For early stance with the left leg in front, 19 muscles showed an inhibitory response, and 31 muscles showed an excitatory response, whereas no response occurred in 46 muscles out of the total 96 muscles included.

For mid stance with the right leg in front, 32 muscles showed an inhibitory response, and 23 muscles showed an excitatory response, whereas no response occurred in 56 muscles out of the total of 112 muscles included. For mid stance with the left leg in front, 27 muscles showed an inhibitory response, and 29 muscles showed an excitatory response, whereas no response occurred in 56 muscles out of the total of 112 muscles included.

For late stance with the right leg in front, 36 muscles showed an inhibitory response, and 12 muscles showed an excitatory response, whereas no response occurred in 48 muscles out of the total of 96 muscles included. For late stance with the left leg in front, 28 muscles showed an inhibitory response, and 20 muscles showed an excitatory response, whereas no response occurred in 48 muscles out of the total of 96 muscles included.

Task 3: Selected traces from the walking data were selected to align to include the six phases of the step cycle mimicked during Task 2. These traces were selected because they occurred during the early, middle and late stance phases with each leg in front during the double-support phases of walking. For early, and late double-support stance phases with the right leg in front during walking, the data from 14 participants were analysed, and for mid stance with the right leg in front, data from 15 participants were analyzed. For early, middle and late double-support stance phases with the left leg in front during walking, the data from 15 participants were analysed.

For the early double-support stance phase during walking with the right leg in front, 6 muscles showed an inhibitory response, and 32 muscles showed an excitatory response, whereas no response occurred in 71 muscles out of the total of 112 muscles analyzed. For the early double-support stance phase with the left leg in front during walking, 7 muscles showed an inhibitory response, and 32 muscles showed an excitatory response, whereas no response occurred in 81 muscles out of the total of 120 muscles analyzed.

For the mid double-support stance phase with the right leg in front during walking, 16 muscles showed an inhibitory response, and 26 muscles showed an excitatory response,

whereas no response occurred in 78 muscles out of the total of 120 muscles analyzed. For the mid double-support stance phase with the left leg in front during walking, 11 muscles showed an inhibitory response, and 22 muscles showed an excitatory response, whereas no response occurred in 87 muscles out of the total of 120 muscles analyzed.

For the late double-support stance phase with the right leg in front during walking, 18 muscles showed an inhibitory response, and 9 muscles showed an excitatory response, whereas no response occurred in 85 muscles out of the total of 112 muscles analyzed. For the late double-support stance phase with the left leg in front during walking, 11 muscles showed an inhibitory response, and 17 muscles showed an excitatory response, whereas no response occurred in 92 muscles out of the total of 120 muscles analyzed.

Descriptive analysis: It is clear from the results that inhibitory responses dominated during Task 1 in most of the muscles, with very few participants showing excitatory responses. Only the gastrocnemius medialis muscle on the left side, contralateral to the stimulus showed mostly excitatory responses during Task 1 across all the participants. Similarly, the excitatory responses dominated in Task 3 across all the points of step cycle analysed in this study as compared to the inhibitory responses. It is interesting to note that during Task 2, excitatory responses (a total of 120 excitatory responses occurred across all postures during Task 2) were relatively more frequent compared to Task 3. However, the inhibitory responses still dominated with a (total 190 inhibitory responses) during Task 2. The results from Task 1 affirmed that interlimb reflex responses exist in healthy

individuals. Careful examination of each muscle across all tasks showed that such responses occurred in a pattern. To learn more about the pattern, right side muscle responses were compared to the left side muscle responses. Additionally, a relative pattern was also examined between agonist and antagonist muscles. Also, the latency period for left side muscle responses was higher than the right side muscle activity. Most of the muscles showed middle and late latency responses and very few early responses. The detailed analysis of each task is described as follows:

Task 1 descriptive analysis: During focused contraction of 30% MVC, the RTA muscle showed a total of 2 excitatory (middle latency) responses and 9 inhibitory (1 early, 3 middle, and 7 late latency) responses, while no response occurred in 5 out of 16 participants (Appendix, Table 1). The LTA showed a total of 1 excitatory (middle latency) response and 8 inhibitory (4 middle and 4 late latency) responses, while no response occurred in 7 out of 16 participants (Appendix, Table 1, Fig 1). On the other hand, the antagonist muscle, RGM, showed 1 excitatory (middle latency) and 6 inhibitory (3 middle and 3 late latency) responses, and no responses occurred in 9 muscles (Appendix, Table 1, Fig 1). Additionally, LGM showed 6 excitatory (1 early, 1 middle and 4 late latency) and 2 inhibitory (2 late latency) responses, and no responses occurred in 8 muscles (Appendix, Table 1, Fig 1). The increased number of excitatory responses in opposite side antagonist muscles may reflect aspects of the inter-limb coordination of lower extremity muscle responses to an upper extremity stimulus.

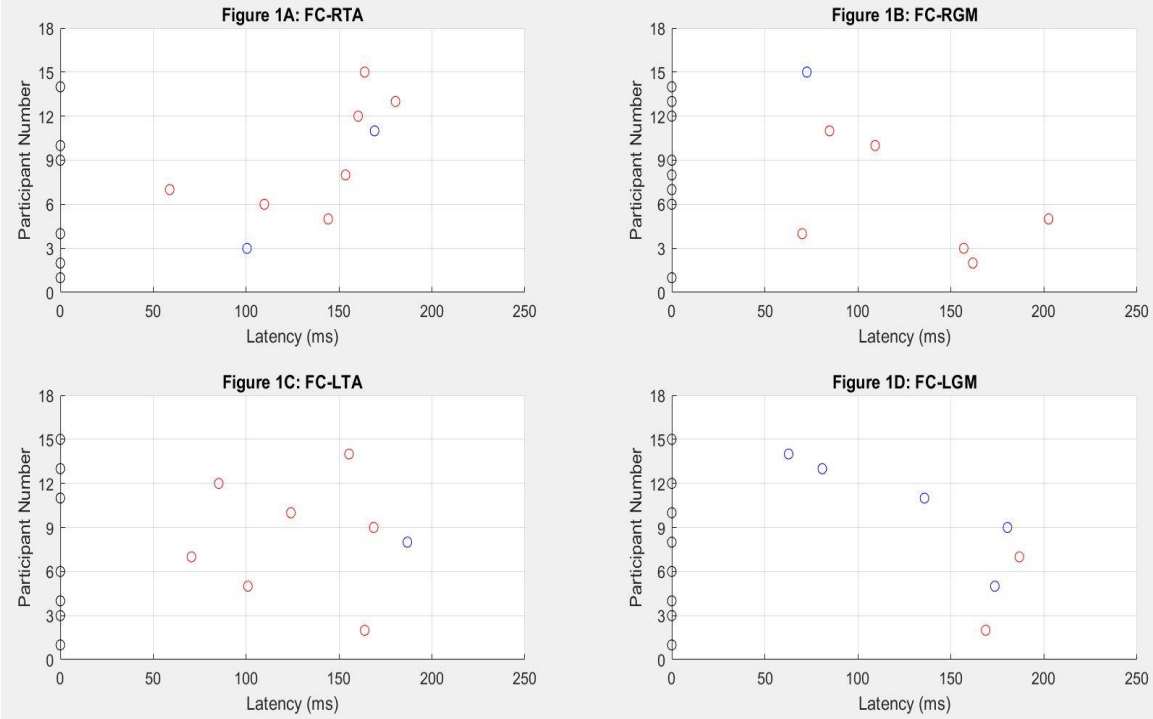

Figure 1: **Interlimb reflex responses observed at 30% focused contractions (FC) in RTA (Fig. 1A), RGM (Fig. 1B), LTA (1C) and LGM (Fig. 1D):** Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant.

Similarly, The RVL muscle showed a total of 2 excitatory (middle latency) responses and 8 inhibitory (3 middle, and 5 late latency) responses, while no response occurred in 6 out of 16 participants (Appendix, Table 1, Fig 2). The LVL showed a total of 3 excitatory (2 middle and 1 late latency) responses and 7 inhibitory (2 early and 5 late latency) responses, while no response occurred in 6 out of 16 participants (Appendix, Table 1, Fig 1). On the other hand, the antagonist muscle, RBF, showed 2 excitatory (1 middle and 1 late latency) and 8 inhibitory (1 early, 3 middle and 4 late latency) responses, and no responses occurred in 5 muscles (Appendix, Table 1, Fig 1).

Additionally, LBF showed 2 excitatory (1 early and 1 late latency) and 7 inhibitory (1 early, 3 middle and 3 late latency) responses, and no responses occurred in 6 muscles (Appendix, Table 1, Fig 1). The increased number of excitatory responses in opposite side antagonist muscles is similar to the pattern observed in TA and GM, further reflecting the possibility of inter-limb coordination of lower extremity muscle responses to an upper-extremity stimulus.

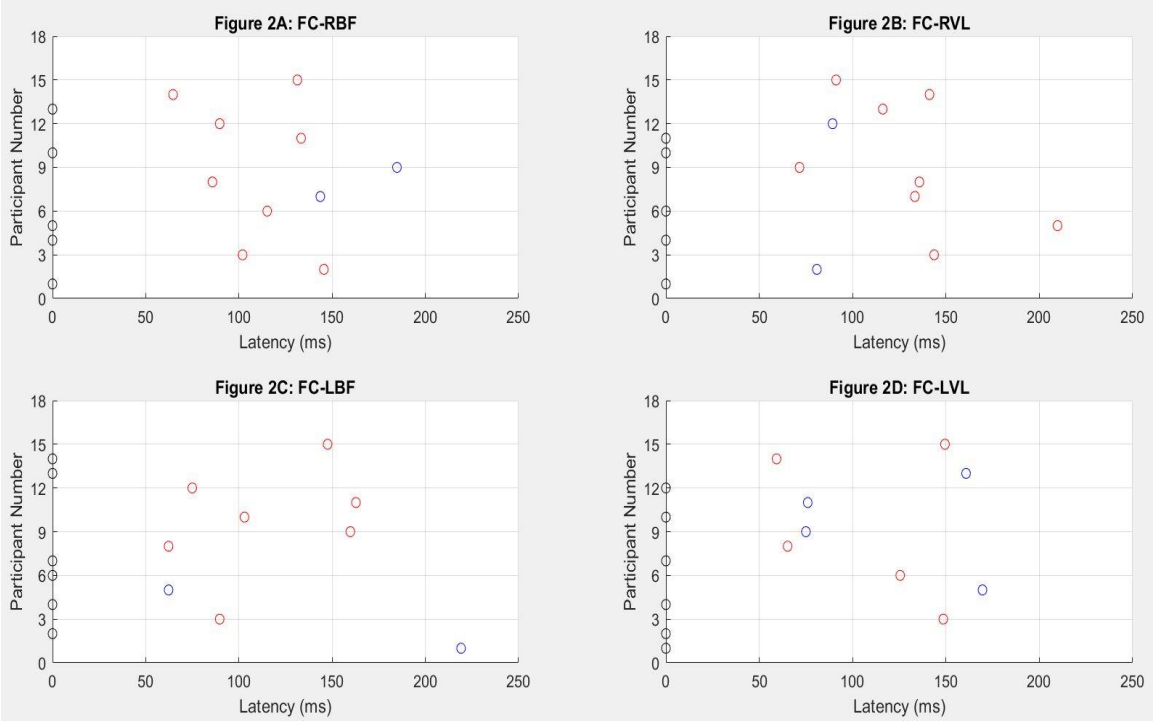

Figure 2: **Interlimb reflex responses observed at 30% focused contractions (FC) in RBF (Fig. 2A), RVL (Fig. 2B), LBF (Fig. 2C) and VL (Fig. 2D):** Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant.

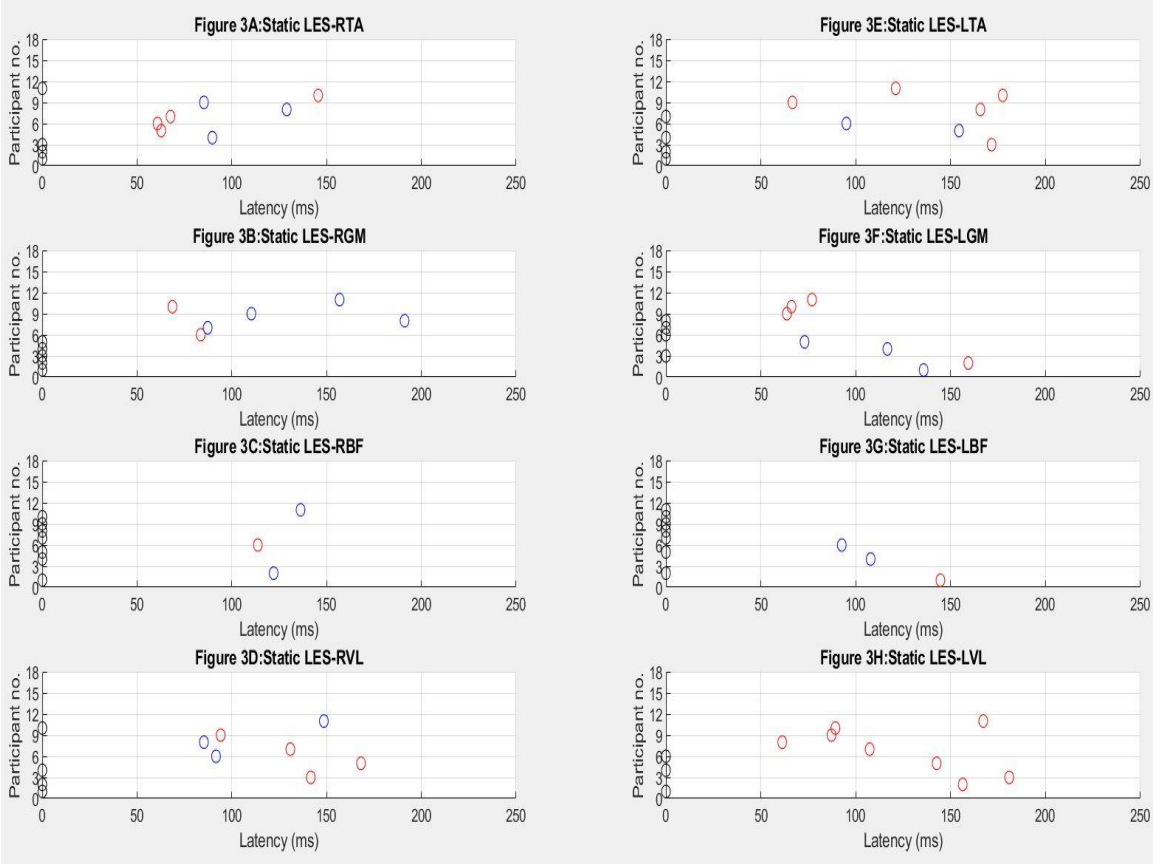

Figure 3: **Interlimb reflex responses observed during early stance double leg support standing posture with the left leg in front during Task 2 (LES) :** the early stance phase represents 25% of the body weight on the left leg with the left foot in front. mimicking a corresponding step cycle phase. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This posture was analyzed across 11 participants.

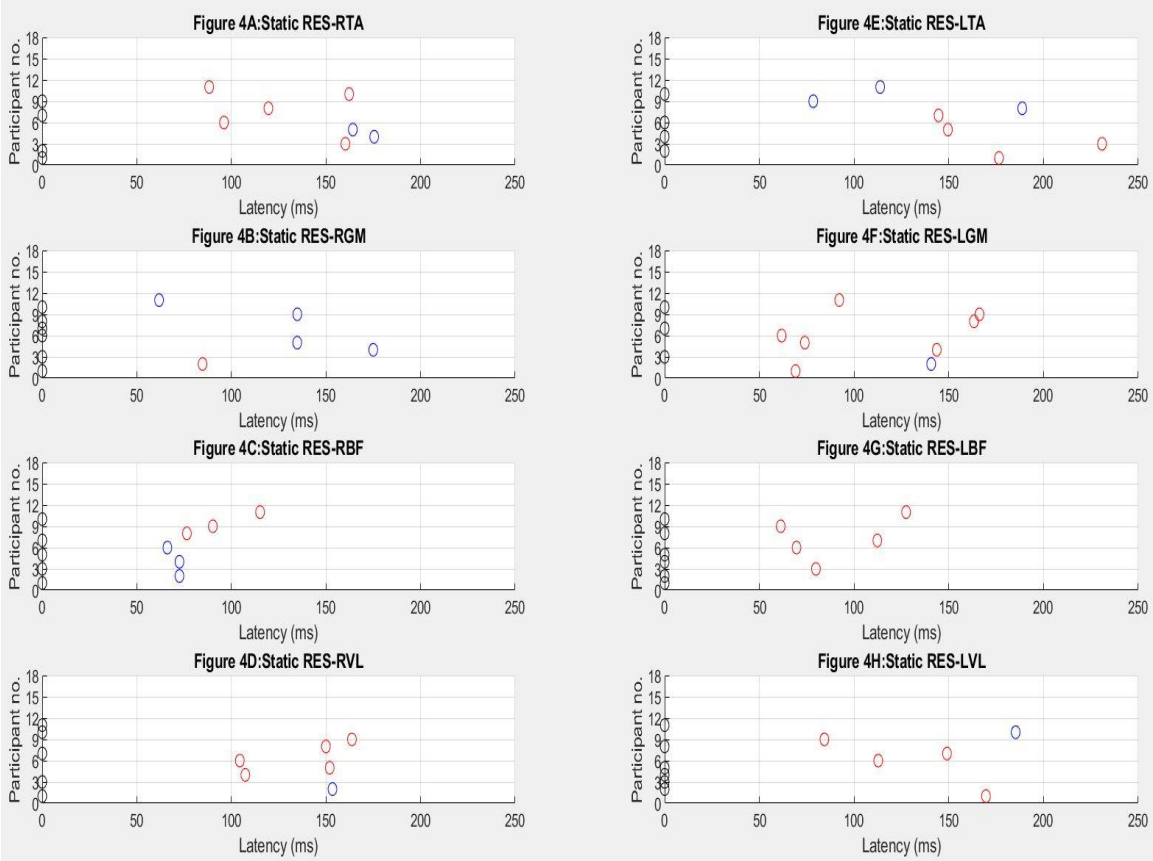

Figure 4: **Interlimb reflex responses observed during early stance double leg support standing posture with the right leg in front during Task 2 (RES):** the early stance phase represents 25% of the body weight on the right leg with the right foot in front, mimicking the corresponding step cycle phase. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This posture was analysed across 11 participants.

Task 2 descriptive analysis: A detailed examination of each standing posture is provided below:

Interlimb reflex responses observed during the early stance phase of double leg support while standing: During static standing in the early phase of double support with the left leg in front (Static-LES), the RTA muscle showed a total of 3 excitatory (2 middle and 1 late latency) responses and 4 inhibitory (3 early and 1 late latency) responses, while no response occurred in 4 out of 11 participants (Appendix, Table 2, Fig 3). The LTA showed a total of 3 excitatory (2 middle and 1 late latency) responses and 4 inhibitory (1 middle and 3 late latency) responses, while no response occurred in 7 out of 11 participants during LES (Appendix, Table 2, Fig 3). On the other hand, the antagonist muscle, RGM, showed 4 excitatory (2 middle and 2 late latency) and 2 inhibitory (1 early and 1 middle latency) responses, and no responses occurred in 5 muscles during LES (Appendix, Table 2, Fig 3). Additionally, LGM showed 3 excitatory (2 middle and 1 late latency) and 4 inhibitory (2 early, 1 middle and 1 late latency) responses, and no responses occurred in 4 muscles (Appendix, Table 2, Fig 3). Similarly, The RVL muscle showed a total of 3 excitatory (2 middle and 1 late latency) responses and 4 inhibitory (1 middle, and 3 late latency) responses, while no response occurred in 4 out of 11 participants (Appendix, Table 2, Fig 3). The LVL showed only inhibitory (1 early, 3 middle and 4 late latency) responses in 8 muscles, while no response occurred in 3 out of 11 participants (Appendix, Table 2, Fig 3). On the other hand, the antagonist muscle, RBF, showed 2 excitatory (late latency) and 2 inhibitory (1 middle and 1 late latency)

responses, and no responses occurred in 7 muscles during LES (Appendix, Table 2, Fig 3). Additionally, LBF showed 2 excitatory (middle latency) and 2 inhibitory (late latency) responses, and no responses occurred in 7 muscles during LES (Appendix, Table 2, Fig 3). The TA muscle showed more inhibitory responses, whereas its antagonist (GM) showed more excitatory responses on both sides of the body. Similarly, the VL showed more inhibitory responses than BF, showing excitatory and inhibitory responses almost equally on both sides of the body.

In the early phase of the double-support static posture with the right leg in front (Static-RES), the RTA muscle showed a total of 4 excitatory (1 early and 3 late latency) responses and 1 inhibitory (1 middle latency) response, while no response occurred in 6 out of 11 participants (Appendix, Table 3, Fig 4). The LTA showed a total of 3 excitatory (2 middle and 1 late latency) responses and 4 inhibitory (late latency) responses, while no response occurred in 4 out of 11 participants during RES (Appendix, Table 3, Fig 4). On the other hand, the antagonist muscle, RGM, showed 4 excitatory (1 early and 3 late latency) responses and 1 inhibitory (middle latency) response, and no responses occurred in 6 RGM muscles during RES (Appendix, Table 3, Fig 4). Additionally, LGM showed 1 excitatory (late latency) and 7 inhibitory (2 early, 2 middle and 3 late latency) responses, and no responses occurred in 3 muscles out of 11 participants during RES (Appendix, Table 3, Fig 4). Similarly, The RVL muscle showed a total of 1 excitatory (late latency) response and 5 inhibitory (2 middle, and 3 late latency) responses, while no response occurred in 5 out of 11 participants (Appendix, Table 3, Fig 4). The LVL showed one excitatory (late latency) and 4 inhibitory (2 middle and 2 late latency) responses in 5

muscles, while no response occurred in 6 out of 11 participants (Appendix, Table 3, Fig 4). On the other hand, the antagonist muscle, RBF, showed 3 excitatory (1 early and 2 middle latency) and 3 inhibitory (late latency) responses, and no responses occurred in 5 muscles during RES (Appendix, Table 3, Fig 4). Additionally, LBF showed only inhibitory (2 early, 2 middle and 1 late latency) responses in 5 muscles, and no responses occurred in 6 muscles (Appendix, Table 3, Fig 4). The TA muscle showed more inhibitory responses on both sides of the body during RES whereas its antagonist GM showed more inhibitory responses on the right side of the body and more excitatory responses on the left side of the body. Since the stimulus occurred on the right side of the body, this may reflect an influence of the stimulus location.

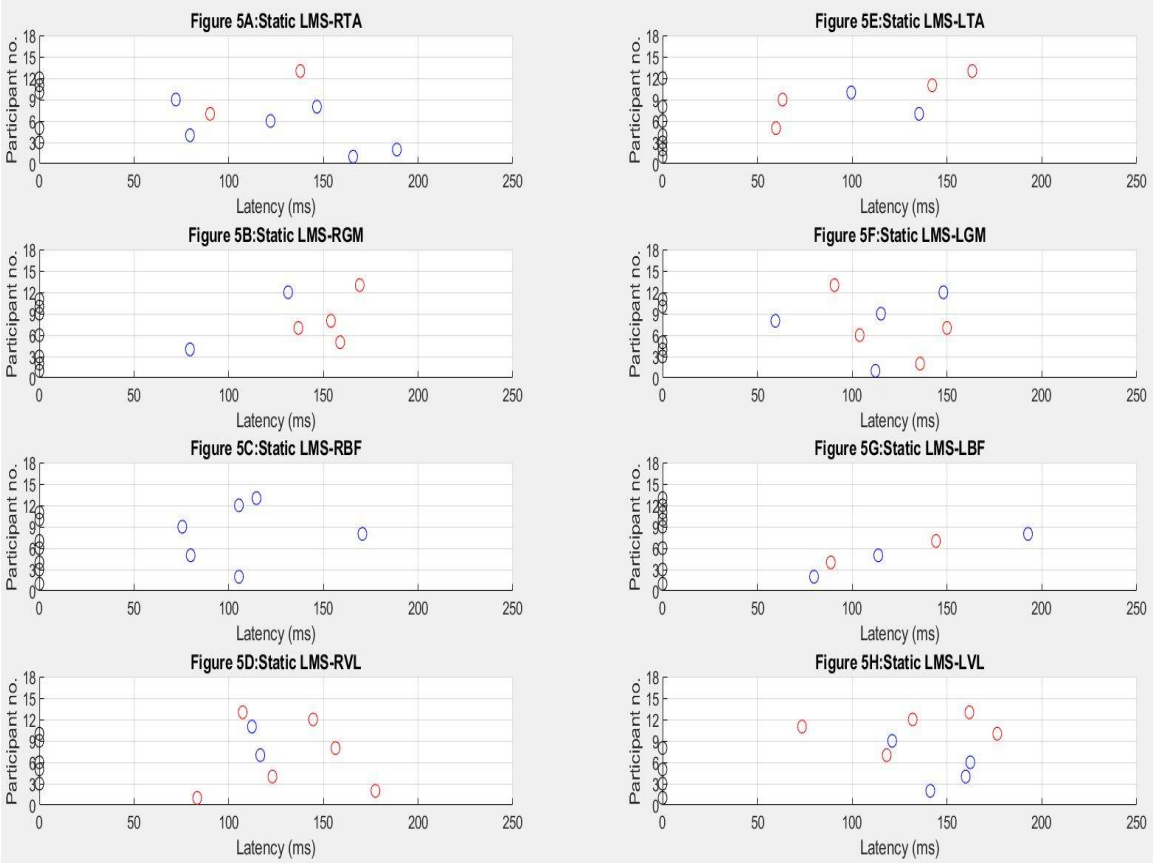

Figure 5: **Interlimb reflex responses observed during mid stance double leg support standing posture with the left leg in front during Task 2 (LMS):** the middle stance phase represents 50% of the body weight on the left foot with left leg in front, mimicking the corresponding step cycle phase. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This posture was analyzed across 11 participants.

Interlimb reflex responses observed during mid stance with double leg support while standing: In the mid standing posture with the left leg in front (Static-LMS), the RTA muscle showed a total of 6 excitatory (2 middle and 4 late latency) responses and 2 inhibitory (1 middle and 1 late latency) responses, while no response occurred in 5 out of 13 participants (Appendix, Table 4, Fig 5). The LTA showed a total of 2 excitatory (1 middle and 1 late latency) responses and 4 inhibitory (2 early and 2 late latency) responses, while no response occurred in 7 out of 13 participants during LMS (Appendix, Table 4, Fig 5). On the other hand, the antagonist muscle, RGM, showed 2 excitatory (1 middle and 1 late latency) and 4 inhibitory (all late latency) responses, and no responses occurred in 7 muscles during LMS (Appendix, Table 4, Fig 5).

Additionally, LGM showed 4 excitatory (1 early, 2 middle and 1 late latency) and 4 inhibitory (2 middle and 2 late latency) responses, and no responses occurred in 5 muscles during LMS (Appendix, Table 4, Fig 5). Similarly, The RVL muscle showed a total of 2 excitatory (middle latency) responses and 6 inhibitory (2 middle, and 4 late latency) responses, while no response occurred in 5 out of 13 participants (Appendix, Table 4, Fig 5). The LVL showed 4 excitatory (late latency) and 5 inhibitory (2 middle and 3 late latency) responses in 9 muscles, while no response occurred in 4 out of 13 participants (Appendix, Table 4, Fig 5). On the other hand, the antagonist muscle, RBF, showed only excitatory (5 middle and 1 late latency) responses in 6 muscles, and no responses occurred in 7 muscles during LMS (Appendix, Table 4, Fig 5). Additionally, LBF showed 3 excitatory (2 middle latency and 1 late latency) and 2 inhibitory (1 middle and 1 late latency) responses, and no responses occurred in 8 muscles during LMS (Appendix, Table 4, Fig 5). The tibialis anterior muscle showed almost equal numbers of excitatory and inhibitory responses on both sides of the body, however more late latency inhibitory responses occured on the left side of the body. A similar pattern was observed

in vastus lateralis on both sides of the body. The GM muscle showed equal numbers of excitatory and inhibitory responses on both sides of the body, however no middle latency excitatory response was observed on the right side of the body and no late latency excitatory responses occurred on the left side of the body.

In the mid standing posture with the right leg in front (Static-RMS), the RTA muscle showed a total of 6 excitatory (1 early, 2 middle and 3 late latency) responses and 4 inhibitory (middle latency) responses, while no response occurred in 3 out of 13 participants (Appendix, Table 5, Fig 6). The LTA showed a total of 4 excitatory (1 middle and 3 late latency) responses and 4 inhibitory (1 early, 2 middle, 1 late latency) responses, while no response occurred in 5 out of 13 participants during RMS (Appendix, Table 5, Fig 6).

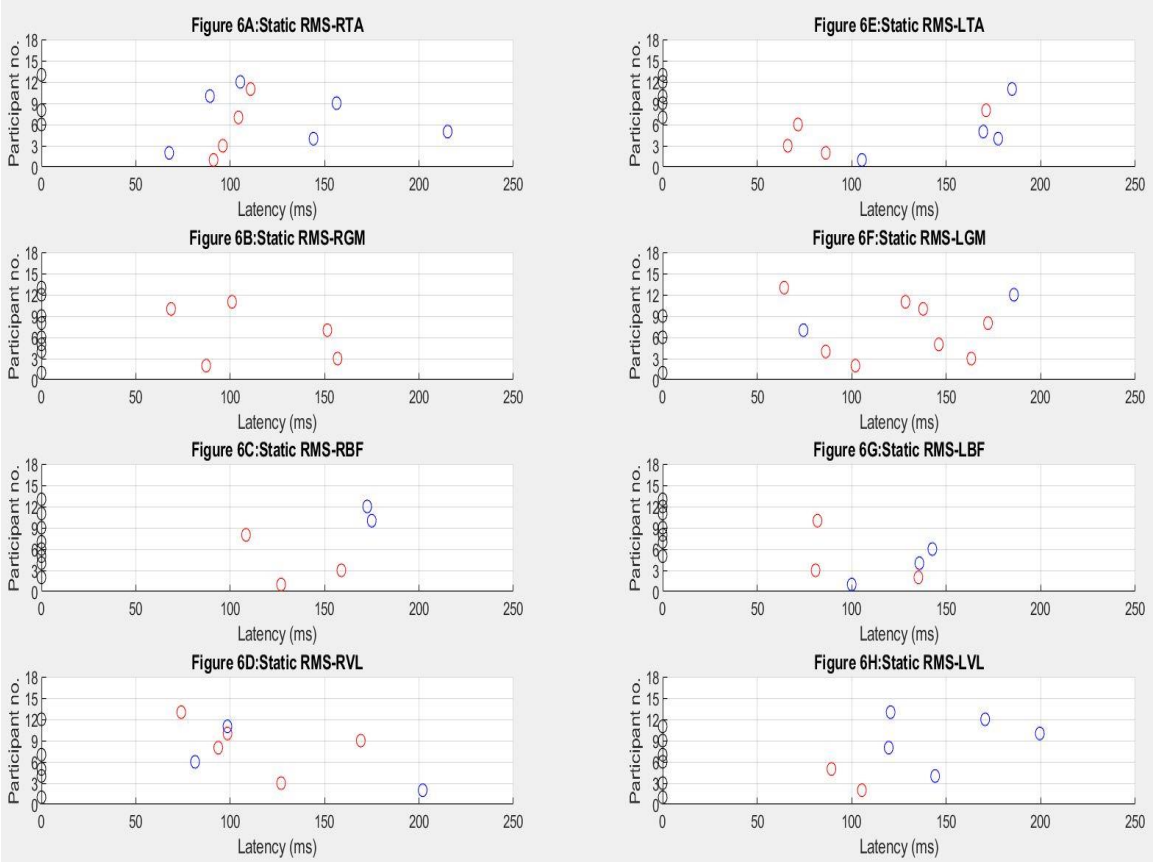

Figure 6: **Interlimb reflex responses observed during mid stance double leg support standing posture with the right leg in front during Task 2 (RMS):** the middle stance phase represents 50% of the body weight on the right foot with the right leg in front, mimicking the corresponding step cycle phase. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This posture was analyzed across 11 participants.

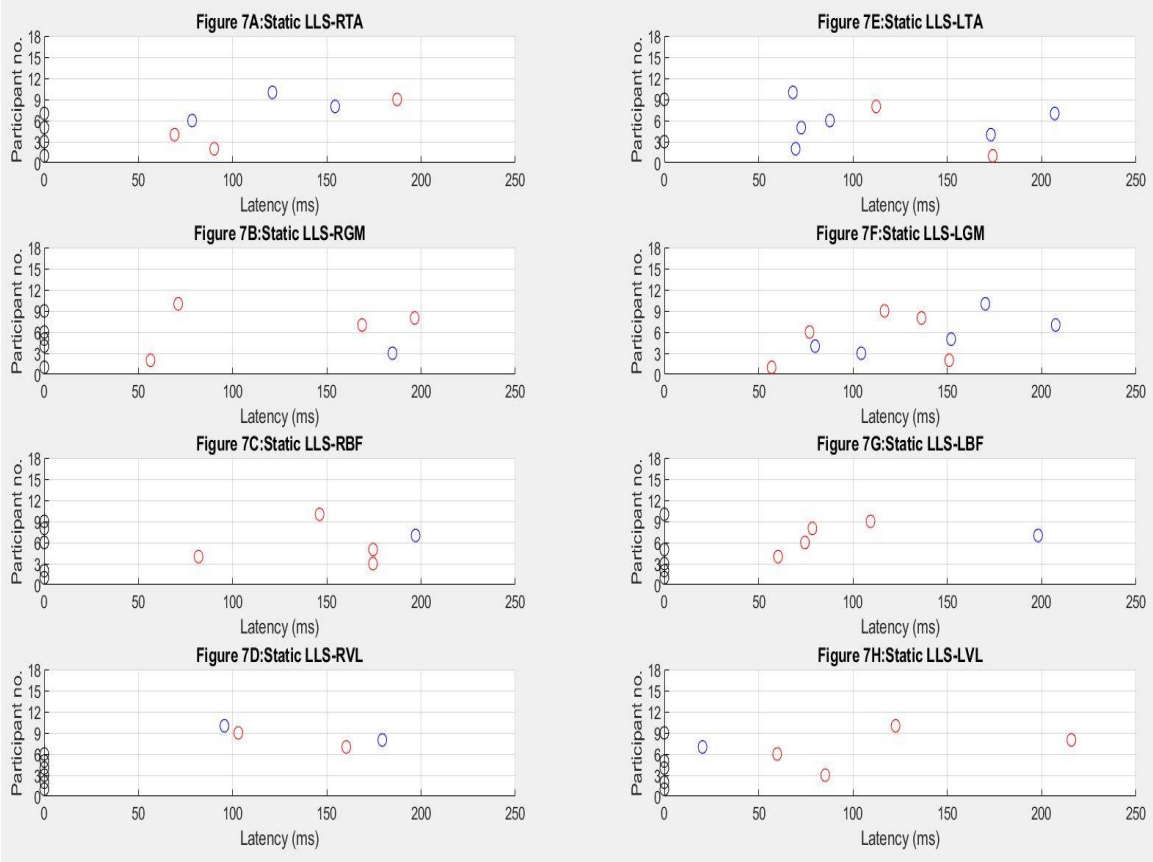

Figure 7: **Interlimb reflex responses observed during late stance double leg support standing posture with the left leg in front during Task 2 (LLS):** the late stance phase represents 75% of the body weight on the left foot with the left leg in front, mimicking the corresponding step cycle phase. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This posture was analyzed across 11 participants.

On the other hand, the antagonist muscle, RGM, showed only excitatory (1 early, 2 middle and 2 late latency) responses in 5 muscles, and no responses occurred in 8 muscles during RMS (Appendix, Table 5, Fig 6). Additionally, LGM showed 3 excitatory (1 middle and 2 late latency) and 8 inhibitory (1 early, 2 middle and 5 late latency) responses, and no responses occurred in 3 muscles out of 13 participants during RMS (Appendix, Table 5, Fig 6). Similarly, The RVL muscle showed a total of 3 excitatory (2 middle and 1 late latency) responses and 5 inhibitory (2 middle, and 3 late latency) responses, while no response occurred in 5 out of 13 participants during RMS (Appendix, Table 5, Fig 6). The LVL showed 5 excitatory (1 middle and 4 late latency) and 2 inhibitory (middle latency) responses in 7 muscles, while no response occurred in 6 out of 13 participants during RMS (Appendix, Table 5, Fig 6). On the other hand, the antagonist muscle, RBF, showed 2 excitatory (late latency) and 3 inhibitory (1 middle and 2 late latency) responses, and no responses occurred in 8 muscles during RMS (Appendix, Table 5, Fig 6). Additionally, LBF showed 3 inhibitory (2 middle and 1 late latency) and 3 excitatory (1 middle and 2 late latency) responses in 6 muscles, and no responses occurred in 6 muscles (Appendix, Table 5, Fig 6). The TA muscle showed almost equal number of excitatory and inhibitory responses, however more late latency excitatory responses occur on the left side of the body during RMS. The GM showed mostly inhibitory responses on both sides of the body, more specifically on the right side of the body like LMS. The VL showed mostly inhibitory responses on the right side of the body whereas mostly excitatory responses on the left side of the body. The BF

showed a similar ratio of excitatory and inhibitory responses on both sides of the body but doubled in number on the left side of the body.

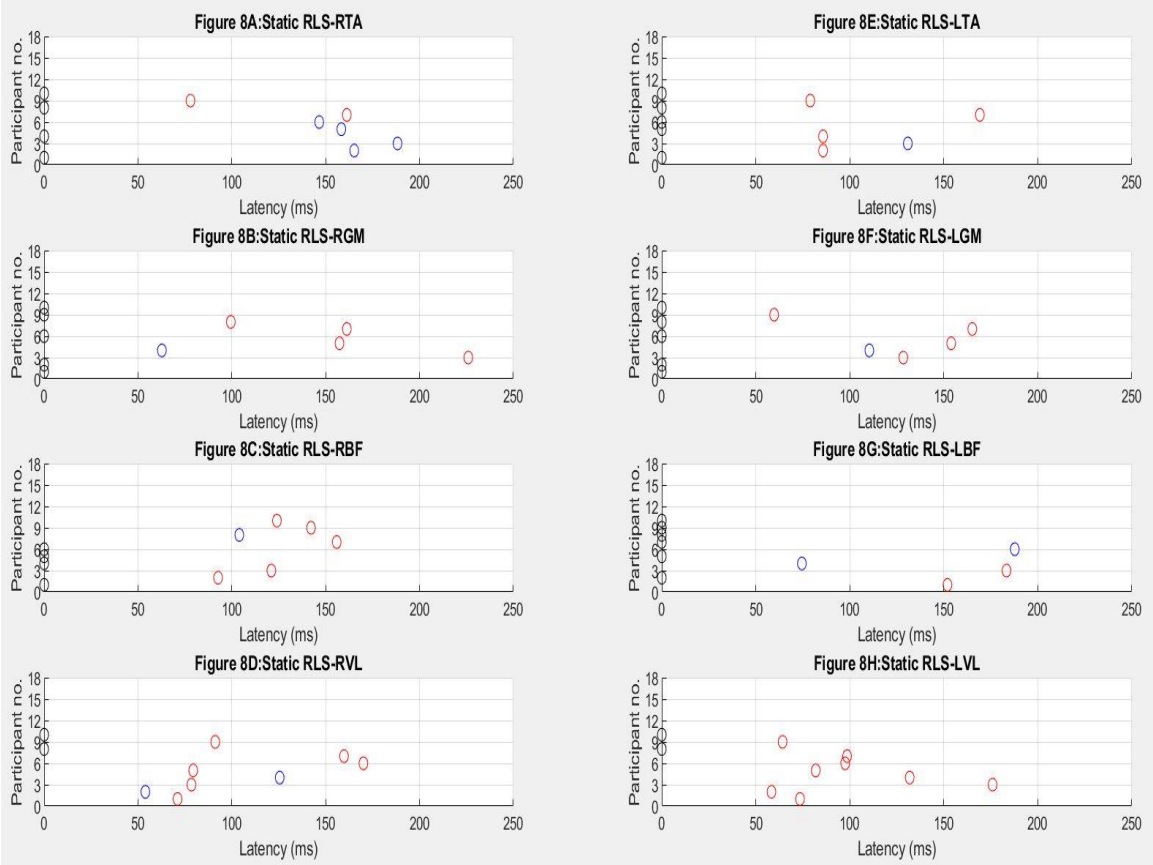

Figure 8: **Interlimb reflex responses observed during late stance double leg support standing posture with the right leg in front during Task 2 (RLS):** the late stance phase represents 75% of the body weight on the right foot with the right leg in front, mimicking the corresponding step cycle phase. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This posture was analyzed across 11 participants.

Interlimb reflex responses observed during late double leg support while standing: In late standing posture with the left leg in front (Static-LLS), the RTA muscle showed a total of 3 excitatory (1 middle and 2 late latency) responses and 3 inhibitory (1 early, 1 middle and 1 late latency) responses, while no response occurred in 4 out of 10 participants (Appendix, Table 6, Fig 7). The LTA showed a total of 6 excitatory (2 early, 2 middle and 2 late latency) responses and 2 inhibitory (1 middle and 1 late latency) responses, while no response occurred in

2 out of 10 participants during LLS (Appendix, Table 6, Fig 7). On the other hand, the antagonist muscle, RGM, showed 1 excitatory (late latency) and 4 inhibitory (1 early, 1 middle, and 2 late latency) responses, and no responses occurred in 5 muscles during LLS (Appendix, Table 6, Fig 7). Additionally, LGM showed 5 excitatory (2 middle and 3 late latency) and 5 inhibitory (1 early, 2 middle and 2 late latency) responses out of 10 muscles during LLS (Appendix, Table 6, Fig 7). Similarly, The RVL muscle showed a total of 2 excitatory (1 middle and 1 late latency) responses and 2 inhibitory (1 middle, and 1 late latency) responses, while no response occurred in 6 out of 10 participants (Appendix, Table 6, Fig 7). The LVL showed only inhibitory (1 early, 1 middle and 2 late latency) responses in 4 muscles, while no response occurred in 6 out of 10 participants (Appendix, Table 6, Fig 7). On the other hand, the antagonist muscle, RBF, showed only 1 excitatory (late latency) and 4 inhibitory (1 middle and 3 late latency) responses in 5 muscles, and no responses occurred in 5 muscles during LLS (Appendix, Table 6, Fig 7). Additionally, LBF showed 1 excitatory (late latency) and 4 inhibitory (1 early and 3 middle latency) responses, and no responses occurred in 5 muscles during LLS (Appendix, Table 6, Fig 7). The TA muscle showed more excitatory responses in comparison to the antagonist muscle GM, more specifically on the left side

of the body, even though more excitatory responses occurred in GM on the left side in comparison to the right side of the body. The BF showed mostly equal inhibitory responses on both sides of the body even though vastus lateralis is all about inhibitory responses more specifically on the left side of the body..

In the late stance standing posture with the right leg in front (Static-RLS), the RTA muscle showed a total of 4 excitatory (late latency) responses and 2 inhibitory (1 middle and 1 late latency) responses, while no response occurred in 4 out of 10 participants (Appendix, Table 7, Fig 8). The LTA showed a total of 1 excitatory (late latency) response and 4 inhibitory (3 middle and 1 late latency) responses, while no responses occurred in 5 out of 10 participants during RMS (Appendix, Table 7, Fig 8). On the other hand, the antagonist muscle, RGM, showed only 1 excitatory (early latency) and 4 inhibitory (1 middle and 3 late latency) responses in 5 muscles, and no responses occurred in 5 muscles during RLS (Appendix, Table 7, Fig 8). Additionally, LGM showed 1 excitatory (middle latency) and 4 inhibitory (1 early and 3 late latency) responses, and no responses occurred in 5 muscles out of 10 participants during RLS (Appendix, Table 7, Fig 8). Similarly, the RVL muscle showed a total of 2 excitatory (1 early and 1 late latency) responses and 6 inhibitory (4 middle, and 2 late latency) responses, while no response occurred in 2 out of 10 participants during RMS (Appendix, Table 7, Fig 8). The LVL showed only inhibitory (2 early, 4 middle and 2 late latency) responses in 8 muscles, while no response occurred in 2 out of 10 participants during RLS (Appendix, Table 7, Fig 8). On the other hand, the antagonist muscle, RBF, showed 1 excitatory (middle latency) and 5 inhibitory (1 middle and 4 late latency) responses, and no responses occurred in 4 muscles during RLS (Appendix, Table 7, Fig 8). Additionally, LBF showed 3 inhibitory (late latency) and 2 excitatory (1 middle and 1 late latency) responses in 5 muscles, and no responses occurred in 5 muscles (Appendix,

Table 7, Fig 8). The TA showed mostly excitatory responses on the right side and mostly inhibitory responses on the left side of the body whereas the antagonist GM showed mostly inhibitory responses on both sides of the body during RLS. This was completely different from what was observed in LLS. The BF and VL showed mostly inhibitory responses on both sides of the body, similar to what was observed in the LLS phase.

Task 3 descriptive analysis: A detailed examination of each selected phase of the step cycle during walking is provided below:

Interlimb reflex responses observed during the early stance phase of double leg support during walking in Task 3: In the early double support stance phase with the left leg in front (Walk-LES), the RTA muscle showed only excitatory responses in 5 muscles, while no responses occurred in 10 out of 15 participants (Appendix, Table 8, Fig 9). The LTA showed a total of 2 excitatory (1 early and 1 late latency) responses and 3 inhibitory (1 early and 2 middle latency) responses, while no responses occurred in 10 out of 15 participants during LES (Appendix, Table 8, Fig 9). On the other hand, the antagonist muscle, RGM, showed only 1 excitatory (middle latency) response in one participant, and no responses occurred in 14 participants during LES in Task 3 (Appendix, Table 8, Fig 9). Additionally, LGM showed a total of 5 excitatory (4 middle and 1 late latency) responses out of 15 muscles during LES (Appendix, Table 8, Fig 9). The RVL muscle showed a total of 7 excitatory (1 early, 5 middle and 1 late latency) responses and 1 inhibitory (early latency) response, while no response occurred in 7 out of 15 participants (Appendix, Table 8, Fig 9). The LVL showed no response in any of the participants (Appendix, Table 8, Fig 9). On the other hand, the antagonist muscle, RBF, showed only 7 excitatory (4 middle and 3 late latency) and 1 inhibitory (middle latency) responses in 8 muscles, and no responses occurred in 7 muscles during LES (Appendix, Table 8, Fig 9). Additionally, LBF showed 5 excitatory (3 middle and 2 late latency) and

2 inhibitory (middle latency) responses, and no responses occurred in 8 muscles during LES (Appendix, Table 8, Fig 9).

Overall, the TA showed mostly excitatory responses on the right side of the body and mostly inhibitory on left side of the body, Although the antagonist muscle GM also showed excitatory responses, they were much fewer in number in comparison to the agonist muscle and more specifically so on the right side of the body. The VL and BF also showrd excitatory responses although no response occurred in LVL.

In the early stance phase during walking with right leg in front (Walk-RES), the RTA muscle showed a total of 8 excitatory (3 early and 5 middle latency) responses and 1 inhibitory (late latency) responses, while no response occurred in 5 out of 14 participants (Appendix, Table 9, Fig 10). The LTA showed a total of 1 excitatory (middle latency) responses and 1 inhibitory (middle latency) responses, while no response occurred in 12 out of 14 participants during RMS (Appendix, Table 9, Fig 10). On the other hand, the antagonist muscle, RGM, showed only 3 excitatory (1 early and 2 middle latency) and 3 inhibitory (late latency) responses in 6 muscles, and no responses occurred in 8 muscles during RES (Appendix, Table 9, Fig 10). Additionally, no response occurred in LGM during RES (Appendix, Table 9, Fig 10). The RVL muscle showed a total of 5 excitatory (middle latency), while no response occurred in 9 out of 14 participants during RES (Appendix, Table 9, Fig 10). The LVL showed only 1 inhibitory (late latency) and 7 excitatory (5 middle and 2 late latency) responses in 8 muscles, while no response occurred in 6 out of 14 participants during RES (Appendix, Table 9, Fig 10). On the other hand, the antagonist muscle, BF, showed only excitatory responses, 1 on right side

(middle latency) and 9 (1 early, 5 middle and 3 late latency) on left side during RES (Appendix, Table 9, Fig 10).

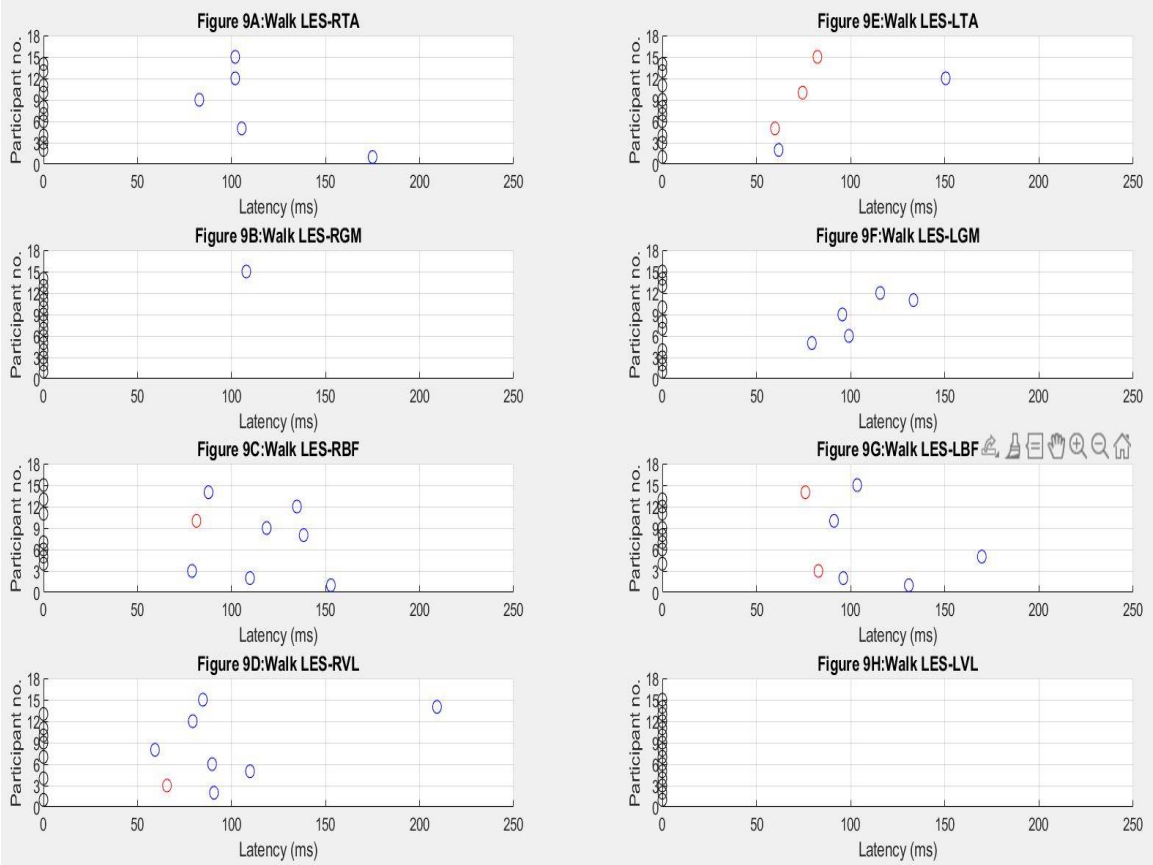

Figure 9: **Interlimb reflex responses observed during the early double leg support stance phase with the left leg in front during walking in Task 3:** the left early stance phase represents a period of double support stance when about 25% of the body weight is on the left foot with the left leg in front. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This phase was analyzed across 11 participants.

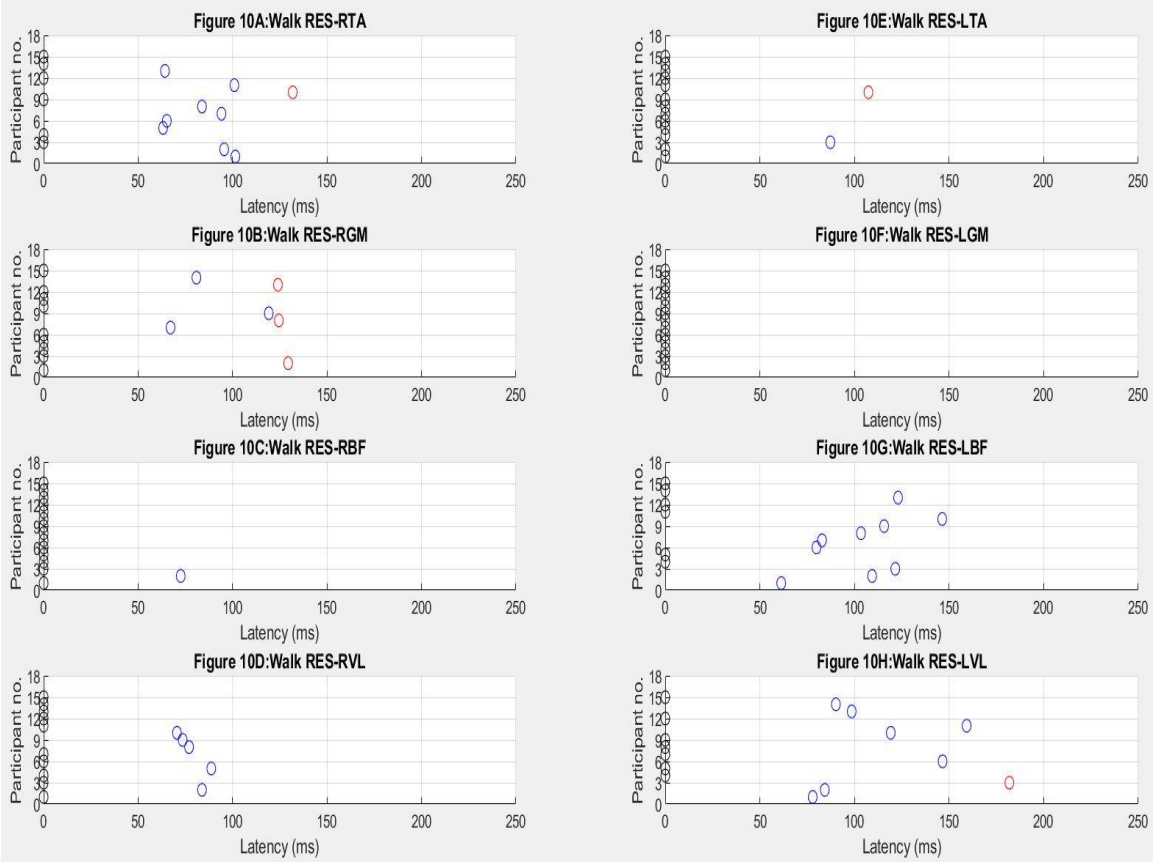

Figure 10: **Interlimb reflex responses observed during the early double leg support stance phase with the right leg in front during walking in Task 3:** the right early stance phase represents a period of double support stance when about 25% of the body weight is on the right foot with the right leg in front. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This phase was analyzed across 11 participants.

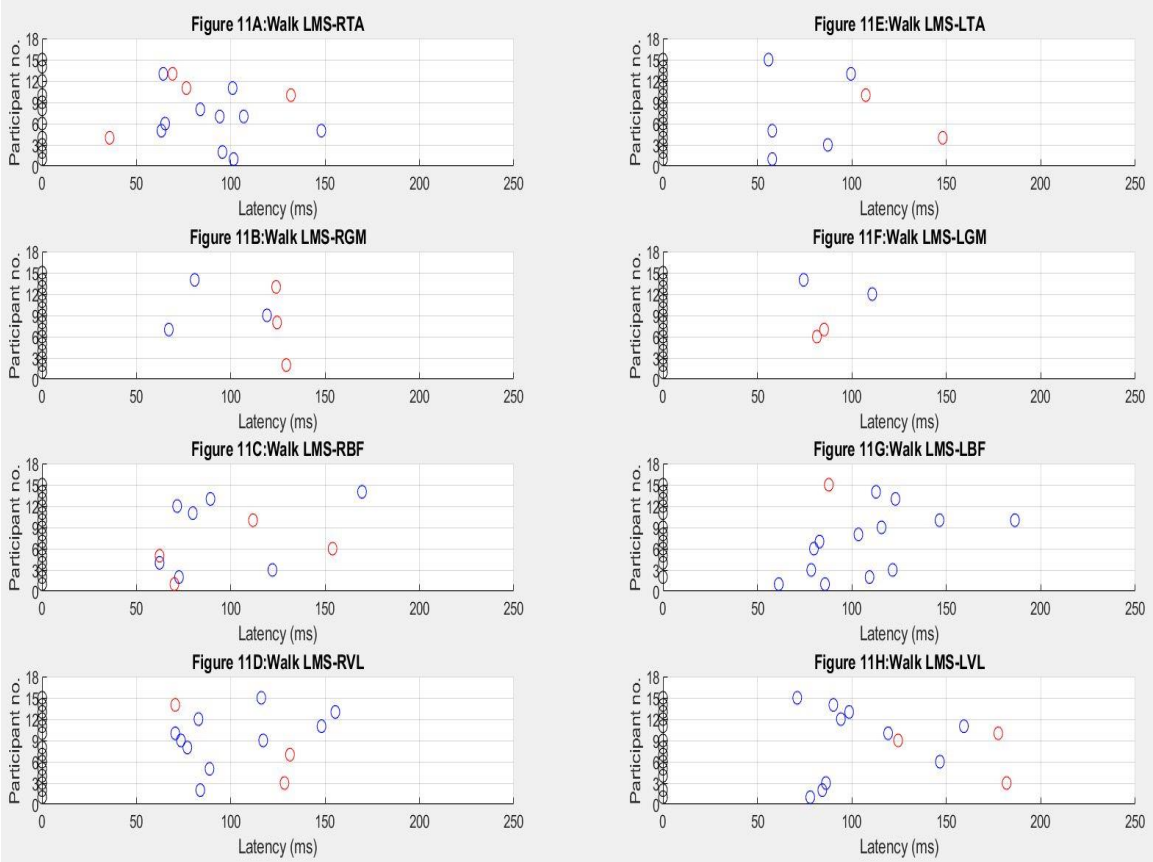

Figure 11: **Interlimb reflex responses observed during the middle of the double leg support stance phase with the left leg in front during walking in Task 3:** the left mid stance phase represents a period of double support stance when about 50% of the body weight is on the left foot with the left leg in front. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This phase was analyzed across 11 participants.

Interlimb reflex responses observed during the mid-stance phase of double leg support during walking in Task 3: In mid stance phase with the left leg in front Task 3 (Walk-LMS), the RTA muscle showed a total of 2 excitatory (1 middle and 1 late latency) responses and 3 inhibitory (2 early and 1 middle latency) responses, while no

response occurred in 10 out of 15 participants (Appendix, Table 10, Fig 11). The LTA showed a total of 4 excitatory (3 early and middle latency) responses and 1 inhibitory (late latency) responses, while no response occurred in 10 out of 15 participants during LMS (Appendix, Table 10, Fig 11). On the other hand, the antagonist muscle, RGM, showed no responses, and LGM showed 2 excitatory (middle latency) and 2 inhibitory (late latency) responses out of 15 muscles during LMS (Appendix, Table 10, Fig 11). The RVL muscle showed a total of 5 excitatory (3 middle and 2 late latency) responses and 3 inhibitory (1 middle and 2 late latency) responses, while no response occurred in 7 out of 15 participants (Appendix, Table 10, Fig 11). The LVL showed 2 inhibitory (late latency) and 3 excitatory (middle latency) responses, while no response occurred in 10 out of 15 participants (Appendix, Table 10, Fig 11). On the other hand, the antagonist muscle, RBF, showed 6 excitatory (1 early, 3 middle and 2 late latency) and 4 inhibitory (1 early, 2 middle and 1 late latency) responses in 10 muscles, and no responses occurred in 5 muscles during LMS (Appendix, Table 10, Fig 11). Additionally, LBF showed 3 excitatory (middle latency) and 1 inhibitory (middle latency) responses, and no responses occurred in 11 muscles during LMS (Appendix, Table 10, Fig 11).

In the mid stance phase with the right leg in front in Task 3 (Walk-RMS), the RTA muscle showed a total of 2 excitatory (1 early and 1 middle latency) responses and 3 inhibitory (middle latency) responses, while no response occurred in 10 out of 15 participants (Appendix, Table 11, Fig 12). The LTA showed 1 excitatory (middle latency) response and 1 inhibitory (late latency) response, while no response occurred in

13 out of 15 participants during RMS (Appendix, Table 11, Fig 12). On the other hand, the antagonist muscle, RGM, showed a total 3 excitatory (early, middle and latency) and 1 inhibitory (middle latency) responses in 4 muscles, and no responses occurred in 11 muscles during RMS (Appendix, Table 11, Fig 12). Additionally, LGM showed only 1 excitatory (middle latency) response, and no response occurred in the remaining 14 participants during RMS (Appendix, Table 11, Fig 12). The RVL muscle showed a total of 3 excitatory (1 early and 2 middle latency) responses, while no response occurred in 7 out of 10 participants during RMS (Appendix, Table 11, Fig 12). The LVL showed only 1 inhibitory (middle latency) response and 7 excitatory (2 early and 5 middle latency) responses in 8 muscles, while no response occurred in 7 out of 15 participants during RMS (Appendix, Table 11, Fig 12). On the other hand, the antagonist muscle, RBF, showed 1 excitatory (early latency) and 3 inhibitory (2 middle and 1 late latency) responses, and no responses occurred in 11 muscles during RMS (Appendix, Table 11, Fig 12). Additionally, LBF showed a total of 3 inhibitory (middle latency) and 4 excitatory (late latency) responses in 7 muscles, and no responses occurred in 8 muscles (Appendix, Table 11, Fig 12).

Interlimb reflex responses observed during the late stance phase of double leg support during walking in Task 3: In the late stance phase with the left leg in front during Task 3 (Walk-LLS), the RTA muscle only showed excitatory (2 early and 2 middle latency) responses in 4 muscles, while no response occurred in 11 out of 15 participants (Appendix, Table 12, Fig 13). The LTA showed 1 excitatory (late latency)

response and 2 inhibitory (1 middle and 1 late latency) responses, while no response occurred in 12 out of 15 participants during LLS (Appendix, Table 12, Fig 13). On the other hand, the antagonist muscle, RGM, showed no response in any muscle and LGM showed 4 excitatory (1 early, 2 middle and 1 late latency) responses out of 15 muscles during LLS (Appendix, Table 12, Fig 13). The RVL muscle showed a total of 4 excitatory (3 middle and 1 late latency) responses and 2 inhibitory (middle latency) responses, while no response occurred in 9 out of 15 participants (Appendix, Table 12, Fig 13). The LVL showed 1 excitatory (middle latency) and 1 inhibitory (middle latency) response in 2 muscles, while no response occurred in 13 out of 15 participants (Appendix, Table 12, Fig 13). On the other hand, the antagonist muscle, RBF, showed 3 excitatory (2 middle and 1 late latency) and 4 inhibitory (1 early, 1 middle and 2 late latency) responses in 7 muscles, and no responses occurred in 8 muscles during LLS (Appendix, Table 12, Fig 13). Additionally, LBF showed only inhibitory (1 middle and 1 late latency) responses in 2 muscles, and no responses occurred in 13 muscles during LLS (Appendix, Table 12, Fig 13).

In the late stance phase with the right leg in front during Task 3 (Walk-RLS), the RTA muscle showed inhibitory (2 middle and 2 late latency) responses in 4 muscles while no response occurred in 10 out of 14 participants (Appendix, Table 13, Fig 14). The LTA only showed 1 excitatory (middle latency) response, while no response occurred in 13 out of 14 participants during RLS (Appendix, Table 13, Fig 14). On the other hand, the antagonist muscle, RGM, showed only excitatory (late latency) responses

in 2 muscles, and no responses occurred in 12 muscles during RLS (Appendix, Table 13, Fig 14). Additionally, LGM showed an inhibitory (middle latency) response only in 1 muscle, and no responses occurred in 13 muscles out of 14 participants during RLS (Appendix, Table 13, Fig 14). The RVL muscle also showed only inhibitory (1 early and 3 late latency) responses to 4 muscles, while no response occurred in 10 out of 14 participants during RMS (Appendix, Table 13, Fig 14). The LVL showed only 3 inhibitory (middle latency) and 5 excitatory (3 early, 1 middle and 1 late latency) responses in 8 muscles, while no response occurred in 6 out of 14 participants during RLS (Appendix, Table 13, Fig 14). On the other hand, the antagonist muscle, RBF, showed only inhibitory (1 middle and 3 late latency) responses in 4 muscles, and no responses occurred in 10 muscles during RLS (Appendix, Table 13, Fig 14). Additionally, LBF showed 4 inhibitory (2 early and 2 middle latency) and 1 excitatory (late latency) responses in 5 muscles, and no responses occurred in 9 muscles (Appendix, Table 13, Fig 14).

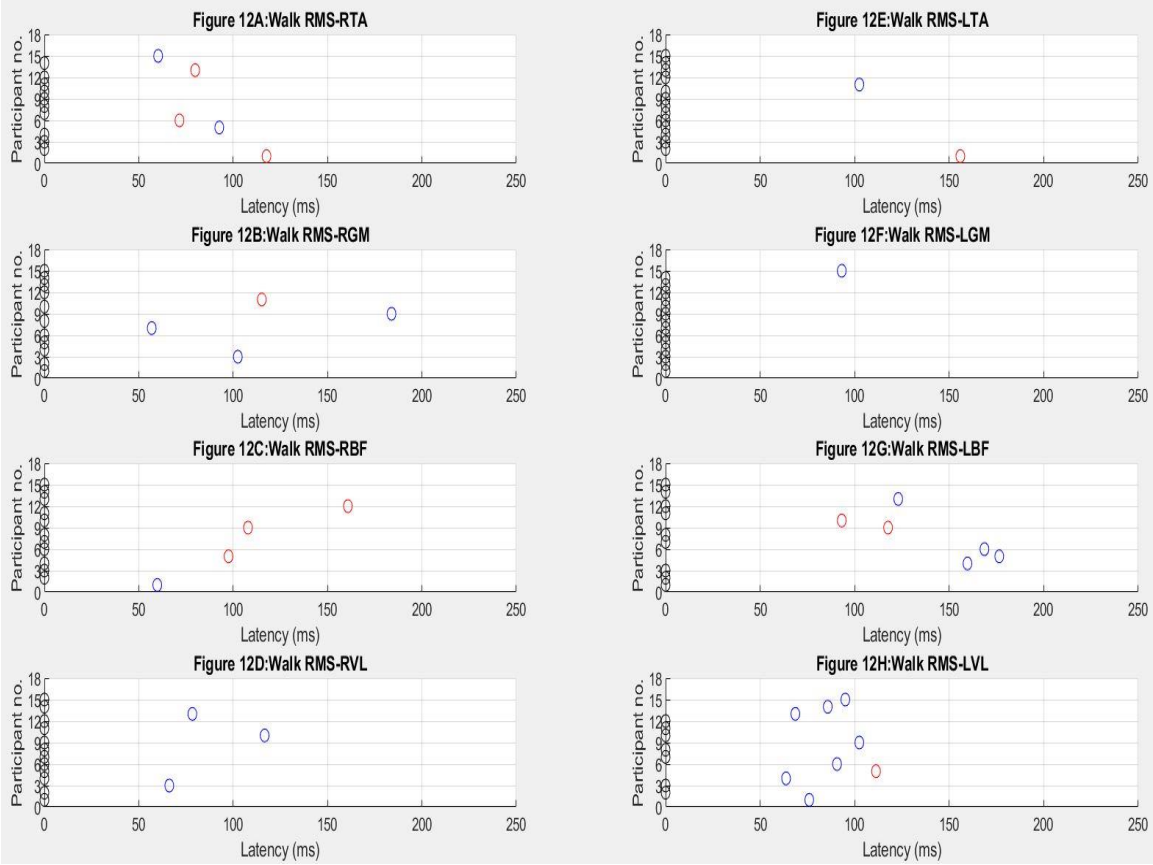

Figure 12: **Interlimb reflex responses observed during the middle of the double leg support stance phase with the right leg in front during walking in Task 3:** the right mid stance phase represents a period of double support stance when about 50% of the body weight is on the right foot with the right leg in front. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This phase was analyzed across 11 participants.

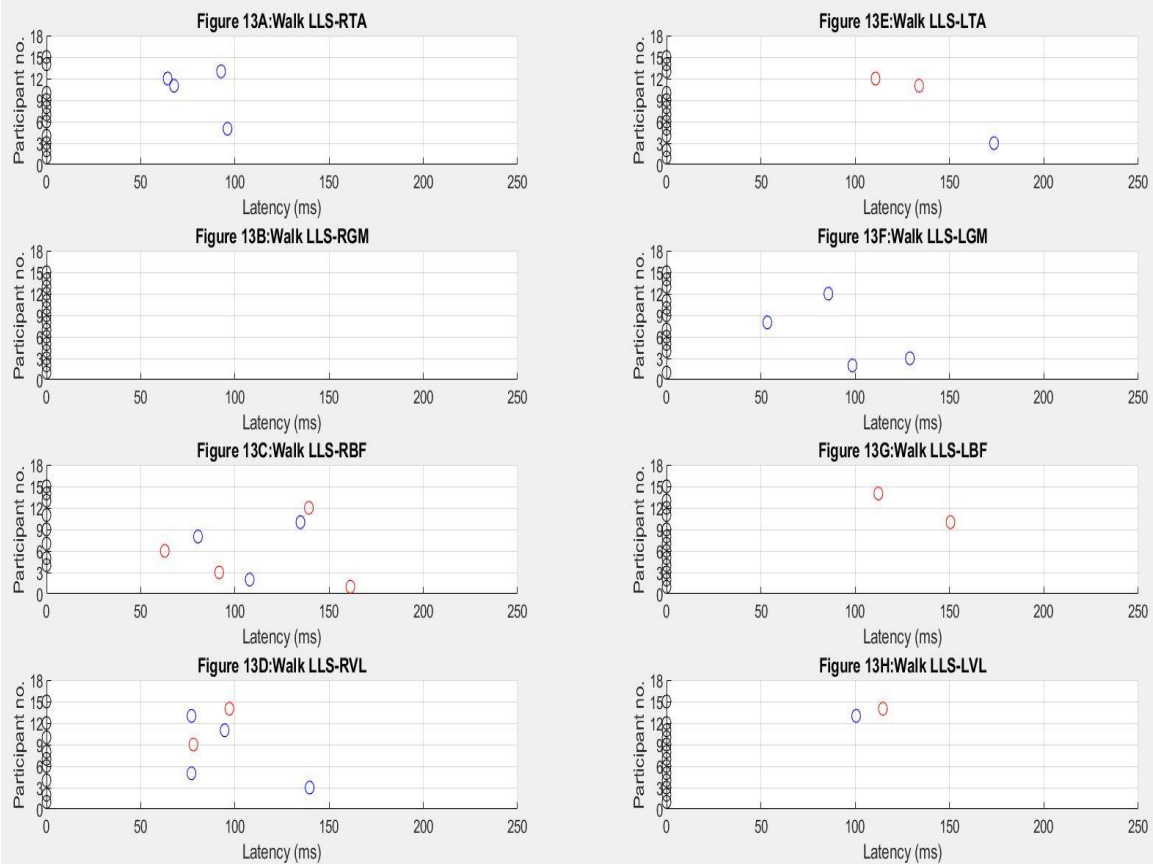

Figure 13: **Interlimb reflex responses observed during late stance double leg support standing posture with the left leg in front during Task 3:** the late stance phase represents 75% of the body weight on the left foot with the left leg in front, mimicking the corresponding step cycle phase. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This phase was analyzed across 11 participants.

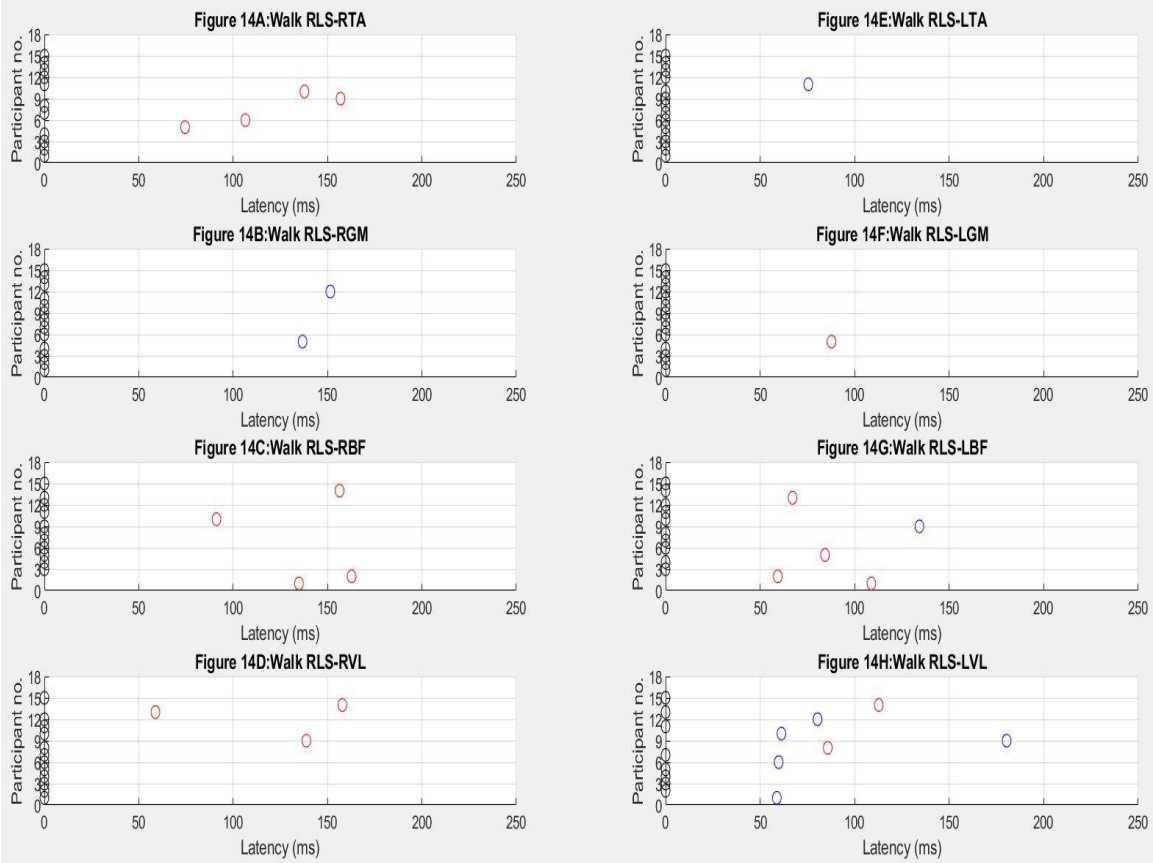

Figure 14: **Interlimb reflex responses observed during the end of the double leg support stance phase with the right leg in front during walking in Task 3:** the right late stance phase represents a period of double support stance when about 75% of the body weight is on the right foot with the right leg in front. Each graph was plotted with participant code numbers on the Y-axis and latency along the X-axis. Red circles in the figure show inhibitory responses and blue circles show excitatory responses. Black circles located on the Y-axis mean the muscle did not show any response in that participant. This phase was analyzed across 11 participants.

Chapter 4: Discussion

This study attempted to address the uncertainty pertaining to the existence of inter-limb reflexes and the characteristics of such reflexes under different postures and conditions. Task 1 required continuous muscle activation with a conscious effort to look at a screen and maintain a focused contractions of 30% MVC of a single selected muscle. Thus this task involved a constant visual stimulus. Similarly, other potential variables were maintained constant such as body posture as well as arm and leg positioning. The only variable was the electrical stimulus received by the participants at a random intervals to elicit a reflex response. Most of the muscles tested in this task showed inhibitory responses, though a few excitatory responses were observed as well. The results obtained from this task were consistent with those of an experiment conducted by Dr. Paul Zehr's group [23]. The evidence from Task 1 confirmed the presence of a reflex neural pathway extending from the upper level to the lower level of spinal cord. Careful examination of the data from Task 1 revealed the possibility of cross-limb coordination of the lower extremities.

The nature of cross-limb coordination involving the upper and lower extremities was examined in Task 2 and Task 3, although Task 2 was primarily used to provide a background level for Task 3. The findings from Task 2 and its differences from the results of Task 3 indicate the possibility that such reflex responses may be position- and/or

context-dependent. This analysis did not include kinematic data from different joints in the body about their position, therefore further detailed investigation is required for that issue.

Walking data from six different phases of the step cycle further indicated the possibility of task dependency of interlimb reflexes. Furthermore, the consistency of the patterns across conditions confirmed the phase-dependent variation of such reflexes. However, to provide the background information and support this claim, kinematic and kinetic data need to be included in future data analysis. The results from Task 2 and Task 3 were again consistent with those Dr. Zehr has reported [25].

The prolonged duration of the data collection sessions in this study raises some concern about the validity of the results. It is possible that fatigue might have affected the results. Perhaps a power spectral analysis should be included in future analyses.

Even with the many reported results, we acknowledge that there was significant conscious effort for the participants in each task. Future research should investigate the extent to which spinal cord and brain activity might affect these results. For now, it appears that spinal interlimb reflexes, control influences from the brain, and various sensory stimuli from the environment, including various forms of feedback, are interrelated and interdependent, as shown in Figure 15.

Although many muscles across all the tasks showed both excitatory and inhibitory responses, it is interesting to note that when these responses are categorized in different epochs of latency, most of the responses were either excitatory or inhibitory only. These

responses showing the consistent results of ipsilateral inhibition or contralateral excitation in some static standing postures and stance phases during walking may indicate the underlying interneuronal connections within the spinal cord. Again, for such conclusions and further discussion it will be crucial to include kinetic and kinematic data as well.

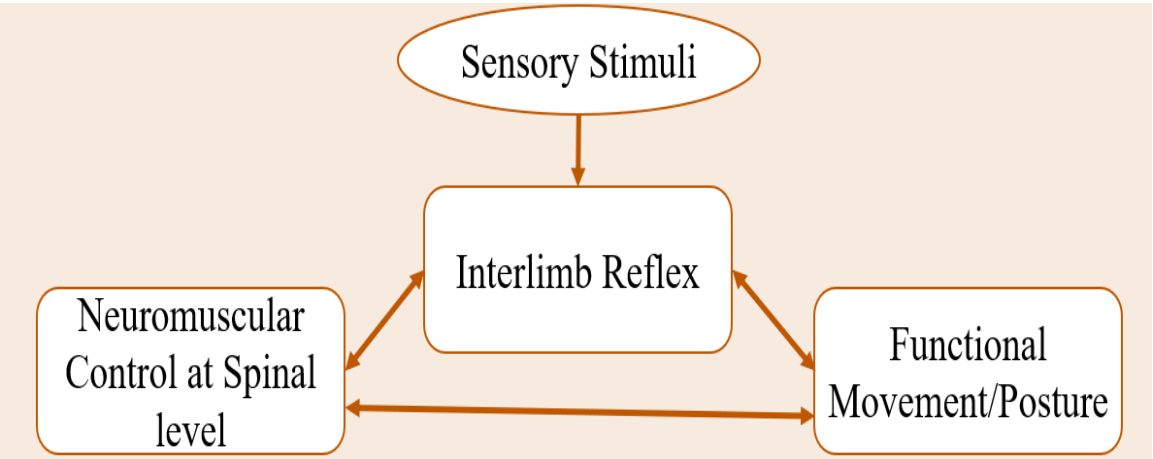

Figure 15: Model for an underlying mechanism in question

This study mainly focused on averaged data across trials and targeted responses to stimulation on one cutaneous nerve. It will also be interesting to compare in the future H-reflex results to this study.

Chapter 5: Conclusions

The results from this study reflected the presence of inter-limb reflex responses in healthy individuals and showed that such responses can be phase-dependent and position-dependent. Some other researchers, like Dr. Zehr, have already provided evidence consistent with these findings. It will be interesting to see how the results of this study and similar future studies lead to a deeper understanding of the inter-dependency of reflex responses based on their latency, as well as to their roles in ongoing voluntary activity.

Appendix

Table 1: Reflex response latency (ms) observed during focused contractions of 30% MVC during Task 1

Participant Code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	No response	No response	No response	No response	No response	No response	219.16	No response
IRP_02	153.96	161.76	145.56	80.86	163.76	168.66	No response	No response
IRP_03	100.46	156.86	101.96	143.66	No response	No response	89.66	148.56
IRP_05	No response	70.06	No response	No response	No response	No response	No response	No response
IRP_06	136.26	202.46	No response	209.76	100.96	173.56	62.26	169.56
IRP_07	144.16	No response	115.16	No response	No response	No response	No response	125.46
IRP_09	109.76	No response	143.66	133.36	70.56	186.76	No response	No response
IRP_10	58.86	No response	85.76	135.76	186.76	181.86	62.26	65.16

IRP_12	153.46	No response	184.76	71.56	168.66	180.36	159.76	74.96
IRP_13	No response	109.26	No response	No response	124.06	No response	102.96	No response
IRP_15	No response	84.76	133.36	No response	No response	135.76	162.76	75.96
IRP_16	80.86	No response	No data	No response	No response	No response	No response	No response
IRP_17	160.26	No response	89.66	89.26	85.26	No response	74.96	145.06
IRP_18	180.36	No response	No response	116.16	No response	80.86	No response	160.76
IRP_19	No response	No response	64.66	141.16	155.36	62.76	No response	59.26
IRP_20	163.76	72.56	131.36	91.16	86.76	No response	147.56	149.46

Table 2: Reflex response latency (ms) observed in Left Early Stance standing posture during Task 2

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	No response	No response	No response	No response	No response	135.78	144.606	No response
IRP_02	No response	No response	122.05	No response	No response	159.309	No response	156.36
IRP_03	No response	No response	264.26	141.66	171.56	No response	262.76	180.86
IRP_06	89.70	No response	No response	No response	No response	116.66	107.86	No response
IRP_07	62.74	No response	No response	168.13	154.41	73.035	No response	142.64
IRP_09	60.78	83.56	113.72	91.66	95.09	No response	92.64	No response

IRP_10	67.64	87.25	No response	130.88	No response	No response	No response	107.35
IRP_11	128.96	191.16	No response	85.26	165.66	No response	No response	61.26
IRP_17	160.26	110.289	No response	94.113	66.662	63.721	No response	87.25
IRP_18	180.36	68.66	No response	No response	177.46	66.16	No response	89.26
IRP_20	163.76	156.86	136.26	148.56	121.06	76.96	No response	167.16

Table 3: Reflex response latency (ms) observed in Right Early Stance standing posture during Task 2

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	No response	No response	No response	No response	176.466	69.113	No response	169.603
IRP_02	No response	84.76	72.54	153.427	No response	140.682	No response	No response
IRP_03	160.26	No response	No response	No response	230.86	No response	79.86	No response
IRP_06	175.48	174.99	72.54	107.36	No response	143.623	No response	No response
IRP_07	164.21	134.8	No response	151.96	149.51	73.995	No response	No response
IRP_09	96.074	No response	66.16	104.46	No response	61.76	69.6	112.74
IRP_10	No response	No response	No response	No response	144.6	No response	112.25	149.02
IRP_11	119.56	No response	76.46	149.96	188.76	163.26	No response	No response

IRP_17	No response	134.85	90.191	163.721	78.427	166.172	61.27	84.309
IRP_18	162.26	No response	No response	No response	No response	No response	No response	185.26
IRP_20	88.26	61.76	115.16	No response	113.76	92.16	127.46	No response

Table 4: Reflex response latency (ms) observed in Left Mid Stance standing posture during Task 2

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	165.682	No response	No response	83.33	No response	112.25	No response	No response
IRP_03	188.76	No response	105.36	177.46	No response	135.76	79.86	141.16
IRP_04	No response	No response	No response	No response	No response	No response	No response	No response
IRP_06	79.51	79.51	No response	123.06	No response	No response	88.72	159.8
IRP_07	No response	158.82	79.9	No response	No response	No response	113.72	No response
IRP_09	122.06	No response	No response	No response	No response	103.92	No response	162.25
IRP_11	90.16	136.76	No response	116.66	135.26	149.96	144.16	118.16
IRP_12	146.56	153.96	170.56	156.36	No response	59.46	192.66	No response
IRP_13	72.06	No response	75.46	No response	63.26	115.16	No response	121.06

IRP_15	No response	No response	No response	No response	99.46	No response	No response	176.46
IRP_17	No response	No response	No response	112.25	142.152	No response	No response	73.525
IRP_18	No response	131.36	105.36	144.56	No response	148.06	No response	131.86
IRP_20	137.76	169.16	114.66	107.36	163.26	90.66	No response	161.76

Table 5: Reflex response latency (ms) observed in Right Mid Stance standing posture during Task 2

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	91.172	No response	126.956	No response	105.387	No response	99.995	No response
IRP_03	67.66	87.26	No response	201.96	86.26	101.96	135.26	105.36
IRP_04	96.07	156.86	158.86	126.96	66.16	163.23	80.878	No response
IRP_06	144.11	No response	No response	No response	177.45	86.27	135.78	144.11
IRP_07	215.16	No response	No response	No response	169.56	234.3	No response	89.26
IRP_09	No response	No response	No response	133.36	71.56	No response	142.64	No response
IRP_11	104.36	151.46	No response	No response	No response	74.46	No response	No response
IRP_12	No response	No response	108.36	93.66	171.06	172.06	No response	119.56
IRP_13	156.36	No response	No response	169.16	No response	No response	No response	No response

IRP_15	89.26	68.66	174.96	98.56	No response	137.76	81.86	199.46
IRP_17	110.78	100.976	No response	98.525	184.799	128.427	No response	No response
IRP_18	105.36	No response	172.56	-88.24	No response	185.76	No response	170.56
IRP_20	No response	No response	No response	74.06	No response	64.26	No response	120.56

Table 6 : Reflex response latency (ms) observed in Left Late Stance standing posture during Task 2

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	No response	No response	No response	NA	174.015	56.86	No response	No response
IRP_02	90.19	56.368	NA	NA	69.603	150.976	No response	No response
IRP_03	-88.24	184.76	174.46	No response	-88.24	104.36	No response	85.26
IRP_06	69.11	NA	81.86	No response	173.04	79.9	60.29	No response
IRP_07	NA	NA	174.51	No response	72.54	151.96	No response	No response
IRP_10	78.46	No response	NA	No response	87.74	76.96	187.74	59.8
IRP_12	-88.24	168.66	197.06	160.26	206.86	207.36	198.06	20.26
IRP_13	154.36	196.56	-88.24	179.36	112.26	136.26	78.46	215.66
IRP_15	187.26	-88.24	-88.24	102.96	-88.24	116.66	109.26	-88.24

IRP_17	121.077	71.074	146.074	95.584	68.133	170.093	No response	122.544

Table 7: Reflex response latency (ms) observed in Right Late Stance standing posture during Task 2

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	No response	No response	No response	71.074	No response	No response	151.956	73.525
IRP_02	165.19	No response	145.56	53.92	85.78	No response	No response	58.33
IRP_03	188.26	225.96	101.96	78.46	130.86	128.46	183.36	175.96
IRP_06	No response	62.74	No response	125.49	85.78	110.38	74.51	131.86
IRP_07	158.33	157.35	No response	79.41	No response	153.92	No response	81.86
IRP_10	146.56	No response	No response	170.09	No response	270.1	187.74	97.54
IRP_12	161.26	161.26	155.86	159.76	169.16	No response	No response	98.56
IRP_13	No response	99.46	103.96	No response	No response	No response	No response	No response
IRP_15	77.96	No response	142.16	91.16	78.96	59.76	No response	64.26
IRP_17	No response	No response	124.015	No response	No response	No response	No response	No response

Table 8: Reflex response latency (ms) observed in Left Early Stance during walking in Task 3

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	174.995	No Response	152.819	No Response	No Response	No Response	130.878	No Response
IRP_02	No Response	No Response	109.79	90.66	61.76	No Response	96.074	No Response
IRP_03	No Response	No Response	78.96	65.66	No Response	No Response	82.86	No Response
IRP_04	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_06	105.39	No Response	No Response	109.81	59.8	79.41	169.6	No Response
IRP_07	No Response	No Response	No Response	89.66	No Response	99.06	No Response	No Response
IRP_09	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_10	No Response	No Response	138.32	59.31	No Response	No Response	No Response	No Response

IRP_11	82.86	No Response	118.66	No Response	No Response	95.56	No Response	No Response
IRP_12	No Response	No Response	81.36	No Response	74.46	No Response	91.16	No Response
IRP_13	No Response	No Response	No Response	No Response	No Response	133.36	No Response	No Response
IRP_15	101.96	No Response	134.76	79.36	150.46	115.66	No Response	No Response
IRP_17	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_18	No Response	No Response	87.76	209.26	No Response	No Response	75.96	No Response
IRP_20	101.96	107.86	No Response	84.76	82.36	No Response	103.46	No Response

Table 9 : Reflex response latency (ms) observed in Right Early Stance during walking in Task 3

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	101.466	No Response	No Response	No Response	No Response	No Response	61.27	77.936
IRP_02	95.56	129.41	72.544	83.82	No Response	No Response	109.31	84.31

IRP_03	No Response	No Response	No Response	No Response	87.26	No Response	121.56	181.86
IRP_04	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_06	63.23	No Response	No Response	88.72	No Response	No Response	No Response	No Response
IRP_07	65.19	No Response	No Response	No Response	No Response	No Response	79.9	146.56
IRP_09	94.11	67.15	No Response	No Response	No Response	No Response	82.84	No Response
IRP_10	83.82	124.51	No Response	76.96	No Response	No Response	103.43	No Response
IRP_11	No Response	119.16	No Response	73.56	No Response	No Response	115.66	No Response
IRP_12	131.86	No Response	No Response	70.56	107.36	No Response	146.36	119.16
IRP_13	100.96	No Response	No Response	No Response	No Response	No Response	No Response	159.26
IRP_15	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_17	64.211	124.01	No Response	No Response	No Response	No Response	123.035	98.525
IRP_18	No Response	80.86	No Response	No Response	No Response	No Response	No Response	90.16
IRP_20	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response

Table 10: Reflex response latency (ms) observed in Left Mid Stance during walking in Task 3

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	No Response	No Response	70.093	No Response	57.838	No Response	85.76	No Response
IRP_02	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_03	No Response	No Response	122.06	128.46	No Response	No Response	78.46	86.26
IRP_04	35.78	No Response	62.25	No Response	148.06	No Response	No Response	No Response
IRP_06	147.99	No Response	62.25	No Response	57.84	No Response	No Response	No Response
IRP_07	No Response	No Response	153.92	No Response	No Response	81.46	No Response	No Response
IRP_09	106.86	No Response	No Response	131.36	No Response	85.29	No Response	No Response
IRP_10	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response

IRP_11	No Response	No Response	No Response	117.16	No Response	No Response	No Response	124.46
IRP_12	No Response	No Response	111.76	No Response	No Response	No Response	186.26	177.46
IRP_13	76.46	No Response	79.86	148.06	No Response	No Response	No Response	No Response
IRP_15	No Response	No Response	71.56	82.86	No Response	110.76	No Response	94.16
IRP_17	69.113	No Response	89.211	155.39	99.505	No Response	No Response	No Response
IRP_18	No Response	No Response	169.56	70.56	No Response	74.46	112.76	No Response
IRP_20	No Response	No Response	No Response	116.16	55.86	No Response	87.76	71.06

Table 11: Reflex response latency (ms) observed in Right Mid Stance during walking in Task 3

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	117.66	No Response	59.799	No Response	155.878	No Response	No Response	75.976
IRP_02	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response

IRP_03	No Response	102.46	No Response	66.16	No Response	No Response	No Response	No Response
IRP_04	No Response	No Response	No Response	No Response	No Response	No Response	159.66	63.72
IRP_06	92.64	No Response	97.544	No Response	No Response	No Response	176.46	111.27
IRP_07	71.56	No Response	No Response	No Response	No Response	No Response	168.62	90.66
IRP_09	No Response	56.86	No Response	No Response	No Response	No Response	No Response	No Response
IRP_10	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_11	No Response	183.86	107.86	No Response	No Response	No Response	117.66	102.46
IRP_12	No Response	No Response	No Response	116.66	No Response	No Response	93.16	No Response
IRP_13	No Response	115.16	No Response	No Response	102.46	No Response	93.16	No Response
IRP_15	No Response	78.46	160.76	No Response	No Response	No Response	No Response	No Response
IRP_17	79.897	No Response	No Response	78.387	No Response	No Response	123.035	68.623
IRP_18	No Response	No Response	No Response	No Response	No Response	No Response	No Response	85.76
IRP_20	60.26	No Response	No Response	No Response	No Response	93.16	No Response	95.06

Table 12: Reflex response latency (ms) observed in Left Late Stance during walking in Task 3

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	No Response	No Response	161.27	No Response	No Response	No Response	No Response	No Response
IRP_02	No Response	No Response	107.838	No Response	No Response	98.53	No Response	No Response
IRP_03	No Response	No Response	91.66	139.66	173.56	128.96	No Response	No Response
IRP_04	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_06	96.074	No Response	No Response	76.956	No Response	No Response	No Response	No Response
IRP_07	No Response	No Response	62.76	No Response	No Response	No Response	No Response	No Response
IRP_09	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_10	No Response	No Response	80.39	No Response	No Response	53.43	No Response	No Response
IRP_11	No Response	No Response	No Response	77.96	No Response	No Response	No Response	No Response

IRP_12	No Response	No Response	134.76	No Response	No Response	No Response	150.46	No Response
IRP_13	67.66	No Response	No Response	94.56	133.86	No Response	No Response	No Response
IRP_15	64.26	No Response	139.26	No Response	110.76	85.76	No Response	No Response
IRP_17	92.642	No Response	No Response	76.956	No Response	No Response	No Response	100.485
IRP_18	No Response	No Response	No Response	97.06	No Response	No Response	112.26	114.66
IRP_20	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response

Table 13: Reflex response latency (ms) observed in Right Late Stance during walking in Task 3

Participant code No	Latency							
	Right side muscles				Left side muscles			
	TA	GM	BF	VL	TA	GM	BF	VL
IRP_01	No Response	No Response	134.85	No Response	No Response	No Response	108.819	58.819
IRP_02	No Response	No Response	162.74	No Response	No Response	No Response	59.31	No Response
IRP_03	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response

IRP_04	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_06	74.51	136.76	No Response	No Response	No Response	87.74	84.31	No Response
IRP_07	106.46	No Response	No Response	No Response	No Response	No Response	No Response	59.799
IRP_09	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response
IRP_10	No Response	No Response	No Response	No Response	No Response	No Response	No Response	85.76
IRP_11	156.86	No Response	No Response	138.76	No Response	No Response	134.26	180.36
IRP_12	137.76	No Response	91.16	No Response	No Response	No Response	No Response	61.26
IRP_13	No Response	No Response	No Response	No Response	75.46	No Response	No Response	No Response
IRP_15	No Response	151.46	No Response	No Response	No Response	No Response	No Response	80.36
IRP_17	No Response	No Response	No Response	58.82	No Response	No Response	67.152	No Response
IRP_18	No Response	No Response	156.36	157.86	No Response	No Response	No Response	112.76
IRP_20	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response

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