Effect of Muscle Action, Load and Velocity Variation on the Bilateral Neuromuscular Response

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ABSTRACT

Ball N, Scurr J. Effect of Muscle Action, Load and Velocity Variation on the Bilateral Neuromuscular Response. JEPonline 2011;14(4):1-12. The purpose of this study was to assess the neuromuscular asymmetry of the medial and lateral gastrocnemius (MG, LG) and soleus (SOL) of the dominant and non-dominant limbs during different muscle actions via electromyography (EMG). Fifteen active male participants completed isometric and isotonic (maximum, sub-maximum, bodyweight), isokinetic (1.05 rad·s⁻¹, 1.31 rad·s⁻¹, and 1.83 rad·s⁻¹), squat jump, and 20 m sprint conditions on the same day. Bilateral asymmetry was only observed in the isokinetic (6.8% to 10.8%) and the squat jump (6.0% to 15.5%) conditions for the SOL, MG, and LG (P=0.05). No relationship was found between magnitude of bilateral asymmetry and load levels. Isometric max (0.4% to 4.2%) and isometric bodyweight conditions (0.6% to 4.2%) showed the lowest bilateral asymmetry ranges across all muscles. Understanding of bilateral asymmetry induced by different muscle actions is important to prevent muscle imbalance and to understand the potential mechanisms of muscular recruitment in tasks.

Key Words: EMG, Triceps Surae, Laterality
INTRODUCTION

Lower limb actions such as jumping, standing and squatting all require both legs to act equally to provide the most efficient movement, and limit the development of bilateral asymmetries which may lead to unilateral trauma and reduced performance (14, 18). Any asymmetry present in the response of the limbs during these tasks may be due to *laterality* which involves the preferred use of one limb over another when executing a motor task and results in an asymmetric response in force or neuromuscular variables from each limb (19). Laterality occurs in varying magnitudes in unilateral (throwing, kicking) or bilateral actions (leg press, vertical jumping) (4, 9). The different asymmetric response shown in these actions indicates that alongside limb dominance the type of action performed, the load used and the speed of the muscle action may also influence the bilateral differences. Whilst functional investigations of laterality are important to assess in-task demands, the effect of different muscle actions, load and velocity on neuromuscular laterality has yet to be fully understood.

Laterality has been associated with experience; poor performance; inappropriate centre of mass control during exercises that aim to overload both limbs, and internal neural strategies (23). For example, inefficient recruitment of muscle fibers by the neural system has been identified in novice compared to trained performers and in non-dominant compared to dominant limb exertions (1). Electromyography (EMG) has provided an insight into neural function between dominant and non-dominant limbs in bilateral and unilateral muscle actions and thus it is justified to use in determining neuromuscular asymmetry (3, 24).

There is limited research that has assessed the effect of muscle action, load and velocity on the bilateral neuromuscular response. Potdevin’s and co-workers (22) work assessing bilateral neuromuscular differences during gait indicated that the differences shown were due to the natural differing roles of propulsion and support of each leg during the gait cycle. Other studies have shown that bilateral neuromuscular differences may be due to the muscle action. No bilateral difference is present in knee flexors during knee extension exercises (13). This is in contrast to an isometric plantar flexion where a bilateral difference in triceps surae EMG activity is present in older people (26). For movements that require concentric and eccentric muscle actions and a faster rate of force development, greater laterality in EMG and force variables is reported compared to activities requiring a gradual force generation mainly due to coordinative efficiency and insufficient muscle fiber recruitment (1,3,5). In isokinetic studies that have looked to quantify movement velocity, despite differences in peak torque measurements, no associated change in EMG is evident in knee extensors (17, 18). Furthermore, multi-joint tasks that require maximum effort (squats, deadlifts, cleans and drop jumps) have shown greater bilateral force differences (15), compared to sub-maximum exertions where the neuromuscular demand is less (7) suggesting that load may influence the bilateral neuromuscular response.

Muscle action, velocity and load have the potential to cause neuromuscular laterality of the lower limbs however these relationships are not well understood. Our research hypothesis states that muscle activation in the dominant leg will be significantly greater than the non-dominant across all muscle actions and loads. Furthermore laterality will be significantly greater in dynamic movements compared to isometric, isotonic and isokinetic tasks and will be significantly greater at higher loads compared to lower loads. Finally laterality will be significantly greater in the biarticular muscles of the triceps surae, compared to the monoarticular muscles.
METHODS

Subjects
Fifteen male participants (mean ± SD; age 24 ± 4.12 year, stature 1.79 ± 0.08 m, mass 77.9 ± 10 kg) volunteered to participate in this study and gave informed consent. All participants participated in physical activity of a moderate intensity at least 3 times per week, and sprinting and jumping were familiar within their activity. An institutional ethical committee approved all experimental procedures used in-line with the Declaration of Helsinki (2000) code of ethics on human experimentation.

Procedures
A familiarization and practice session for all conditions was provided 48 hours prior to testing, which involved practice trials for each condition. The participants completed all conditions on a single day. No encouragement was given throughout the conditions and all tests were randomized. The dominant limb was ascertained via consultation with the participant. A dynamic warm-up (including dynamic flexibility exercises) and practice set were performed before each condition.

To obtain the loads for the conditions all participants were 1 repetition maximum (1RM) tested for an isotonic heel raise, 5 days prior to testing using a standard 1RM protocol (10) which included the following set configurations: (a) Set 1: Athlete to warm-up with a light resistance that easily allows 5 to 10 repetition; provide a 1 min rest; (b) Set 2: Load increased by 10% to 20% more than load used in set 1 to allow 3 to 5 repetitions to be completed; provide a 2 min rest period; (c) Set 3: Load increased by 10% to 20% more than load used in set 2 to allow 2 to 3 repetitions to be completed; provide a 2 to 4 min rest period; (d) Set 4: Load increase by 10% to 20% more than load used in set 3. Athlete attempts 1RM; (e) Set 5: If the athlete is successful, provide a 2 to 4 min rest and increase the load from set 4 by 5% to 10%. If the athlete is unsuccessful, provide a 2 to 4 min rest and decrease the load from set 4 by 5% to 10%; and (f) Set 6: Continue SET 5 guidelines until the athlete can complete one repetition with proper exercise technique at the highest possible load.

A loaded barbell placed across the participants’ scapula region provided the resistance for the loads. The isotonic muscle action required the participant to raise the heel at a cadence of 1 sec to their peak plantar flexion range of motion (as indicated by a goniometer), followed immediately by a controlled return.

Isometric and isotonic heel raise
Participants performed four standing isometric (ISOM) and isotonic (ISOT) heel raises with the knee extended, at three load conditions: 100% of 1RM (ISOMMAX, ISOTMAX), 75% of 1RM (ISOMsubmax, ISOTsubmax), and an unloaded bodyweight condition (ISOMBW, ISOTBW). The isotonic heel raise was performed in line with the technique used in the 1RM assessment. The isometric heel raise used the same technique as the isotonic condition however required the participant to raise their heel at a cadence of 1 sec to the maximum point of plantar flexion and then hold for 3 sec to provide an isometric period of activity. The center of the barbell and the midline of the participant’s body were individually marked and aligned to ensure balanced barbell placement for each condition occurred.

Isokinetic concentric plantar flexion
A calibrated multi-joint system 3 Pro Isokinetic Dynamometer (Biodex, USA) was used to perform concentric isokinetic plantar flexions. The participant lay supine with the hips and knees extended. Velcro straps secured the chest, pelvis, thigh and foot to the dynamometer bed. A towel was folded under the straight knee to minimize hyperextension. The ankle joint axis of rotation (distal to the lateral malleolus) was aligned with the axis of the lever arm of the dynamometer. The
dorsiflexion/plantar flexion range of motion was recorded for each participant (range of 10°
dorsiflexion to 45° plantar flexion). To correct the measured torques for the effects of gravity, limb
weight was measured with the ankle relaxed. Following a practice, four maximum concentric active
plantar flexions and passive dorsiflexion were performed at angular velocities of 1.05 rad·s\(^{-1}\)
(ISOK\(_{\text{SLOW}}\)), 1.31 rad·s\(^{-1}\) (ISOK\(_{\text{MED}}\)) and 1.83 rad·s\(^{-1}\) (ISOK\(_{\text{FAST}}\)) with 3 min rest between each velocity.
Each leg (dominant and non-dominant) was tested in a random order.

**Squat jump**
Participants performed four maximum squat jumps, descending to a knee flexion angle of 90° (as
indicated by a goniometer) for 3 sec and then jumping for maximum height. Participant’s arms
remained across their chest throughout the movement and during the 3 min rest period between each
jump.

**20 m sprint**
Participants performed four straight-line, 20 m sprints of maximum effort from a two-point stance. A
minimum of 3 min rest between each trial was provided.

**Electromyography**
During all conditions EMG data were collected at 1000 Hz using an 8-channel Datalog EMG system
(Biometrics, Gwent, UK). The contracted muscle belly of the dominant and non-dominant medial
(MG) and lateral gastrocnemius (LG) and soleus (SOL) were identified. Electrode position was
marked in accordance with SENIAM recommendations. The skin was prepared by shaving and
cleansing to reduce impedance levels (≤10 kΩ). Biometrics SX230 active (Ag/AgCl) bipolar pre-
amplified disc electrodes (Gain x 100; Input impedance >100 MO; common mode rejection ratio >96
dB; noise 1-2 µV rms; bandwidth 20-450 Hz) with a 1 cm separation distance were adhered parallel
with the muscle fibers, using hypoallergenic adhesive tape (3M, UK). A passive reference electrode
(Biometrics R300) was placed on the skin overlying the elbow. The Datalog used both a high-pass
third order filter (18 dB/octave; 20 Hz) to remove DC offsets due to membrane potential, and a low-
pass filter for frequencies above 450 Hz. The electrodes also contained an eight order elliptical filter
(-60 dB at 550 Hz). All data were uploaded to a Toshiba laptop (Japan) using the Datalog Analysis
Package (Biometrics, UK).

**Data processing**
Raw EMG signals (mV) from each condition were filtered using a root mean squared (RMS) filter
applied at a window length of 20 ms. Shewarts protocol (+3SD above the baseline level) was
employed to determine the onset and offset of muscle activity. In the isometric condition, peak RMS
EMG was recorded from the 3 sec isometric period as indicated via an event marker (Biometrics,
UK). Peak RMS EMG from the isotonic condition was taken between the onset of the EMG activity to
the cessation of the activity. Peak RMS EMG from the concentric isokinetic conditions was taken
during the isokinetic window as indicated by the Biodex software. Peak RMS EMG from the squat
jump was recorded from the propulsion phase of the jump. For the 20 m sprint, peak RMS EMG was
recorded from each gait cycle in each sprint. A mean of the peak RMS EMG from each repetition for
each participant was then calculated for each condition and referred to as the mean peak task
specific EMG reference value. Based on the opinion that the plantar flexors work synergistically
opposed to in isolation (11), the EMG activity of the SOL, MG and LG were combined and normalized
using a reference value that comprised of the combined EMG amplitudes from the sprint.
Normalization of electromyograms

When looking at the muscles individually the peak EMG value obtained across the whole of the sprint trial for each participant was used to normalize that individuals task specific EMG reference value from all conditions (normalized % = (task EMG/ peak sprint EMG) x 100) (3). This normalization method was shown to be standardized and reproducible in line with recommendations for normalization methods and has been used previously to normalize high speed tasks (2,3). When looking at the triceps surae muscles collectively within the leg the normalization values for each muscle were summated and then used to normalize the summated EMG values of each muscle during the task. Laterality was calculated as the absolute percentage difference between the normalized EMG values of the triceps surae of each limb.

Statistical Analyses

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 14, SPSS Inc., Chicago, IL). All data were shown to be normally distributed using Shapiro Wilk test of normality (P>0.05) and showed homogenous variance using Levene’s statistic (P>0.05). Data were statistically analyzed using within-leg and between-leg comparisons as a factor of condition (isometric, isotonic, and isokinetic), load (maximum, sub-maximum, and bodyweight), and side (dominant, non-dominant) using a 3 x 3 x 6 MANOVA (condition x load x muscle). For the sprint and SJ data, a 2 x 6 ANOVA (condition x muscle) was used. Tukey post-hoc tests were used to identify laterality between conditions, loads, sides, and muscles (P=0.05). To assess the presence of laterality between conditions and loads, combined EMG activity of the triceps surae muscles within the same leg was compared using a 5 x 3 univariate ANOVA (P=0.05).

RESULTS

Between limbs

The dominant limb SOL EMG was 4.5% greater than the non-dominant (Figure 1). The dominant limb MG EMG was 4.8% greater than the non-dominant (Figure 2), with the dominant LG 7.2% greater than the non-dominant LG (Figure 3). When combining the EMG amplitudes from all the conditions (Figure 4), the dominant leg elicited greater normalized EMG activity compared to the non-dominant for each triceps surae muscle (P=0.021(1), F=3.292, power: 0.749) and in when the triceps surae EMG data were summated within leg (P=0.05(1), F=7.877, power: 0.799).

Between condition

The EMG activity of both limbs differed greatly between conditions indicating a varied EMG response to different muscle actions (P=0.001(12), F = 4.908, power =1). Differences between dominant and non-dominant limb EMG were shown in the ISOK\textsubscript{FAST} condition for all muscles (SOL: P=0.02; MG: P=0.05; LG: P=0.02). The squat jump also showed increased dominant EMG activity in the SOL (P=0.02) and LG (P=0.04) and ISOK\textsubscript{SLOW} and ISOK\textsubscript{MED} showed preferential dominant EMG activation in the SOL (P=0.03; P=0.04 respectively) and MG (P=0.05; P=0.02). The isometric, isotonic, and sprint conditions showed an equal neuromuscular activation in the triceps surae between limbs. When combining the EMG activity of all the triceps surae muscles (Figure 4) only the ISOK\textsubscript{FAST} and the squat jump showed differences in EMG activity between limbs.
Figure 1. Normalized EMG values for the dominant and non-dominant soleus between varying muscle actions (n=15) (a = significant to 0.05)

Figure 2. Normalized EMG values for the dominant and non-dominant medial gastrocnemius between varying muscle actions (n=15) (a = significant to 0.05)
**Between loads**

Load did not influence laterality for the isometric and isotonic conditions with maximum, sub-maximum and body weight loads eliciting similar EMG activation levels for each muscle (P=0.282\(^{(12)}\), F=1.194, power: 0.693). All isokinetic velocities produced similar levels of laterality indicating a response of the triceps surae independent of muscle action velocity. Isometric max (0.4% to 4.2%) and isometric bodyweight conditions (0.6% to 4.2%) showed the lowest laterality ranges across all muscles. As expected the EMG activity of both the dominant and non-dominant limb was greater in the maximum conditions compared to the BW conditions for both isometric and isotonic conditions in each muscle (P<0.0001\(^{(6)}\), F=5.950; power: 0.998).

**Between muscle**

The LG showed greater laterality between dominant and non-dominant triceps surae for all conditions (7.5%) compared to the SOL (4.5%) and MG (4.8%) (Figures 1 to 3). The SOL had lower laterality values compared to the MG and LG across conditions; however for the sprint condition this trend was reversed with the MG (3.8%) and LG (2.8%) showing lower laterality than the SOL (6.1%). The squat jump showed the greatest laterality of any condition for the LG (15.5%). The sprint and squat jump condition showed greater EMG activity levels for the SOL, MG and LG in both limbs (80.9% to 87.7%; 66.0% to 88.6%, respectively) compared to all static conditions (P<0.0001). Within the leg, the EMG activity for the SOL, MG and LG were similar indicating a equal response despite variance.

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Figure 3. Normalized EMG values for the dominant and non-dominant lateral gastrocnemius between varying muscle actions (n=15) \(a = \text{significant to 0.05}\)
in muscle action, velocity and load conditions (P>0.05). This was found for both the dominant and non-dominant limb (Figures 1 to 3).

**DISCUSSION**

The purpose of this study was to assess the effect of different muscle actions, velocity, and load on the bilateral EMG response of the triceps surae. The primary findings showed that the dominant limb elicited greater EMG activity compared to the non-dominant limb, and that isokinetic plantar flexions and squat jumping elicited an asymmetric neuromuscular response for the triceps surae. Load had no effect on laterality and no differences were shown between biarticular and monoarticular muscles activation as a factor of muscle action and load.

**Effect of Conditions on Between Limb EMG Responses**

All conditions elicited greater EMG levels in the dominant limb opposed to the non-dominant limb in agreement with Simon and Ferris (24) who suggested that a chronic asymmetrical neural drive to the dominant and non-dominant limbs may have developed. Thereby, long term potentiation could have created the asymmetry due to the preferred use of the dominant limb. Although previous studies have not related neuromuscular response to the dominant velocity generation during throwing and kicking activities (9), this study suggests that there may be EMG amplitude and limb dominance relationship in jumping and unilateral isokinetic activity.
Effect of Condition on Between Limb EMG Laterality
This study has shown that an EMG bilateral difference between limbs exists in different muscle actions and loads. This is in agreement with past research on knee flexors (13). The asymmetric triceps surae activation shown in the isokinetic condition may be because the concentric plantar flexions were performed unilaterally. Isokinetic plantar flexions require a unilateral maximum effort throughout the range of motion, thus no preferential recruitment of the dominant limb could occur (23). This should have led to higher normalized EMG values and lower laterality compared to bilateral conditions and submaximum exertions. However, the current study showed the opposite with low normalized EMG values and high laterality. Peak torque and EMG activity have shown poor intra-reliability in isokinetic plantar flexions due to the small isokinetic window (compared to knee and shoulder) (2,12). The ability of the ankle to generate the pre-set velocity of the dynamometer over the limited range of motion requires coordinated and efficient muscle recruitment. The non-dominant limb may not possess efficient mechanisms and, therefore, may not recruit the same amount of fibers as the dominant side, reducing EMG amplitudes (1,18). The results of this study suggest that isokinetic plantar flexion muscle actions should not be utilized by coaches to train athletes. Instead, other forms of muscle action may be more beneficial for balanced muscle recruitment.

The results of this study showed laterality in the neuromuscular response of the triceps surae during the squat jump. This finding may occur for a number of reasons, such as the internal neural drive mechanism of preferential stimulation of dominant limbs (24), the need for a squat jump to generate power quickly (6), or whole body coordination. The squat jump is used frequently within early stage plyometric training programs to train the rapid extension of the hip, knee and ankle and to assess jump height without the contribution of the stretch-shortening cycle (6). As the squat jump involves the coordinated proximal to distal transference of momentum from hip to knee to the ankle, the bilateral differences in plantar flexion at the ankle may stem from laterality issues occurring at the hip and knee being transferred distally. Zajac (27) showed the negative influence of increased knee flexion angle on gastrocnemii function. The poor coordination of the non-dominant lower limb may lead to an increased knee flexion angle at take-off, thereby reducing muscle fiber recruitment compared to the dominant limb (1). Based on the results of this study, the squat jump should be used sparingly in training programs due to the neuromuscular laterality shown in the triceps surae.

The 20 m sprint, isometric and isotonic exercises did not induce significant bilateral neuromuscular laterality in the triceps surae, supporting the use of these actions in training programs. These actions displayed the common drive that is proposed to occur during bilateral activation (13). Although the sprint is a dynamic task requiring rapid force development like the squat jump, the sprint showed very low laterality in each muscle, which may be due to the idiosyncratic nature of the exercise (16). Furthermore, a slight asymmetry in gait tasks may be inherent due to the suggested complementary roles of each lower limb to braking and propulsion within a gait cycle (22).

Effect of Load on EMG Laterality
As expected EMG activity in the triceps surae increased with increasing load, however load did not increase laterality between limbs, indicating that muscle action had a greater influence on laterality levels. The BW conditions showed the lowest levels suggesting that use of these methods to stimulate a bilateral neuromuscular response in the early phases of injury rehabilitation is warranted to allow simultaneous development (21).

Within Limb EMG Responses to Different Conditions
In line with previous literature, minimal difference in EMG activation between the monoarticular SOL and the biarticular MG and LG during static and dynamic plantar flexion muscle actions were
identified (20). The triceps surae worked synergistically rather than in isolation (11,25) and there was no preferential recruitment influenced by muscle action velocity (8,25). The poor laterality of the LG identified in this study may relate to the mechanics and geometry of this muscle (25). Therefore, it is supported that trainers should work on functional plantar flexion rather than target individual muscles of the triceps surae.

**CONCLUSIONS**

The present study revealed that laterality in dominant and non-dominant triceps surae neuromuscular activity is present in fast isokinetic plantar flexions and squat jumps. If using these tasks for training or testing purposes, awareness of this laterality is required. Alternatively, these tests may serve as a method with which to highlight the level of limb laterality that may occur between triceps surae. This study showed that isometric, isotonic and sprint actions produced similar bilateral neuromuscular responses in triceps surae EMG activity. Therefore, the use of these muscle actions in training programs would not exacerbate any inherent bilateral differences. The sprint action produced the greatest neuromuscular response, with low levels of triceps surae laterality, which suggests this muscle action as an appropriate training exercise for this muscle group. Within the static muscle actions the load influenced the level of EMG activity generated, but it did not affect the laterality response. This study provided further evidence the plantar flexors should be trained as a unit rather than the individual triceps surae muscles. Knowledge of the between limb response of different muscle actions is also important for research carried out on single limbs actions as the bilateral response between limbs may differ.

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