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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

31 **ABSTRACT**

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

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

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

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

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44 **Keywords:**

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

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56 **INTRODUCTION**

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

69 Due to the differing attachments and fiber compositions of the muscles of the TS which influence
70 force generation capability, the need to look at them individually is evident⁷⁻⁹. However as they work
71 collectively to produce ankle plantar flexion, the ability to understand the contribution of each
72 synergist to the total muscle activation required for movement completion is needed. Synergism or
73 muscle co-ordination is defined as the distribution of force among individual muscles to produce a
74 given motor task ¹⁰. Muscle activation during low level contractions has been shown to rotate in the
75 TS, knee extensors, and elbow flexors while force levels are maintained, indicating that the muscles
76 work together to produce the desired outcome ¹¹⁻¹⁴. De Luca and Erim ¹⁵ concluded that the CNS
77 considers synergistic muscles as a functional unit as opposed to individual muscles when producing or
78 maintaining force, based on the common drive being shown in wrist muscle motor units. Obata *et al* ¹⁶
79 also supported the theory of synergistic common drive in the triceps surae by showing a functional
80 coupling of inputs for synergistic plantar flexors, as indicated by common EMG frequency responses.
81 The aforementioned studies' approach to muscle synergism support the notion of a dynamic system
82 controlling movement patterns, whereby an inherent between-muscle variability will be present within

83 the synergistic muscle group¹⁷; however the goal and the outcome of the movement will remain
84 unchanged. Thus the motor control system recruits motor units not in an established pattern, but does
85 so based on factors such as nature of action, goal of the movement, and individual skill level¹⁷ The
86 aforementioned papers and motor control theories suggest that, while individual muscles assist in
87 movement-specific tasks, their contributions may not be patterned. Thus, it is valid to consider them
88 as a single unit.

89 Examining the interplay in muscle activation within a muscle group has been researched previously.
90 When assessing the synergistic responses within the quadriceps muscle to a low level isometric task, a
91 reduction in motor unit activation in 1 muscle is offset by increased activation in another¹⁸. This term
92 has been coined alternate muscle activation and utilizes compensatory neural recruitment from
93 adjacent synergists to maintain force levels^{18,14,19}. At higher isometric force loads (>40% MVC) the
94 alternate muscle activation phenomenon has not been shown²⁰. The absence of this phenomenon at
95 lower levels may be due to an incomplete saturation of recruited muscle fibers, as this is not
96 considered to occur until ~80% MVC²¹. The alternate activation phenomenon provides insight into
97 synergistic activation within a muscle group at very low level (<5% MVC), long duration isometric
98 tasks, however limited research exists regarding responses of the TS muscle group to higher intensity
99 activities that are not isometric. Kinugasa²² showed a different distribution of muscle activation
100 among TS muscles during a single leg calf-raise exercise, and Ball and Scurr²³ showed that
101 normalized EMG activation levels differed between the TS muscles based on task and intensity. Jones
102 and Caldwell²⁴ showed the modification of muscle activation in the bi-articular muscles (hamstrings,
103 rectus femoris, gastrocnemius) when jump direction was changed, noticing particularly a trade-off in
104 activation between the hamstrings and rectus femoris, without significant alteration in ground
105 reaction force. This suggests that muscle activation patterns are altered to maintain the necessary force
106 outputs to complete the jump. Jones and Caldwell²⁴ focussed on a within-task variation, however an
107 understanding on how the distribution of this muscle activation in a muscle group may change
108 between different tasks with similar joint actions is not well understood.

109 We used a simple RMS proportionality ratio, whereby individual muscle activation is pooled, and
110 each individual muscle's activation is expressed in relation to the total activation. The process of
111 expressing neuromuscular activation as a ratio or in relation to the activation of other muscles has
112 been used previously in studies of lower back pain ²⁵, fatigue, ²⁶ and closed chain kinetic exercises
113 ^{27,28}, for the purposes of understanding co-contraction ratios within movement or to show preferential
114 recruitment of 1 muscle over another. We used the ratio in the form of a proportional percentage
115 contribution to assess changes in the distribution of muscle activation between synergists during
116 different tasks. The aim of the study is to assess whether the percentage contribution of each muscle
117 to the total neuromuscular activation of the triceps surae varies with load and joint action type as
118 generated by different tasks. Furthermore, we aimed to assess the intra-subject reliability of the RMS
119 proportionality ratio between days and between weeks.

120

121 **MATERIALS AND METHODS**

122 **Participants**

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

129

130 **Procedures**

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

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

140

141 *1RM Strength Assessment*

142 All participants were 1RM tested for an isotonic heel-raise using a standard protocol ²⁹. The isotonic
143 heel raise required the participant to stand with both knees extended and raise the heel at a cadence of
144 1 s to the maximum point of plantar flexion followed immediately by a controlled return. The
145 maximum point was defined as maximal plantar flexion during an unloaded heel raise task. Load was
146 placed on the scapula region of the participant with a barbell.

147

148 *Isometric and Isotonic Tasks*

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

155

156 *Isokinetic Task*

157 A calibrated Biodex 3-Pro Isokinetic Dynamometer (Biodex, USA) recorded the concentric isokinetic
158 plantar flexion. The participant lay supine with the hip and knee extended. Velcro straps secured the
159 chest, pelvis, thigh, and foot to the dynamometer bed. A towel was folded under the straight knee to
160 minimize hyperextension. The ankle joint axis of rotation distal to the lateral malleolus was aligned
161 with the axis of the lever arm of the Biodex. The dorsiflexion/plantarflexion range of motion was
162 recorded for each participant (range: 10° dorsiflexion to 45° plantar-flexion). Limb weight was
163 measured with the ankle relaxed in order to correct the measured torques for the effects of gravity.
164 Following a sub-maximal practice, 4 maximal concentric plantar-flexions and passive dorsiflexions

165 were performed at angular velocities of $1.05 \text{ rad}\cdot\text{s}^{-1}$ (ISOK_{SLOW}), $1.31 \text{ rad}\cdot\text{s}^{-1}$ (ISOK_{MED}), and 1.83
166 $\text{rad}\cdot\text{s}^{-1}$ (ISOK_{FAST}). A 1-minute rest was provided between each repetition.

167

168 *Squat Jump Task*

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

173

174 **Electromyography**

175 During all tasks, EMGs were collected (1000 Hz) using an 8-channel Datalog EMG system
176 (Biometrics, UK). The contracted muscle belly of the dominant medial (MG) and lateral
177 gastrocnemius (LG) and soleus (SOL) were identified. The dominant limb was defined as the limb
178 used to kick a ball. Electrodes were positioned in accordance with the SENIAM project guidelines.
179 Electrode placement was marked using a chinograph pencil and reapplied each day until the final
180 testing session³⁰. No electrode removal occurred within day. The skin was prepared by shaving and
181 cleansing to reduce impedance ($\leq 10 \text{ k}\Omega$). Biometrics SX230 active (Ag/AgCl) bipolar pre-amplified
182 disc electrodes (Gain x 1000; Input impedance $>100 \text{ M}\Omega$; common mode rejection ratio $>96 \text{ dB}$;
183 noise $1\text{-}2 \mu\text{V rms}$; bandwidth 20-450 Hz) with 1 cm separation were applied parallel to the muscle
184 fibers using hypoallergenic tape (3M, UK). A passive reference electrode (Biometrics R300) was
185 placed on the wrist pisiform. The Datalog used a high-pass third-order filter (18 dB/octave; 20 Hz) to
186 remove DC offsets due to membrane potential and a low-pass filter for frequencies above 450 Hz. The
187 electrodes contained an eight-order elliptical filter (-60 dB at 550 Hz).

188

189 **Data Processing**

190 In the Datalog Analysis Software (Biometrics, UK) the raw EMG signals (mV) recorded from each
191 task were root mean squared (RMS) and filtered at a window length of 20 ms. Window length was
192 chosen on the basis of the suggested ranges to allow for detection of rapid alterations in EMG

193 activation, as may be found in high-speed tasks ³¹. Due to the variance in EMG amplitudes that are
194 provided by varying the filtering window length, this was applied to the EMG activation from all
195 tasks. Shewhart's protocol determined onset and offset of muscle activation by calculating the mean
196 of three 50 ms. windows of inactivity prior to the test and calculating 2SD above this mean value ³⁰.
197 In the *isometric task*, mean RMS EMG was recorded from the 3 s isometric period as indicated by an
198 event marker (Biometrics, UK). Mean RMS EMG from the *isotonic task* was taken from between-
199 EMG amplitude onset and offset of the concentric contraction. Mean RMS EMG from the concentric
200 *isokinetic task* were taken during the isokinetic window as indicated by the Biodex system. Mean
201 RMS EMG from the *SJ* was recorded from the propulsion phase of the jump as indicated by a contact
202 switch (Biometrics, UK). Total EMG was the sum score of the EMG activation from each triceps
203 surae muscle during that task:

204

205 $SOL\ mV + MG\ mV + LG\ mV = Total\ TS\ Activation.$

206

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

209

210 $(Individual\ Muscle\ Activation / Total\ TS\ Activation) * 100$

211

212 **Statistical analysis**

213 Log-transformed typical error of measurement as an intra-subject coefficient of variance percentage
214 ($TEM_{CV\%}$) were used to assess the intra-subject reliability of the RMS ratio percentage of each muscle
215 and the total muscle activation between days (Day 1-2) and between weeks (Day 2-3). In accordance
216 with British Association of Sport and Exercise Sciences (BASES), International Society for the
217 Advancement of Kinanthropometry (ISAK), and Yang et al. ³², reliability threshold values for
218 $TEM_{CV\%}$ were set at excellent (<5%), good (5-12%), acceptable (12-16%), and poor (>16%). These
219 thresholds have been used effectively in previous research ³³. These thresholds are highlighted in the
220 results tables using shading. We used IBM SPSS for Windows (version 19) to perform repeated-

221 measures ANOVAs to assess the main effects between the % proportions between each task.
222 Differences were evaluated further with *post hoc* Bonferonni pairwise comparisons to assess the
223 clinically significant differences between each task for each muscle and between each muscle within
224 each task. The 95% confidence limits of these mean differences were also recorded.

225

226 **RESULTS**

227 *Comparisons between Tasks.*

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

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

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

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

249 *Between Day Reliability of Total EMG Activation*

250 Between-day analysis of total EMG activation required by the TS to complete the task was assessed
251 (Table 1). The SJ task was shown to be acceptable between days and between weeks. ISOK_{MED} and
252 ISOK_{FAST} had good/acceptable reliability across all 3 days. The ISOT_{SUBMAX} and ISOK_{SLOW} were
253 poor between weeks, whereas ISOM_{BW} was poor between days (>16% TEM_{CV%}).

254 *Between Day reliability of EMG activation per Muscle*

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

264

265 **DISCUSSION**

266 This study showed that the RMS proportionality ratio within the TS changes according to the task and
267 intensity requirements. The LG contributed least to total muscle activation for each task; MG
268 contributed more in the static isometric and isotonic tasks, whereas SOL was the dominant contributor
269 in the SJ. Reliable total EMG activation both between days and weeks was shown for all tasks apart
270 from ISOM_{BW} and ISOT_{BW}. The reliability of each individual muscle's contribution to total muscle
271 activation was task dependant, with ISOM_{MAX}, ISOT_{MAX}, ISOK_{SLOW}, and ISOK_{MED} showing

272 acceptable reliability between days and between weeks for every muscle. The increased reliability at
273 the higher contraction intensities is likely due to fewer possible muscle activation solutions available
274 to carry out the task based on the assumed higher motor unit recruitment required³⁴. This is in
275 contrast to lower intensity tasks whereby a larger number of muscle activation solutions would be
276 available as less of the motor unit pool is recruited³⁴.

277 This study showed that the RMS proportionality ratio varies depending on the type of task required by
278 the neuromuscular system. This supports the notion put forward by Kinugasa, et.al.²² that the amount
279 of activated muscle and its distribution would differ in the TS when placed under different conditions
280 and echoes the dynamical systems approach to variable control of motor patterns³⁵. Prior studies have
281 indicated differing roles for individual TS muscles within different tasks^{36,6,37}. During walking, SOL
282 is considered to play a more important role than MG,³⁶ and it has also been shown that differing
283 activation levels occur during isometric and jump tasks^{24 38}. In our study MG and SOL contributed
284 most to total muscle activation in any task, and LG contributed least in all tasks. The cause for the
285 greater contribution from MG may lie in its anatomical structure. The MG has shorter fascicle lengths
286 and larger fascicle angles compared to LG⁸ and thus contains more fibers per unit volume³⁹. The
287 shorter fascicle lengths and density of muscle fibers in MG may lend itself to increased activation
288 within the dynamic-based movements compared to the LG, although in isometric movements fascicle
289 lengths and angles have not been shown to differentiate and influence force levels⁴⁰.

290 Interestingly, based on twitch fiber composition, this study showed that MG contributed most to total
291 activation in isometric and isotonic tasks, however in the dynamic ballistic action (SJ) the SOL
292 contributed most to total activation, which has been shown in a previous study²⁴. Although a ballistic
293 movement, the plantar flexion requirements of the SJ are based mainly on carrying out force
294 generated at hip and knee extension. Luhtanen and Komi⁴¹ showed that trunk (10%) and knee
295 extension (56%) caused 66% of the total take-off velocity compared to 22% from plantar flexion. This
296 was further compounded by Jones and Caldwell²⁴ who showed that ankle plantar flexion occurred last
297 in a vertical jump, with EMG activation from LG and SOL peaking later than vastus lateralis. The SJ
298 may also prevent optimal use of MG, as the jump commences in a bent-knee position. In this position

299 MG is slack, and thus any contractile ability is diminished until the slack is removed⁴². Creswell,
300 et.al.⁴³ showed activation of MG and LG both decrease as muscle length decreases based on isometric
301 exertions. SOL activation remained relatively high at all knee angles, thus indicating that the reduced
302 ratio contribution for MG compared to SOL during an SJ may be the result of an un-optimal muscle
303 length at the commencement of the SJ action, where most force is generated. Sirin and Patla¹² also
304 showed that trade-off between individual muscles of the plantar flexors was more evident in the
305 extended knee position compared to the bent knee position. The ISOM, ISOT and ISOK tasks were all
306 completed in the knee extended position which may cause the differences between the different TS
307 muscles. Any differences shown are likely due to the muscle action and intensity of the task opposed
308 to the influence of the knee angle.

309 The low LG contributions in all the tasks may be the result of the proportion of LG to total TS
310 volume. Kinugasa²² showed that LG makes up 16% of total TS volume compared to MG (31%) and
311 SOL (53%). LG is considered to play a complementary role within the TS during isometric plantar
312 flexion, whereby the movement can be produced without initial activation of the LG,⁴⁴ and MG and
313 SOL are the prime movers. Thus the contribution of LG may be more dominant in the latter stages of
314 the movement, which would not be picked up in our analysis, as mean EMG was used for assessment.
315 Furthermore, Nardone, et.al.⁴⁵ explored the shift in activation from fast to slow twitch muscle during
316 eccentric actions in the TS using EMG. They suggested preferential recruitment of SOL over LG
317 during the task; however initiation of the task required more LG activation. LG has been shown to be
318 activated preferentially in cycling activities, where increased knee flexion occurs⁴⁶; LG is proposed to
319 act as a mediator to transfer energy between knee and ankle, compared to MG which is more utilized
320 in ankle plantar flexion. The work of Nardone⁴⁷, Kinugasa²² and Ericson⁴⁶ indicates that the role of
321 LG role in contributing to movement changes depending on the task (isometric, eccentric or cycling),
322 which is supported further by our data. The RMS proportionality ratio may be affected by electrode
323 placement, however Kouzahki et al¹⁸ showed no differences in EMG activation between proximal
324 and distal portions of the quadriceps muscles during a low level isometric contraction in addition to
325 no time lag effects. Kinugasa et al²² also showed no regional activation differences in proximal and

326 distal EMG activation in SOL and LG during a single leg calf raise, however distal portions of MG
327 had greater activation compared to proximal. We followed the SENIAM guidelines for electrode
328 placements, where the electrode was placed on the distal portion of the MG. This indicates that the
329 RMS proportionality ratios shown here can be considered representative of proportions at the whole
330 muscle level. We did not remove the electrodes between tasks on a single day. Any potentiation
331 effects from previous exercise that may cause elevated motor neuron pool excitability would be
332 factored out, as all tests within-day were randomized.

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

353 factors. Our study presents RMS values as a ratio with no electrode removal, thus activation variations
354 are in relation to each other, which supports synergistic theory that movements can be accounted for
355 via numerous synergies ².

356

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

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377 **Abbreviations:**

378 EMG – electromyography

379 TS – Triceps Surae

380 SOL – Soleus

381 MG – Medial Gastrocnemius

382 LG – Lateral Gastrocnemius

383 1RM – one repetition maximum

384 RMS – Root mean square

385 CV – coefficient of variation

386 ISOM_{MAX} – Isometric Maximum

387 ISOM_{SUBMAX} – Isometric sub-maximum

388 ISOM_{BW} – Isometric Bodyweight

389 ISOT_{MAX} – Isotonic Maximum

390 ISOT_{SUBMAX} – Isotonic sub-maximum

391 ISOT_{BW} – Isotonic Bodyweight

392 ISOK_{SLOW} – Isokinetic Slow (1.05 rad·s⁻¹)

393 ISOK_{MED} – Isokinetic Medium (1.31 rad·s⁻¹)

394 ISOK_{FAST} – Isokinetic Fast (1.83 rad·s⁻¹)

395 SJ – Squat Jump

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515 Table 1: Reliability ($TEM_{CV\%}$ and 95% Confidence limits) of pooled muscle activation (SOL+
516 MG + LG) across all conditions between days and between weeks (n = 15). Shading indicates
517 $TEM_{CV\%}$ threshold ■ = excellent (<5%); ■ = good (5-12%); ■ = acceptable (12-16%); ■ =
518 poor (16%>)

TASK	Between Day			Between Week		
	$TEM_{CV\%}$	Upper	Lower	$TEM_{CV\%}$	Upper	Lower
ISOM _{MAX}	12.9	10.5	20.4	9.8	7.9	15.2
ISOM _{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
ISOT _{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

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529 Table 2: Reliability ($TEM_{CV\%}$) of mean RMS EMG proportionality ratios across all
 530 conditions between days and between weeks for the SOL, MG and LG (n = 15). Shading
 531 indicates $TEM_{CV\%}$ threshold ■ = excellent (<5%); ■ = good (5-12%); ■ = acceptable (12-
 532 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

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537 **Figure Captions**

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

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

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

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