Int J Physiol Pathophysiol Pharmacol 2025;17(2):52-60
www.ijppp.org /ISSN:1944-8171/IJPPP0163645

Original Article

Evaluation of self-reported dominance in upper and lower limbs and its relationship with fatigue onset in dominant limbs using surface electromyography (sEMG) in young adults

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Received January 31, 2025; Accepted April 19, 2025; Epub April 25, 2025; Published April 30, 2025

Abstract: Background: “Laterality”, or “lateral preference” indicates how differently or rather ‘differentially’ one tends to use a pair of sense organs or limbs. The most widely studied aspect of laterality is handedness. However, research on footedness has not received the same level of attention. Previous studies primarily relied on questionnaires to determine limb dominance, which may not provide the most accurate assessments. The present study aims to generate reliable objective data regarding both upper and lower limb dominance by analyzing surface electromyography (sEMG) parameters. Additionally, it seeks to correlate these findings with perceived limb dominance as indicated by questionnaire responses. Methods and material: It was a cross-sectional observational study. The physiological parameters were recorded in the Clinical Physiology Laboratory. 20 male, healthy participants of 19-20 years participated in the study voluntarily. After recording of their demographic data, the study participants were assessed twice to ascertain the dominance of both upper and lower limbs. At first, they responded to the study questionnaires to report self-determined dominance of upper and lower limbs. Following this, the performance of both upper and lower limbs was evaluated by recording of surface EMG of specific muscles of the limbs at rest and during sustained contraction using a pre-defined load till the onset of fatigue. On the basis of normality test, the data were expressed as median with interquartile range. Wilcoxon signed rank test was performed to compare the parameters of sEMG. SPSS software version 20.0 (IBM Inc., USA) was used to analyse the data. A two-tailed *P* value less than 0.05 was taken as the cut-off level of significance. Results: Based on questionnaire analysis, out of 20 participants, one was left-handed and the rest were right-handed. Six participants were found to use both legs and the rest were right leg dominant. Following analysis, no significant difference between the parameters of surface EMG (sEMG) of the corresponding muscles of the two upper and lower limbs was found. Even no significant difference between the time to set fatigue in right and left upper and lower limbs was observed. Conclusions: The result of the present study indicates that the dominant and the non-dominant limbs have attained differences in such a manner that it has not affected their performances significantly. However, their different, though sometimes overlapping aspects of motion and movements is helpful for the performance of a given task.

Keywords: Limb dominance, surface electromyography, sustained contraction, fatigue

Introduction

“Laterality”, or “lateral preference” is a broad term that gives us information regarding how differently or rather ‘differentially’ one tends to use a pair of sense organs (eyes, ears, etc.) or limbs (hands or feet). This differential use of any organ is often called ‘asymmetrical use’ in various studies [1, 2]. The most widely studied of them is the preference for hand - right or left, known as ‘Handedness’. The handedness of an individual has been under study since time immemorial. Studies demonstrated, how fetal movements and preferences, especially thumb sucking and mouth movements are reflected in the handedness, later in life [3, 4]. However, laterality, especially handedness is not constant throughout life. This ‘shift’ in handedness occurs when an individual loses the dominant hand and achieves similar functioning of the

https://doi.org/10.62347/JYBH8642

non-dominant hand through practice [4]. However, the study found that though the practice plays a significant role, it is not the sole factor in the formation and consolidation of neural asymmetries [5]. More type I muscle fibers were found in the dominant arm of extensor carpi radialis brevis muscles [6]. Furthermore, lateralization of complicated tasks tends to develop later in life, mostly during the growing years [7].

Studies found that there was little or no role of lower limb dominance at least in regulating posture and gait [8, 9]. A previous study analysed the plantar pressure and postural balance in both static and dynamic conditions in healthy population. But there was no significant difference was found based on limb dominance in plantar pressure and postural balance in the subjects [10]. It was further reported that perceived lower limb dominance was not able to predict the performance of lower limbs in performing certain tasks [11]. Moreover, it was documented that handedness follows footedness in right-handers, but not in left-handers [12]. However, previous study reported the role of both lower limbs in controlling posture and gait and pointed towards functional differences between the lower limbs [13]. Even it was reported that the dominant leg in 93% of the healthy adult subjects had more volume (by an average 349 mL more) than that of the non-dominant one [14]. Moreover, a recent study documented higher muscle activation in non-dominant limbs during movement phases, which also depends on the test's choice (whether isokinetic or isotonic). It finally affects performance outcome [15]. Despite these recent advancements, the determination of footedness is still lacking the same level of enthusiasm and research as that of handedness. Moreover, previous studies relied only on questionnaires like Edinburgh Handedness test, to determine the dominant/preferred limb [16].

Studies in Sports Medicine found pronounced asymmetry in the upper limbs regarding side-to-side phase angle (PhA) value in elite tennis players [17]. The study conducted on patients suffering from Anterior cruciate ligament tear (ACL), found that there are more chances of the dominant leg to regain maximal function than the non-dominant one (maximal kinetic knee extensor strength) [18]. Studies like these, which try to find a relation between limb dominance and injury rehabilitation, could be of use to clinicians in treating patients/athletes.

The studies that were conducted to relate subjective and objective data to find out limb dominance, usually relied on a combination of questionnaires and performance-based tests [11]. These performance-based tasks are generally biased in choosing the limb for a given task. Therefore, surface electromyography (sEMG) is an optimal technique for the comparison of subjective and objective data related to limb dominance. Moreover, sEMG was used previously to determine the onset of fatigue in hands and legs [19-23]. The data obtained from sEMG would therefore supplement and re-confirm the subjective appreciation of the onset of fatigue in the given limb. Previous studies employed the protocol of repeated voluntary contractions to ascertain the onset of fatigue in the upper limbs [24-27]. In this instance, hand dominance might affect the result [23, 24]. Therefore, it would be better if sustained contractions, in individual muscle groups were taken into account as in a previous study [28]. Therefore, the present study has tried to improve upon the previous ones, firstly by generating reliable objective data from surface EMG (sEMG) parameters and correlating with the questionnaire results. The present study also intended to determine the onset of fatigue on the basis of sEMG parameters objectively to ascertain the dominance limb.

Materials and methods

It was a cross-sectional observational study. The study was approved by the Institutional Ethics. The study was approved by the Institute Ethics Committee, AIIMS, Bhubaneswar, and was was in accordance with the Helsinki Declaration of 1975, as revised in 2000.

Committee, AIIMS, Bhubaneswar, and was in accordance with the Helsinki Declaration of 1975, as revised in 2000. 20 male, healthy participants irrespective of practicing the sports, of the age group of 19-20 years participated in the study voluntarily. The participants have fulfilled the inclusion and exclusion criteria laid down for the study. The study participants were comprised of young adults who practiced sports/did not practice sports with

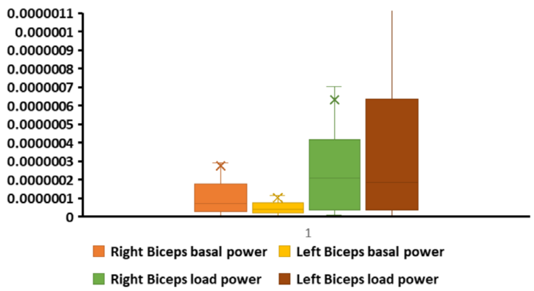

Figure 1. Comparison of basal power and load mean peak power (mV^2/Hz) of the right and left biceps muscles.

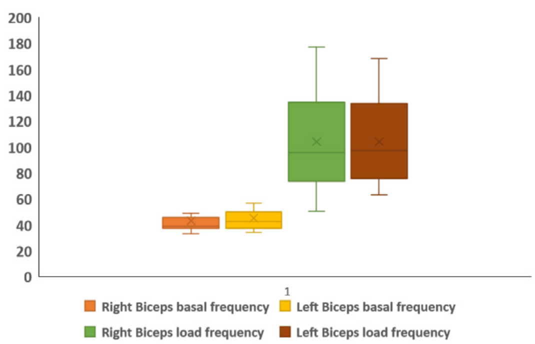

Figure 2. Comparison of mean peak frequency (in Hz) at basal (resting condition) and mean peak frequency (in Hz) while lifting a defined weight of the right and left biceps muscles.

no history of nerve and muscle injury of the recent past, orthopedic surgery, any systemic illness and medication which could affect the performance of muscles. The study was conducted in Clinical Physiology Laboratory of the Department of Physiology. After obtaining their written consent, demographic details of them were recorded in the designated data collection form. Their anthropometric measurements such as height, weight, and BMI were recorded. The study participants were assessed twice for their limb dominance. At first, they responded to the questionnaire to report self-determined dominant side and then they were assessed for the performance of both upper and lower limbs during sustained muscle contraction and at the onset of fatigue by sEMG.

Assessment of self-reported limb dominance using questionnaires

The Edinburgh handedness test: The 4-item Edinburgh handedness inventory-short form was used in the present study instead of the original 10 item questionnaire, which had fulfilled all of the fit tests and indices such as relevance and reliability [28]. The responses were marked as "always right", "usually right", "both equally", "usually left", and "always left", with scores assigned to them as +100, +50, 0, -50, -100, respectively. To calculate the laterality, individual scores from all the items were summed up and divided by four. A total score between +61 to +100 indicated right handedness; between +60 to -60 indicated mixed handedness (ambidexterity); and that between -61 to -100 indicated left handedness.

The Waterloo footedness questionnaire: The Waterloo footedness questionnaire-Revised consisting of 21-item questions was used in the present study as it can reliably assess both foot preference for stabilizing and mobilizing tasks as reported by the previous study [29]. For each item in the questionnaire, two responses were provided, indicating the foot preference, as "right" or "left". If the subject was comfortable doing the given task with both legs equally, then he/she was instructed to tick both responses. For each "right" leg a score of +1 was awarded, and for each "left" leg, a response of a score of "-1" was awarded. At the end, individual scores were calculated for each leg. Scores of both legs were summed up and analyzed. For a net score between +13 to +7, the individual was assigned as 'right footed'; a score between +6 to -6 indicated 'mixed footedness'; a score between -7 to -13 indicated 'left footedness'.

Recording of sEMG to determine the onset of fatigue in upper and lower limb muscles: The performance of both limbs of the subjects was evaluated objectively by recording sEMG of specific muscles of both upper and lower limbs. For upper limbs, sEMG of biceps brachii and brachioradialis simultaneously were recorded at resting condition as well as during sustained contraction using a load of 4.5 kg till the onset of fatigue. For lower limbs, sEMG of quadriceps and tibialis anterior were recorded simultaneously in similar conditions using a load of 4 kg during sustained contraction. The subject was asked to sit on the chair. Following proper cleansing, the three surface electrodes i.e., active and reference electrodes were

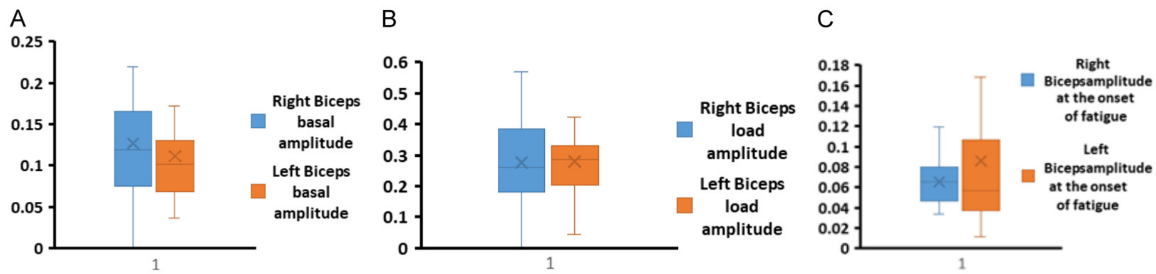

Figure 3. Comparison of mean peak amplitude (mV) of Biceps muscles on both sides. A. Compares mean peak amplitude (mV) of right and left biceps at rest. B. Presents the comparison of mean peak amplitude (mV) of right and left biceps while lifting a defined weight. C. Illustrates the comparison of mean peak amplitude (mV) of right and left biceps at the onset of fatigue.

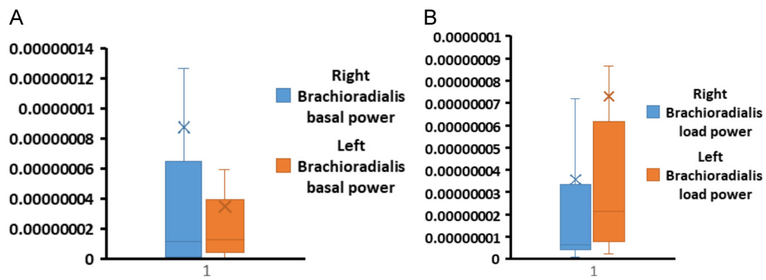

Figure 4. Illustrates the comparison of mean peak power (mv^2/Hz) of the brachioradialis muscle on both sides. In (A), the mean peak power (mv^2/Hz) of the right and left brachioradialis is compared at a basal state. (B) Shows the comparison of mean peak power (mv^2/Hz) of the right and left brachioradialis while lifting a defined weight.

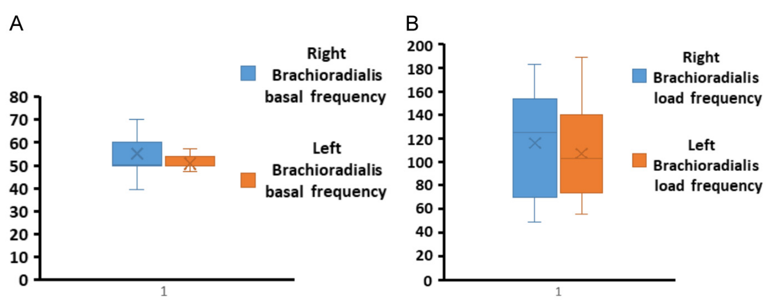

Figure 5. Comparison of mean peak frequency (Hz) of Brachioradialis Muscles on Both Sides. (A) Shows the comparison of mean peak frequency (Hz) of the right and left brachioradialis muscles at rest, while (B) illustrates the comparison of the mean peak frequency (Hz) of the right and left brachioradialis muscles when lifting a defined weight.

placed on the designated muscle belly, and ground electrode was placed on nearby bony prominence (for upper limb, olecranon process, and for lower limb, on patella) and the wires were connected to digital acquisition system through jack box (MP36RWSW/WS, Biopac Systems Inc., Goleta, CA, USA). To record hand performance, the subject was asked to extend his arm to shoulder height with his palm facing upwards. The basal sEMG was recorded for 2 min. Immediately after 2 min, a weight of 4.5 kg was hung with the help of a cotton sling, a little ahead of elbow joint. The sEMG was recorded during sustained contraction till the time the subject can hold the weight. Along with it, the time was also noted to mark the onset of fatigue subjectively. For recording the leg strength/performance, the subject was asked to extend the leg horizontally, making a straight horizontal line. Then the basal sEMG was recorded for 2 min. Following this, a weight of 4 kg was hung with the help of a cotton sling just ahead of knee joint. The sEMG was recorded during sustained contraction till the time the subject can hold the weight. Along with it, the time was also noted to mark the onset of fatigue subjectively. The recording of sEMG was done using 10-500 Hz filter at a sampling rate of 2 kHz (2000 Hz).

After the collection of data, it was analysed with the help of Acknowledge software (Biopac Systems Inc., Goleta, CA, USA). The EMG signals were computed over 1-s, non-overlapping epochs. The power spectral density was estimated with Hanning windowing to obtain mean peak power, mean peak frequency. The data were further analysed for derived root mean square to obtain mean peak amplitude of muscle contraction at basal, during sustained con-

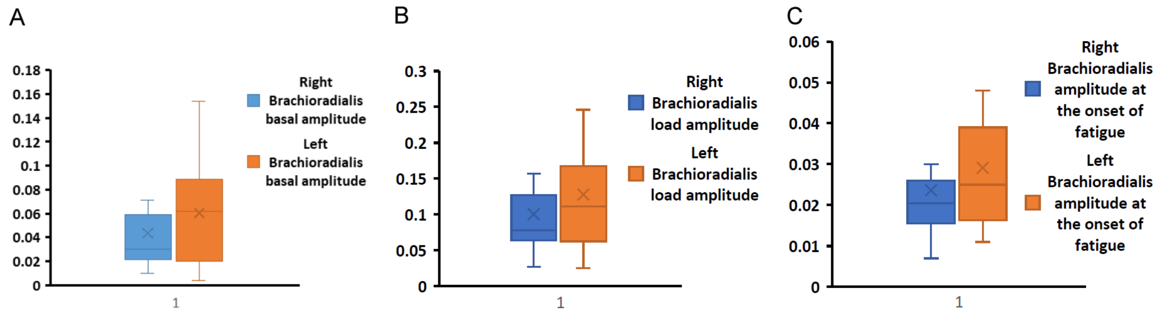

Figure 6. Compares mean peak amplitude (mV) of brachioradialis muscle on both sides. A. Compares mean peak amplitude (mV) of right and left brachioradialis at the basal state. B. Compares mean peak amplitude (mV) of the right and left brachioradialis while lifting a defined weight. C. Illustrates the comparison of mean peak amplitude (mV) of right and left brachioradialis at the onset of fatigue.

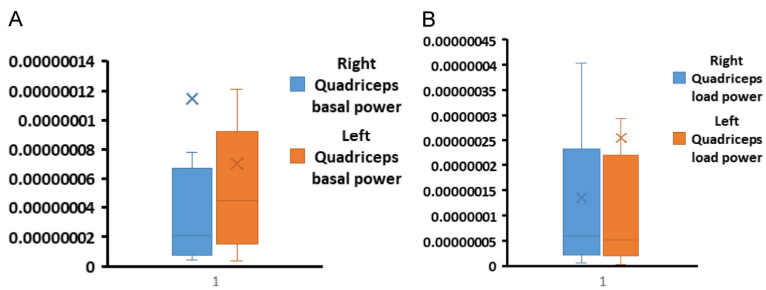

Figure 7. Illustrates the comparison of mean peak power (mv^2/Hz) of quadriceps muscle on both sides. In (A), the mean peak power (mv^2/Hz) of right and left quadriceps is compared at a basal state. (B) Shows the comparison of mean peak power (mv^2/Hz) of right and left quadriceps while lifting a defined weight.

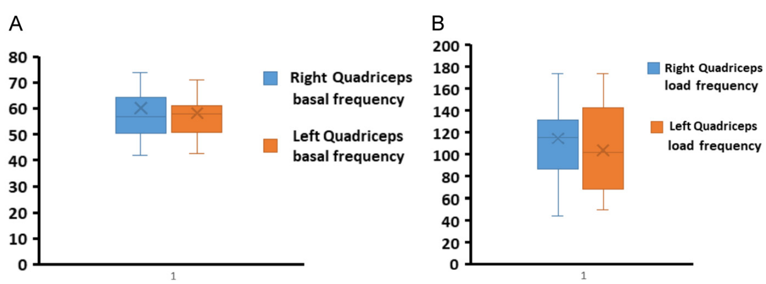

Figure 8. Comparison of mean peak frequency (Hz) of quadriceps muscles on Both Sides. (A) Shows the comparison of mean peak frequency (Hz) of the right and left quadriceps muscles at rest, while (B) illustrates the comparison of the mean peak frequency (Hz) of the right and left quadriceps muscles when lifting a defined weight.

traction and at the onset of fatigue while lifting the weight. During this analysis, the data were divided into 300 ms, non-overlapping epochs.

Statistics

Descriptive analysis was done for all parameters. Normality test was done and the data were found to be non-normally distributed. The data were expressed as median with interquartile range. Wilcoxon signed-rank test was performed to compare the parameters of sEMG of right and left upper and lower limb muscles. The statistical tests were applied with the help of SPSS version 20.0 (IBM Inc., USA). A two-tailed *P* value less than 0.05 was taken as the cut-off level of significance.

Results

20 subjects of 19-20-year-age group participated in the present study. All participants were male. Out of 20 study participants, one was found to be left-handed and the rest were found to be right-handed based on the analysis of Edinberg handedness inventory. Six participants were found to use both legs and the rest were found to be right-leg dominant on the basis of analysis of Waterloo footedness questionnaire.

Analysis of parameters of sEMG of upper limbs at basal (rest), loaded (during sustained contraction while lifting the load) and at the onset of fatigue

The comparisons between the parameters of sEMG of corresponding muscles (biceps and brachioradialis) were analysed. The **Figures 1-6** displayed the comparison of the parameters of

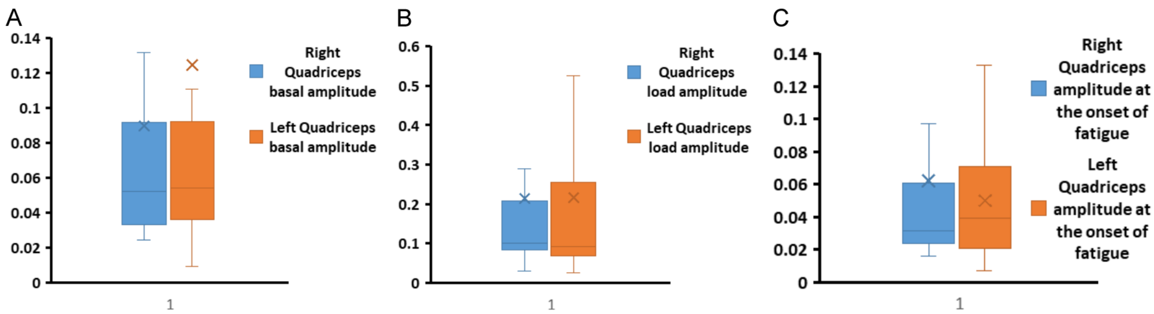

Figure 9. Compares mean peak amplitude (mV) of quadriceps muscle on both sides. A. Compares mean peak amplitude (mV) of right and left quadriceps at the basal state. B. Compares mean peak amplitude (mV) of the right and left quadriceps while lifting a defined weight. C. Illustrates the comparison of mean peak amplitude (mV) of right and left quadriceps at the onset of fatigue.

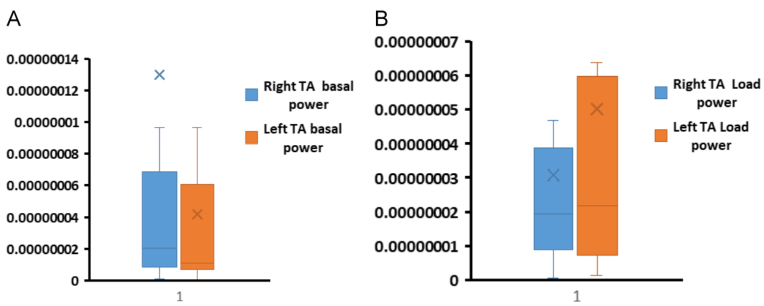

Figure 10. Illustrates the comparison of mean peak power (mv^2/Hz) of tibialis anterior muscle on both sides. In (A), mean peak power (mv^2/Hz) of right and left tibialis anterior is compared at a basal state. (B) Shows the comparison of mean peak power (mv^2/Hz) of right and left tibialis anterior while lifting a defined weight.

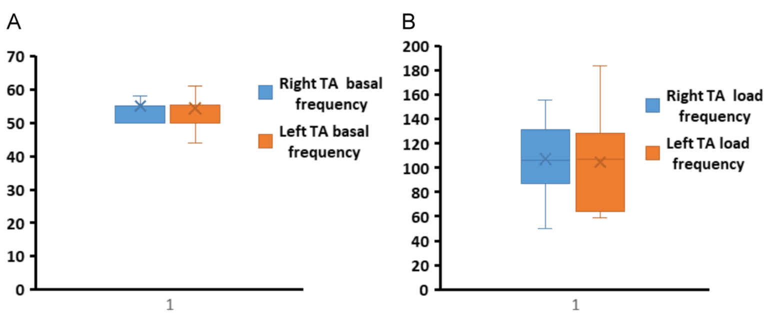

Figure 11. Comparison of mean peak frequency (Hz) of tibialis anterior muscles on both sides. (A) Shows the comparison of mean peak frequency (Hz) of the right and left tibialis anterior muscles at rest, while (B) illustrates the comparison of the mean peak frequency (Hz) of the right and left tibialis anterior muscles when lifting a defined weight.

sEMG of biceps and brachioradialis muscles between two upper limbs. There was no significant difference between the parameters of sEMG of the corresponding muscles of the two upper limbs.

Analysis of parameters of sEMG of both lower limbs at basal (rest), loaded (during sustained contraction while lifting the load) and at the onset of fatigue

The comparison between the parameters of sEMG of corresponding muscles (quadriceps and tibialis anterior) between two lower limbs was analysed. The **Figures 7-12** displayed the comparison of the parameters of sEMG of quadriceps and tibialis anterior muscles between two lower limbs. There was no significant difference between the parameters of sEMG of the corresponding muscles of the two lower limbs.

Analysis of the time to set fatigue in upper and lower limb

Figure 13 displays the comparison of the time to set fatigue in right and left upper limbs and lower limbs respectively. There was no significant difference between the time to set fatigue in right and left upper limbs and lower limbs.

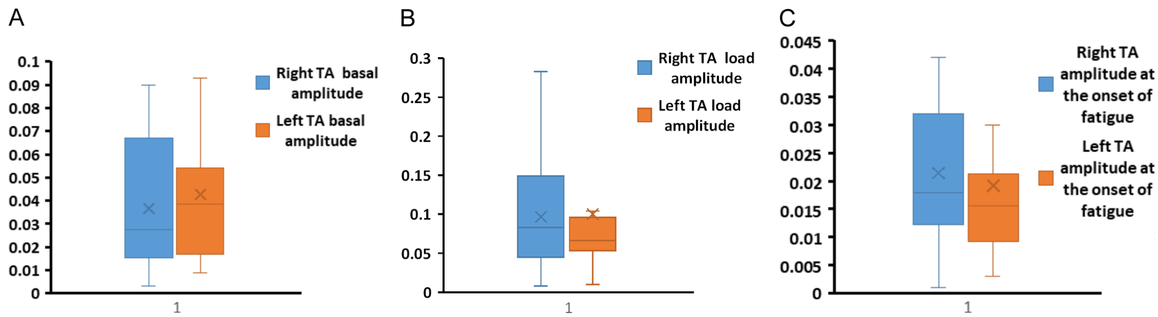

Figure 12. Compares mean peak amplitude (mV) of tibialis anterior muscle on both sides. A. Compares mean peak amplitude (mV) of right and left tibialis anterior at the basal state. B. Compares mean peak amplitude (mV) of right and left tibialis anterior while lifting a defined weight. C. Illustrates the comparison of mean peak amplitude (mV) of right and left tibialis anterior at the onset of fatigue.

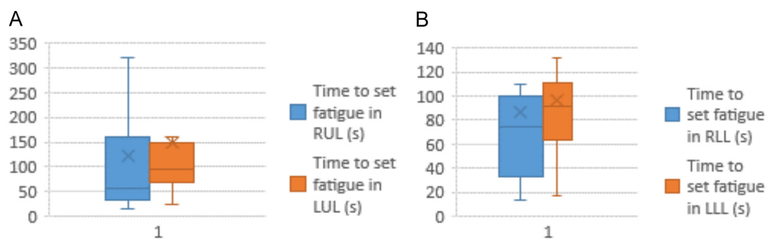

Figure 13. Comparison of the time taken to set fatigue in the upper limb (s) (A) and in the lower limb (s) (B).

Discussion

The present study aimed to identify the relationship between limb dominance in the upper and lower limbs. While it is often assumed that the leg opposite the dominant hand is the dominant leg, the results indicated no clear consensus on whether the dominant arm can reliably predict which leg will be dominant, or vice versa.

Research indicates that the dominant and non-dominant limbs are structurally different and correspond to different hemispheres of the brain, each serving distinct functions in movement control [14]. According to Wang et al. (2007), the dominant limb excels in coordinating inter-segmental dynamics through feedforward mechanisms that determine the speed and trajectory of movement. In contrast, the non-dominant limb plays a key role in impedance control [30].

The study documented that while the dominant limb performed more accurately and stably when reaching from one fixed starting position to three different target positions, the non-dominant limb showed better accuracy and performance when reaching from multiple starting positions to a single target position [30]. Such findings suggest that each hemispherelimb system is specialized in carrying out different functions during movements. It has been reported that the dominant hand performs finer tasks, such as writing. However, the non-dominant hand can hold objects and minimize positional error, thereby enhancing overall motor performance [31]. The results of the present study also pointed out that in terms of the onset of fatigue, there is no statistically relevant difference between corresponding muscles of both limbs (dominant and non-dominant), whether it was the upper limb or the lower limb, which was under observation.

There are morphological and physical differences between the dominant and non-dominant limbs. A previous study reported that the dominant leg has slightly more volume than the non-dominant leg [14]. Previous studies in the field of sports suggested that asymmetries between limbs may not influence moderation in training, as it may not determine their performance output [32, 33]. Earlier study documented that the parameters determining the performance of a limb, such as strength, endurance, etc. depend on a plethora of factors including performing muscle groups [30]. Although the dominant and non-dominant limbs have developed differently from each other, and are concerned with different 'functional' aspects of producing movements, the net result does not make the dominant system 'superior' to the non-dominant one, and vice versa. Both systems are more or less capable of producing the same performance. The difference between the dominant and non-dominant legs might be their function, rather than their ability to perform. Even the time required for setting in of fatigue in corresponding muscle groups showed no statistically relevant difference between the dominant and non-dominant systems. This points out to the possibility that both, the dominant and the non-dominant limbs have attained differences in such a manner that their performances have not changed significantly, at the same time they are concerned with different, though sometimes overlapping aspects of motion and movements, for a given task performance.

The present study has several limitations. The sample size is limited so that the conclusion cannot be generalized. Moreover, it was confined to the performance-determining parameters like power, frequency of contraction, and amplitude of contraction recorded by sEMG. It was observed that there were no significant differences between the dominant and non-dominant limbs as far as parameters like mean frequency and mean amplitude of muscle contraction while lifting a defined weight were concerned. It was also observed that the median value of the mean amplitude of the corresponding muscles except tibialis anterior recorded at the onset of fatigue, was more for the left limb in both upper and lower limbs, though not statistically significant. However, this parameter alone could not provide a piece of stalwart evidence to prove that the left limb was dominant over the right in the present study group. Therefore, more work is needed with the involvement of more muscles (especially those involved in postural control) in a larger population to say this with certainty. Further studies, which include both performance variables like onset of fatigue, power, etc. and functional variables like fine motion, reaching movements, stabilizing movements, are needed to give more insight into the topic.

Conclusion

The results of the current study indicate that while there are differences between the dominant and non-dominant limbs, these differences do not significantly impact their performances. However, the distinct, and at times overlapping, aspects of motion and movement of each limb are beneficial for the performance of specific tasks.

Acknowledgements

The investigators acknowledge the contribution of all the students who have participated in the study voluntarily.

Disclosure of conflict of interest

None.

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