Title: Task and Intensity alters the RMS proportionality ratio in the Triceps Surae

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Running Title: Triceps surae EMG ratio in varying tasks

Keywords:

Electromyography, triceps surae, synergists, soleus, gastrocnemius, neuromuscular ratio

ABSTRACT

INTRODUCTION: Dynamic movements require synergistic involvement of numerous muscles, whereby different muscular and task demands could alter the ratio of this synergistic activation.

METHODS: Participants completed isometric, isotonic, isokinetic, and squat jump (SJ) tasks. Mean RMS EMG was collected from the medial and lateral gastrocnemius (MG, LG) and soleus (SOL), then pooled, and each muscle's activation was expressed as a percentage of the pooled activation.

RESULTS: The MG contributed 9-14% more to total muscle activation in isometric and isotonic tasks versus the SJ task. The SOL contributed 8% more to the SJ task compared to the isometric and isotonic tasks. Across all tasks, MG activation was 4.0 % greater than SOL and 10.5% greater than LG. SOL activation was 6.5% greater in all tasks compared to LG.

DISCUSSION: Task and intensity influences the ratio of activation in the triceps surae.

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INTRODUCTION

Dynamic movements require synergistic involvement of numerous muscles across many joints in order to produce the desired outcome [1,2]. At the joint level, individual muscles usually responsible for producing the joint actions are often grouped, for example, knee extensors, hip flexors, and plantar flexors. One such muscle group is the triceps surae (TS), which consists of the soleus (SOL), medial gastrocnemius (MG), and lateral gastrocnemius (LG) muscles and produces plantar flexion and stabilization of the ankle complex in the transverse plane when contracted. The TS is an important group in activities such as walking, running, and jumping[3,4], where its components act both synergistically and independently to produce given outcomes. Tamaki, *et.al.* [5] indicated that there are numerous combinations of synergistic activation within the TS, while Neptune *et al* [6] intimated that the roles a TS muscle plays in a muscle action may be modified by other synergistic muscles. This suggests that the neuromuscular interplay between the 3 muscles may vary dependant on the task and its intensity.

Due to the differing attachments and fiber compositions of the muscles of the TS which influence force generation capability, the need to look at them individually is evident[7-9]. However as they work collectively to produce ankle plantar flexion, the ability to understand the contribution of each synergist to the total muscle activation required for movement completion is needed. Synergism or muscle co-ordination is defined as the distribution of force among individual muscles to produce a given motor task [10] . Muscle activation during low level contractions has been shown to rotate in the TS, knee extensors, and elbow flexors while force levels are maintained, indicating that the muscles work together to produce the desired outcome [11-14]. De Luca and Erim [15] concluded that the CNS considers synergistic muscles as a functional unit as opposed to individual muscles when producing or maintaining force, based on the common drive being shown in wrist muscle motor units. Obata *et al* [16] also supported the theory of synergistic common drive in the triceps surae by showing a functional coupling of inputs for synergistic plantar flexors, as indicated by common EMG frequency responses. The aforementioned studies' approach to muscle synergism support the notion of a dynamic system controlling movement patterns, whereby an inherent between-muscle variability will be present within the synergistic muscle group[17]; however the goal and the outcome of the movement will remain unchanged. Thus the motor control system recruits motor units not in an established pattern, but does so based on factors such as nature of action, goal of the movement, and individual skill level[17] The aforementioned papers and motor control theories suggest that, while individual muscles assist in movement-specific tasks, their contributions may not be patterned. Thus, it is valid to consider them as a single unit.

Examining the interplay in muscle activation within a muscle group has been researched previously. When assessing the synergistic responses within the quadriceps muscle to a low level isometric task, a reduction in motor unit activation in 1 muscle is offset by increased activation in another [18]. This term has been coined alternate muscle activation and utilizes compensatory neural recruitment from adjacent synergists to maintain force levels [18,14,19]. At higher isometric force loads (>40% MVC) the alternate muscle activation phenomenon has not been shown [20]. The absence of this phenomenon at lower levels may be due to an incomplete saturation of recruited muscle fibers, as this is not considered to occur until ~80% MVC [21]. The alternate activation phenomenon provides insight into synergistic activation within a muscle group at very low level (<5% MVC), long duration isometric tasks, however limited research exists regarding responses of the TS muscle group to higher intensity activities that are not isometric. Kinugasa [22] showed a different distribution of muscle activation among TS muscles during a single leg calf-raise exercise, and Ball and Scurr [23] showed that normalized EMG activation levels differed between the TS muscles based on task and intensity. Jones and Caldwell[24] showed the modification of muscle activation in the bi-articular muscles (hamstrings, rectus femoris, gastrocnemius) when jump direction was changed, noticing particularly a trade-off in activation between the hamstrings and rectus femoris, without significant alteration in ground reaction force. This suggests that muscle activation patterns are altered to maintain the necessary force outputs to complete the jump. Jones and Caldwell[24] focussed on a within-task variation, however an understanding on how the distribution of this muscle activation in a muscle group may change between different tasks with similar joint actions is not well understood.

We used a simple RMS proportionality ratio, whereby individual muscle activation is pooled, and each individual muscle's activation is expressed in relation to the total activation. The process of expressing neuromuscular activation as a ratio or in relation to the activation of other muscles has been used previously in studies of lower back pain [25], fatigue, [26] and closed chain kinetic exercises [27,28], for the purposes of understanding co-contraction ratios within movement or to show preferential recruitment of 1 muscle over another. We used the ratio in the form of a proportional percentage contribution to assess changes in the distribution of muscle activation between synergists during different tasks. The aim of the study is to assess whether the percentage contribution of each muscle to the total neuromuscular activation of the triceps surae varies with load and joint action type as generated by different tasks. Furthermore, we aimed to assess the intra-subject reliability of the RMS proportionality ratio between days and between weeks.

MATERIALS AND METHODS

Participants

Fifteen recreationally active men (age: 25 ± 4.7 yrs.; Stature: 1.79 ± 0.05 m; body mass: 76.9±8.5 kg) gave informed consent to participate. Stature was recorded using a stadiometer (Leicester, UK), and mass was recorded using calibrated weighing scales (SECA, Germany). All participants had a minimum of 1 year of resistance training experience. Jumping was familiar within all the sports they played. The investigation was approved by an institutional review board for use on human participants in line with the Declaration of Helsinki (2000) code of ethics on human experimentation.

Procedures

Participants initially attended a familiarization session on each test, paying particular attention to technique and posture. Following a minimum 48 hour rest, their next testing session involved assessment of individual 1-repetition maximum (1RM) which was used to assign loads in the isometric and isotonic tasks. The first testing session was conducted no less than 5 days after 1RM testing and involved completion of all tasks in a randomized order based on a Latin squares design. Repeat sessions were then conducted the next day (between-days) and 1 week later (between-weeks).

In the testing sessions a standardized warm up comprising 5 minutes of a general warm up and 5 minutes of dynamic stretches were completed before each method. A minimum of 10 minutes rest was provided between each task.

1RM Strength Assessment

All participants were 1RM tested for an isotonic heel-raise using a standard protocol [29]. The isotonic heel raise required the participant to stand with both knees extended and raise the heel at a cadence of 1 s to the maximum point of plantar flexion followed immediately by a controlled return. The maximum point was defined as maximal plantar flexion during an unloaded heel raise task. Load was placed on the scapula region of the participant with a barbell.

Isometric and Isotonic Tasks

Participants performed 4 standing isometric (ISOM) and isotonic (ISOT) heel raises (using the technique described in the previous section). The isotonic heel raise was performed using the technique in the previous section. An isometric heel raise followed the isotonic technique, where the heel was raised at a cadence of 1 s to the maximum point of plantar flexion and held in this position for 3 s. Three loads were used based on the pre-assessed 1RM; 100% ($ISOM_{MAX}$; $ISOT_{MAX}$), 75% ($ISOM_{submax}$; $ISOT_{submax}$), and bodyweight (no barbell) ($ISOM_{BW}$; $ISOT_{BW}$).

Isokinetic Task

A calibrated Biodex 3-Pro Isokinetic Dynamometer (Biodex, USA) recorded the concentric isokinetic plantar flexion. The participant lay supine with the hip and knee 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 Biodex. The dorsiflexion/plantarflexion range of motion was recorded for each participant (range: 10° dorsiflexion to 45° plantar-flexion). Limb weight was measured with the ankle relaxed in order to correct the measured torques for the effects of gravity. Following a sub-maximal practice, 4 maximal concentric plantar-flexions and passive dorsiflexions were performed at angular velocities of 1.05 rad·s^{-1} (ISOK$_{SLOW}$), 1.31 rad·s^{-1} (ISOK$_{MED}$), and 1.83 rad·s^{-1} (ISOK$_{FAST}$). A 1-minute rest was provided between each repetition.

Squat Jump Task

Participants performed 4 maximal squat jumps (SJ) on each testing day. The participant descended to a knee flexion angle of 90° (as indicated by a goniometer), paused for 3s, and then jumped for maximum height. The participant's arms remained across the chest or to the side throughout the movement. Participants were allowed a 3-min rest between jumps.

Electromyography

During all tasks, EMGs were collected (1000 Hz) using an 8-channel Datalog EMG system (Biometrics, UK). The contracted muscle belly of the dominant medial (MG) and lateral gastrocnemius (LG) and soleus (SOL) were identified. The dominant limb was defined as the limb used to kick a ball. Electrodes were positioned in accordance with the SENIAM project guidelines. Electrode placement was marked using a chinograph pencil and reapplied each day until the final testing session [30]. No electrode removal occurred within day. The skin was prepared by shaving and cleansing to reduce impedance (≤10 kΩ). Biometrics SX230 active (Ag/AgCl) bipolar pre-amplified disc electrodes (Gain x 1000; Input impedance >100 MΩ; common mode rejection ratio >96 dB; noise 1-2 µV rms; bandwidth 20-450 Hz) with 1 cm separation were applied parallel to the muscle fibers using hypoallergenic tape (3M, UK). A passive reference electrode (Biometrics R300) was placed on the wrist pisiform. The Datalog used 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 contained an eight-order elliptical filter (-60 dB at 550 Hz).

Data Processing

In the Datalog Analysis Software (Biometrics, UK) the raw EMG signals (mV) recorded from each task were root mean squared (RMS) and filtered at a window length of 20 ms. Window length was chosen on the basis of the suggested ranges to allow for detection of rapid alterations in EMG activation, as may be found in high-speed tasks [31]. Due to the variance in EMG amplitudes that are provided by varying the filtering window length, this was applied to the EMG activation from all tasks. Shewhart's protocol determined onset and offset of muscle activation by calculating the mean of three 50 ms. windows of inactivity prior to the test and calculating 2SD above this mean value [30]. In the *isometric task*, mean RMS EMG was recorded from the 3 s isometric period as indicated by an event marker (Biometrics, UK). Mean RMS EMG from the *isotonic task* was taken from between-EMG amplitude onset and offset of the concentric contraction. Mean RMS EMG from the concentric *isokinetic task* were taken during the isokinetic window as indicated by the Biodex system. Mean RMS EMG from the *SJ* was recorded from the propulsion phase of the jump as indicated by a contact switch (Biometrics, UK). Total EMG was the sum score of the EMG activation from each triceps surae muscle during that task:

SOL mV + MG mV + LG mV = Total TS Activation.

RMS ratio percentage was then calculated by representing each individual's muscle activation as a proportion of the total:

*(Individual Muscle Activation / Total TS Activation) *100*

Statistical analysis

Log-transformed typical error of measurement as an intra-subject coefficient of variance percentage ($\text{TEM}_{\text{CV\%}}$) were used to assess the intra-subject reliability of the RMS ratio percentage of each muscle and the total muscle activation between days (Day 1-2) and between weeks (Day 2-3). In accordance with British Association of Sport and Exercise Sciences (BASES), International Society for the Advancement of Kinanthropometry (ISAK), and Yang et al. [32] , reliability threshold values for $\text{TEM}_{\text{CV\%}}$ were set at excellent (<5%), good (5-12%), acceptable (12-16%), and poor (>16%). These thresholds have been used effectively in previous research [33]. These thresholds are highlighted in the results tables using shading. We used IBM SPSS for Windows (version 19) to perform repeatedmeasures ANOVAs to assess the main effects between the % proportions between each task. Differences were evaluated further with *post hoc* Bonferonni pairwise comparisons to assess the clinically significant differences between each task for each muscle and between each muscle within each task. The 95% confidence limits of these mean differences were also recorded.

RESULTS

Comparisons between Tasks.

The RMS ratio percentage for each task can be seen in Figure 1. Across all tasks there was a significant difference in muscle activation (*P*>0.0001; power 0.997); MG on average 4.00% was greater in all tasks compared with SOL (*P*=0.044; 95% CI: 0.95-7.9%). SOL in contrast was 6.5% greater in all tasks compared with LG (*P*=0.012; 95% CI: 1.4-11.7%). MG had 10.5% greater relative activation compared to LG in all tasks (*P*=0.01; 95% CI: 4.7-16.4%). Figure 2 shows the total muscle activation required for each task. The SJ required significantly greater total activation compared to all other tasks apart from the ISOK task (*P* < 0.05). ISOM BW required significantly lower total activation compared to all other tasks (*P* < 0.05)

Analysis of individual muscle contributions showed that SOL was significantly different between tasks (*P*=0.04; power = 0.913). *Post hoc* tests (Figure 3) revealed that SOL contributed ~8% more to total muscle activation in SJ compared to ISOM $_{\text{SUBMAX}}$ (*P*=0.05; 95% CI: 0.0-15%), ISOT $_{\text{SUBMAX}}$ (*P*=0.016; 95% CI: 1.00-15.6%), and ISOT $_{\text{BW}}$ (*P*=0.019; 95% CI: 0.93-16.3%).

MG was also shown to be significantly different between tasks (*P*<0.0001; power = 1.000). *Post hoc* tests for MG (Figure 3) revealed the contribution of MG to the SJ to be 9-14% lower than the isometric and isotonic tasks. *Post hoc* tests also revealed the contribution of MG to the ISOK$_{\text{FAST}}$ task to be 7-15% lower that the isometric and isotonic tasks. LG was also shown to be significantly different between tasks (*P*=0.02; power = 0.93). However, *post hoc* tests only revealed differences between 2 pairs and only at the 0.1 alpha level.

Within task MG was shown to contribute significantly more to total synergist activation in the ISOM and ISOT tasks, whereas SOL contributed more during the SJ task (Figure 4). No differences were shown between the individual muscle contributions in the ISOK tasks.

Between Day Reliability of Total EMG Activation

Between-day analysis of total EMG activation required by the TS to complete the task was assessed (Table 1). The SJ task was shown to be acceptable between days and between weeks. ISOK $_{MED}$ and ISOK $_{FAST}$ had good/acceptable reliability across all 3 days. The ISOT$_{SUBMAX}$ and ISOK $_{SLOW}$ were poor between weeks, whereas ISOM $_{BW}$ was poor between days (>16% TEM$_{CV\%}$).

Between Day reliability of EMG activation per Muscle

All isotonic (10.35-14.15%) and isokinetic (9.18-12.77%) tasks produced a reliable contribution of SOL EMG activation to the completion of each task both between days and between weeks (Table 2). ISOM$_{SUBMAX}$ and SJ also produced reliable contributions both between days and between weeks. The ISOM $_{BW}$ task did not require a reliable contribution of SOL to the task completion. All tasks apart from ISOT $_{BW}$ between days required a reliable contribution of MG EMG activation to complete the tasks (Table 2). MG produced the lowest reliability of all muscle groups, with good reliability being shown between day and between weeks in 8 of the tasks. The ISOM $_{MAX}$, ISOT $_{MAX}$, ISOK $_{SLOW}$, and ISOK $_{MED}$ produced a reliable contribution of LG activation to complete the task (Table 2). ISOT $_{BW}$ produced the lowest reliable contribution across all conditions.

DISCUSSION

This study showed that the RMS proportionality ratio within the TS changes according to the task and intensity requirements. The LG contributed least to total muscle activation for each task; MG contributed more in the static isometric and isotonic tasks, whereas SOL was the dominant contributor in the SJ. Reliable total EMG activation both between days and weeks was shown for all tasks apart from ISOM $_{BW}$ and ISOT $_{BW}$. The reliability of each individual muscle’s contribution to total muscle activation was task dependant, with ISOM $_{MAX}$, ISOT $_{MAX}$, ISOK $_{SLOW}$, and ISOK $_{MED}$ showing acceptable reliability between days and between weeks for every muscle. The increased reliability at the higher contraction intensities is likely due to fewer possible muscle activation solutions available to carry out the task based on the assumed higher motor unit recruitment required [34]. This is in contrast to lower intensity tasks whereby a larger number of muscle activation solutions would be available as less of the motor unit pool is recruited [34].

This study showed that the RMS proportionality ratio varies depending on the type of task required by the neuromuscular system. This supports the notion put forward by Kinugasa, et.al. [22] that the amount of activated muscle and its distribution would differ in the TS when placed under different conditions and echoes the dynamical systems approach to variable control of motor patterns[35]. Prior studies have indicated differing roles for individual TS muscles within different tasks [36,6,37]. During walking, SOL is considered to play a more important role than MG, [36] and it has also been shown that differing activation levels occur during isometric and jump tasks [24] [38]. In our study MG and SOL contributed most to total muscle activation in any task, and LG contributed least in all tasks. The cause for the greater contribution from MG may lie in its anatomical structure. The MG has shorter fascicle lengths and larger fascicle angles compared to LG [8] and thus contains more fibers per unit volume [39]. The shorter fascicle lengths and density of muscle fibers in MG may lend itself to increased activation within the dynamic-based movements compared to the LG, although in isometric movements fascicle lengths and angles have not been shown to differentiate and influence force levels [40].

Interestingly, based on twitch fiber composition, this study showed that MG contributed most to total activation in isometric and isotonic tasks, however in the dynamic ballistic action (SJ) the SOL contributed most to total activation, which has been shown in a previous study[24]. Although a ballistic movement, the plantar flexion requirements of the SJ are based mainly on carrying out force generated at hip and knee extension. Luhtanen and Komi [41] showed that trunk (10%) and knee extension (56%) caused 66% of the total take-off velocity compared to 22% from plantar flexion. This was further compounded by Jones and Caldwell[24] who showed that ankle plantar flexion occurred last in a vertical jump, with EMG activation from LG and SOL peaking later than vastus lateralis. The SJ may also prevent optimal use of MG, as the jump commences in a bent-knee position. In this position

MG is slack, and thus any contractile ability is diminished until the slack is removed [42]. Creswell, et.al. [43] showed activation of MG and LG both decrease as muscle length decreases based on isometric exertions. SOL activation remained relatively high at all knee angles, thus indicating that the reduced ratio contribution for MG compared to SOL during an SJ may be the result of an un-optimal muscle length at the commencement of the SJ action, where most force is generated. Sirin and Patla[12] also showed that trade-off between individual muscles of the plantar flexors was more evident in the extended knee position compared to the bent knee position. The ISOM, ISOT and ISOK tasks were all completed in the knee extended position which may cause the differences between the different TS muscles. Any differences shown are likely due to the muscle action and intensity of the task opposed to the influence of the knee angle.

The low LG contributions in all the tasks may be the result of the proportion of LG to total TS volume. Kinugasa [22] showed that LG makes up 16% of total TS volume compared to MG (31%) and SOL (53%). LG is considered to play a complementary role within the TS during isometric plantar flexion, whereby the movement can be produced without initial activation of the LG, [44]and MG and SOL are the prime movers. Thus the contribution of LG may be more dominant in the latter stages of the movement, which would not be picked up in our analysis, as mean EMG was used for assessment. Furthermore, Nardone, et.al. [45] explored the shift in activation from fast to slow twitch muscle during eccentric actions in the TS using EMG. They suggested preferential recruitment of SOL over LG during the task; however initiation of the task required more LG activation. LG has been shown to be activated preferentially in cycling activities, where increased knee flexion occurs [46]; LG is proposed to act as a mediator to transfer energy between knee and ankle, compared to MG which is more utilized in ankle plantar flexion. The work of Nardone [47], Kinugasa [22] and Ericson[46] indicates that the role of LG role in contributing to movement changes depending on the task (isometric, eccentric or cycling), which is supporteed further by our data. The RMS proportionality ratio may be affected by electrode placement, however Kouzahki et al [18] showed no differences in EMG activation between proximal and distal portions of the quadriceps muscles during a low level isometric contraction in addition to no time lag effects. Kinugasa et al [22] also showed no regional activation differences in proximal and distal EMG activation in SOL and LG during a single leg calf raise, however distal portions of MG had greater activation compared to proximal. We followed the SENIAM guidelines for electrode placements, where the electrode was placed on the distal portion of the MG. This indicates that the RMS proportionality ratios shown here can be considered representative of proportions at the whole muscle level. We did not remove the electrodes between tasks on a single day. Any potentiation effects from previous exercise that may cause elevated motor neuron pool excitability would be factored out, as all tests within-day were randomized.

Total muscle activation required to complete the task remained reliable between days and between weeks. The reliability of total activation was acceptable, indicating that a common level of muscle activation is required to complete the tasks over a short time period. Ball et al [33] showed non-acceptable reliability for individual absolute peak EMG activation from each individual TS muscle. This indicates that reliability may be improved when 'pooling' the activation contributions and representing the data as relative to total activation. Reliability of EMG is considered poorer than conventional outcome measures based on the sensitivity of the measuring device and the relatively small numbers generated. Reliability may also be affected by extrinsic factors such as electrode removal and replacement. In recognition of the limitations, we did not consider the normalized activation of the muscle, thus comparisons between tasks may be considered invalid. However all tasks occurred in the same day with no electrode removal, and the EMG values represent the mean total muscle activation of each muscle in order to complete that task. Trials were not included unless task completion occurred. Surface EMG is limited in its ability to record deep muscles, thus other plantar flexors or assistance muscles such as fibularis longus, fibularis brevis and tibialis posterior could not be recorded, and thus their contributions to the movements are unknown. Previous studies that have used ratios/proportions of activation have either used root mean square (RMS) or peak of a linear envelope EMG signal as the value to use in producing the ratio [26,27,25]. Previous studies that utilize ratios have also assessed dynamic actions as opposed to isometric actions alone[25,27]. This is in light of the work of Farina, et.al. [48] on decoding the neuromuscular signal, whereby raw EMG signals should be viewed with caution based on amplitude cancellation, muscle movement and other limiting factors. Our study presents RMS values as a ratio with no electrode removal, thus activation variations are in relation to each other, which supports synergistic theory that movements can be accounted for via numerous synergies [2].

This study shows that differing recruitment strategies are placed on the TS when the task and intensity changes. MG and SOL contribute most to total muscle activation in each task, and LG provides the lowest contribution to all tasks. The RMS proportionality ratio of synergistic activation used between days and weeks is reliable. Assessing muscle activation requirements of synergistic muscles using the RMS proportionality ratio is a reliable approach to understanding synergist contributions. Future studies should consider the influence of bilateral exercises on synergistic contributions and proportionality from different sections of the movement. Further research should also be conducted based on how proportionality of muscle activation varies throughout the range of motion of different movements.

Abbreviations:

EMG – electromyography
TS – Triceps Surae
SOL – Soleus
MG – Medial Gastrocnemius
LG – Lateral Gastrocnemius
1RM – one repetition maximum
RMS – Root mean square
CV – coefficient of variation
ISOM_{MAX} – Isometric Maximum
$\text{ISOM}_{\text{SUBMAX}}$ – Isometric sub-maximum
ISOM_{BW} – Isometric Bodyweight
ISOT_{MAX} – Isotonic Maximum
$\text{ISOT}_{\text{SUBMAX}}$ – Isotonic sub-maximum
ISOT_{BW} – Isotonic Bodyweight
$\text{ISOK}_{\text{SLOW}}$ – Isokinetic Slow (1.05 $\text{rad}\cdot\text{s}^{-1}$)
ISOK_{MED} – Isokinetic Medium (1.31 $\text{rad}\cdot\text{s}^{-1}$)
$\text{ISOK}_{\text{FAST}}$ – Isokinetic Fast (1.83 $\text{rad}\cdot\text{s}^{-1}$)
SJ – Squat Jump

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Table 1: Reliability ($\text{TEM}_{\text{CV\%}}$ and 95% Confidence limits) of pooled muscle activation (SOL+ MG + LG) across all conditions between days and between weeks (n = 15). Shading indicates $\text{TEM}_{\text{CV\%}}$ threshold ■ = excellent (<5%); ▨ = good (5-12%); □ = acceptable (12-16%); = poor (16%>)

TASK	Between Day			Between Week		
	$\text{TEM}_{\text{CV\%}}$	Upper	Lower	$\text{TEM}_{\text{CV\%}}$	Upper	Lower
ISOM_{MAX}	12.9	10.5	20.4	9.8	7.9	15.2
$\text{ISOM}_{\text{SUBMAX}}$	13.0	10.6	20.5	18.0	15.0	29.5
ISOM_{BW}	18.6	15.5	30.7	11.9	9.7	18.7
ISOT_{MAX}	9.7	7.8	15.0	12.2	9.9	19.1
$\text{ISOT}_{\text{SUBMAX}}$	11.4	9.2	17.8	16.0	13.2	25.9
ISOT_{BW}	14.8	12.1	23.6	11.7	9.5	18.3
ISOK_{60}	12.8	10.4	20.1	18.4	15.3	30.3
ISOK_{75}	12.5	10.2	19.7	12.5	10.2	19.7
ISOK_{105}	12.5	10.1	19.6	11.2	9.1	17.5
SJ	9.8	7.9	15.1	9.2	7.4	14.2

Table 2: Reliability ($TEM_{CV\%}$) of mean RMS EMG proportionality ratios across all conditions between days and between weeks for the SOL, MG and LG (n = 15). Shading indicates $TEM_{CV\%}$ threshold ■ = excellent (<5%); ▩ = good (5-12%); □ = acceptable (12-16%); = poor (16%>)

TASK	**Between Day**			**Between Week**		
	SOL	MG	LG	SOL	MG	LG
ISOM $_{MAX}$	15.71	8.82	15.27	17.44	10.10	12.68
ISOM $_{SUBMAX}$	13.80	8.10	18.11	14.10	8.30	11.31
ISOM $_{BW}$	19.99	10.30	26.08	18.40	12.00	21.00
ISOT $_{MAX}$	14.15	9.74	13.48	11.18	8.11	11.04
ISOT $_{SUBMAX}$	12.92	7.61	22.17	10.35	11.53	14.91
ISOT $_{BW}$	12.70	19.28	42.53	11.95	9.59	21.48
ISOK $_{SLOW}$	12.18	14.74	13.23	12.44	12.91	15.66
ISOK $_{MED}$	9.18	9.91	13.52	12.77	13.14	15.02
ISOK $_{FAST}$	12.27	10.83	12.44	10.82	11.64	21.59
SJ	8.52	6.73	11.21	9.00	10.73	17.11

Figure Captions

Figure 1: RMS proportionality ratio of each TS muscle to total muscle activation during different tasks.

Figure 2: Total muscle activation (SOL + MG + LG) based on mean RMS (mV) required for task completion.

Figure 3: Significant percentage differences (*P*<0.05) between each condition for SOL and MG muscles. LG is not shown, since there was no significant percentage difference between conditions.

Figure 4: Significant percentage differences (*P*<0.05) between each muscle for each condition. The ISOK task is not shown, since there was no significant percentage difference between muscles.