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Comparison of Upper Extremity Muscle Activation Levels Between Isometric and Dynamic Maximum Voluntary Contraction Protocols

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ABSTRACT

Background: Muscle activations (MA) during maximum voluntary contractions (MVC) are commonly utilized to normalize muscle contributions. Isometric MVC protocols may not activate muscles to the same extent as during dynamic activities, such as falls on outstretched hands (FOOSH), that can occur during sport or recreational activities. **Objective:** The purpose of this study was to compare the peak MA of upper extremity muscles during isometric and dynamic MVC protocols. **Methods:** Twenty-four (12 M, 12 F) university-aged participants executed wrist and elbow flexion and extension actions during five-second MVC protocols targeting six upper extremity muscles (three flexors and three extensors). Each protocol [isometric (ISO); dynamic (eccentric (ECC), concentric (CON), elastic band (ELAS), unresisted (UNRES)] consisted of three contractions (with one-minute rest periods between) during two sessions separated by one week. Muscle activation levels were collected using standard electromyography (EMG) preparations, electrode placements and equipment reported previously. **Results:** Overall, the ECC and CON dynamic protocols consistently elicited higher peak muscle activation levels than the ISO protocol for both males and females during both sessions. Over 95% of the CON trials resulted in mean and peak muscle activation ratios greater than ISO, with 56.3% being significantly greater than ISO ($p < 0.05$). **Conclusion:** Higher activation levels can be elicited in upper extremity muscles when resistance is applied dynamically through a full range of motion during MVC protocols.

Key words: Electromyography, Upper Extremity, Biomechanical Phenomena, Muscle Contraction, Arm, Forearm

INTRODUCTION

Falls on outstretched hands (FOOSH) have been recognized as a predominant injury mechanism for the upper extremities that affects a wide variety of populations, including the elderly, due to accidental falls from a trip or slip (Palvanen et al., 2000), as well as children and young adults participating in recreational sports such as snowboarding (Idzikowski, Janes, & Abbott, 2000) and rollerblading (Mirhadi, Ashwood, & Karagkevrekis, 2015). Simulated FOOSH have been studied extensively within the laboratory environment in order to quantify the response of the upper extremities following impact (e.g., Burkhart & Andrews, 2013; Burkhart, Brydges, Stefanczyk, & Andrews, 2017; Gyemi, Clarke, van Wyk, Altenhof, & Andrews, 2018). Electromyography (EMG) is an important tool for determining the protective role of the upper extremity musculature when arresting the momentum of the body associated with FOOSH. For instance, multiple studies have reported patterns of preparatory muscle activity in the arm and forearm in anticipation of sudden external load changes characteristic of this dynamic impact event (Dietz, Noth, & Schmidtbleicher, 1981; DeGoede & Ashton-Miller, 2002; Burkhart & Andrews, 2013), wherein modifications to these pre-impact muscle activation levels can significantly influence the acceleration magnitudes at the elbow, and thus, the capacity of the upper extremity to attenuate impact shock (Burkhart & Andrews, 2010). Moreover, differences in neuromuscular activation strategies have also been identified for different age groups during the pre- as well as post-impact phases of unexpected FOOSH (Lattimer, Lanovaz, Farthing, Madill, Kim, & Arnold, 2016).

Maximum voluntary contractions (MVC) are widely used in EMG studies to normalize muscle activation levels, allowing for more accurate and reliable comparison of the relative muscle activity across various task demands. Normalizing an EMG signal in relation to a reference MVC value is not a new concept (Burden, 2010), with both the Journal

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of Electromyography and Kinesiology and the Surface EMG for the Non-Invasive Assessment of Muscles (SENIAM) project providing general guidelines on this methodological approach to normalization. In a comprehensive review by Burden (2010), eight different MVC methods were identified that have been previously used to normalize EMG, including variations of maximal and sub-maximal isometric, dynamic, and isokinetic contractions. Although it still remains unclear as to what method should be considered optimal, to date, many researchers rely on isometric protocols to achieve maximal muscle activation to normalize EMG signals, even when testing dynamic task-based movements, due to the simplicity and repeatability associated with their execution (Burden, 2010).

However, it has been suggested that isometric contractions may be an inappropriate method of obtaining MVC values for EMG normalization, particularly for tasks involving unrestricted dynamic movements, since they are static in nature and thus do not account for movement of the skin and electrode over the muscle belly (Mirka, 1991). Furthermore, isometric protocols may not activate the muscles to their true maximum levels, as shown by the many studies that have reported muscle activation levels from a variety of tasks (e.g., rehabilitation, walking, jogging, running, isolated muscle actions) greater than 100% of the isometric MVC value (Jobe, Radovich, Tibone, & Perry, 1984; Decker, Hintermeister, Faber, & Hawkins, 1999; Gazendam & Hof, 2007; Higashihara, Ono, Kubota, Okuwaki & Fukubayashi, 2010; McGill & Sharratt, 1990; Morris, Kemp, Lees, & Frostick, 1998; Nilsson, Thorstensson, & Halbertsma, 1985; Simonsen, Alkjær, & Raffalt, 2012). As a result, isometric MVC protocols should be used with caution if the relative muscle activations associated with highly dynamic muscle actions are to be quantified more accurately (Ball & Scurr, 2013).

While it has been recommended that alternative normalization methods, such as dynamic MVC protocols, require further investigation (Burden, 2010), there is limited research available that provides direct comparisons between isometric and dynamic MVCs for the same task. Rouffet and Hautier (2008) previously found that MVCs collected during a dynamic bicycling task resulted in greater levels of muscle activation than those collected during traditional isometric contractions. Similarly, studies by Ball and Scurr (2010) and Suydam, Manal, & Buchanan (2017) recorded greater MVC values during maximal jump and sprint tasks compared to both isometric and fast isokinetic contractions. In contrast, Hunter, St. Clair Gibson, Lambert, & Noakes (2002) showed that dynamic MVCs performed on a cycle ergometer actually generated less muscle activation than the corresponding isometric MVCs.

Although these studies highlight the importance of using dynamic MVC protocols for normalizing the EMG from dynamic tasks, overall, only two types of contractions (i.e., isometric and isokinetic) were compared across three dynamic normalization methods. More importantly, each of the aforementioned studies solely focused on muscle activity in the lower extremity; currently, to the best knowledge of the authors, there is no information regarding how different MVC protocols may influence dynamic tasks for the upper extremity. Therefore, the purpose of this study was to directly compare the mean and peak muscle activation levels resulting from several dynamic MVC collection protocols to those determined from an isometric protocol for several muscles of the upper extremity spanning the wrist and elbow joints.

METHODS

Participants and Study Design

The repeated-measures design of this experimental study involved twenty-four university-aged participants (12 male, 12 female: mean (SD) ages, heights, and body masses of 23.3 (3.8) years and 21.0 (2.9) years; 1.81 (0.09) m and 1.63 (0.11) m; 81.4 (12.8) kg and 61.3 (10.3) kg, respectively) who were free from current or previous upper extremity and back injuries. Participants provided signed informed consent and all experimental methods were approved by the institution's Research Ethics Board.

Instrumentation

Kendall bi-polar disposable Ag/Ag-Cl rectangular surface electrodes (23 mm x 33 mm) (Tyco Healthcare Group LP, Mansfield, MA; ES40076-H59P) were used to collect muscle activation levels from six muscles of the upper extremity: the Biceps Brachii (BB), Brachioradialis (Br), long head of Triceps Brachii (Tr), Anconeus (An), Extensor Carpi Ulnaris (EC), and Flexor Carpi Ulnaris (FC). Electrode pairs were placed over the muscle bellies of each muscle on each participant's dominant forearm (self-attributed) and arm in the direction of their lines of action using an inter-electrode distance of 2 cm (see Table 1 for details of electrode placements). The EMG signals were differentially amplified (±2.5 V; AMT-8 Bortec Calgary Canada; Bandwidth 10–1000 Hz, CMRR = 115 dB at 60 Hz, input impedance =10 G X), full wave rectified, and filtered with a dual pass

Table 1. Description of the selected upper extremity muscles and EMG electrode placement

Muscle	Electrode Placement
Biceps Brachii (BB)	1/3 of the distance proximally from the cubital fossa between the acromion and cubital fossa
Brachioradialis (Br)	2 finger breadths from the cubital crease with forearm in neutral position
Long head Triceps Brachii (Tr)	2 finger breadths medially at 50% of distance between the acromion and the olecranon
Anconeus (An)	1 finger breadth lateral to olecranon, electrodes oriented down and medially
Extensor Carpi Ulnaris (EC)	1/3 of the distance from the lateral epicondyle between the lateral epicondyle and the ulnar styloid
Flexor Carpi Ulnaris (FC)	2 finger breadths from the ulnar border on the proximal third of the forearm

2nd order Butterworth filter at a cut-off frequency of 4 Hz. The cut-off frequency was determined by residual analysis of multiple trials (Winter, 2009). Prior to applying the electrodes, the skin was shaved (where necessary) and lightly abraded with a 70% isopropyl alcohol solution. Hypafix® (BSN Medical Inc., Charlotte, NC), a hypoallergenic surgical tape, was also placed over the electrodes to further secure them to the skin during testing.

Procedures

Once the electrodes were applied, the participants performed five different MVC protocols: 1) isometric (ISO), 2) eccentric (ECC), 3) concentric (CON), 4) elastic band (ELAS), and 5) un-resisted (UNRES) (described fully in Table 2). For each MVC protocol, four separate muscle actions were completed to collect muscle activity of the flexor and extensor muscle groups crossing the elbow and wrist joints, including: a) elbow flexion, b) elbow extension, c) wrist flexion, and d) wrist extension. Three trials of each MVC protocol were executed by the participants; each trial lasted approximately five seconds with one-minute of rest between each trial to avoid muscle fatigue. The MVC protocols were presented randomly to reduce order effects and verbal encouragement was provided during each trial to help the participant elicit a maximal contraction (Mcnair, Depledge, Brettkelly & Stanley, 1996; Binboga, Tok, Catikkas, Guyen, & Dane, 2013).

In order to limit the participant's posture from impacting the EMG activity, all trials for the MVC protocols (with the exception of ELAS elbow flexion and elbow extension) were collected in a standard seated position (Figure 1), in which straps were used to secure the participant's chest and thighs to isolate the upper extremity movements. When necessary, a height adjustable table was also included to execute the muscle actions required for certain MVC protocols. Manual resistance was used to perform the ISO, ECC,

Table 2. Description of MVC protocols and muscle actions

MVC Protocol	Muscle Action			
	Elbow Flexion	**Elbow Extension**	**Wrist Flexion**	**Wrist Extension**
Isometric (ISO)	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upward). Participant instructed to flex the forearm about the elbow against a fixed resistance applied by the researcher to the ventral aspect of the forearm.	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upward). Participant instructed to push against the fixed table in an attempt to extend the forearm about the elbow. Researcher applied a small resistance to the ventral aspect of the forearm to prevent it from lifting off the table during the trial.	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upward) and wrist in a neutral position. Participant instructed to flex the hand about the wrist against a fixed resistance applied by the researcher to the volar aspect of the hand.	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upward) and wrist in a neutral position. Participant instructed to extend the hand about the wrist against a fixed resistance applied by the researcher to the dorsal aspect of the hand.
Eccentric (ECC)	Participant seated with forearm in full flexion (i.e., hand almost touching shoulder) and palm facing towards the body. Researcher applied resistance to the participant's palm to move the forearm through a full range of motion about the elbow until fully extended. Participant instructed to resist the extension motion by activating the elbow flexors.	Participant seated with forearm in full extension (i.e., at the side) and palm facing forward. Researcher applied resistance to the dorsal aspect of the participant's hand to move the forearm through a full range of motion about the elbow until fully flexed. Participant instructed to resist the flexion motion by activating the elbow extensors.	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upward). Starting in full wrist flexion, the researcher applied resistance to the participant's palm to move the hand through a full range of motion about the wrist until fully extended. Participant instructed to resist the extension motion by activating the wrist flexors.	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upward). Starting in full wrist extension, the researcher applied resistance to the dorsal aspect of the participant's hand to move it through a full range of motion about the wrist until fully flexed. Participant instructed to resist this flexion motion by activating the wrist extensors.

(Contd...)

Table 2. (*Continued*)

MVC Protocol	Muscle Action			
	Elbow Flexion	**Elbow Extension**	**Wrist Flexion**	**Wrist Extension**
Concentric (CON)	Participant seated with forearm in full extension (i.e., at the side) and palm facing forward. Participant instructed to flex the forearm about the elbow through the full range motion until fully flexed while the researcher applied resistance against the participant's palm.	Participant seated with forearm in full flexion (i.e., hand almost touching shoulder) and palm facing towards their body. Participant instructed to extend the forearm about the elbow through the full range of motion until fully extended while the researcher applied resistance against the dorsal aspect of the participant's hand.	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upward). Starting in full wrist extension, participant instructed to flex the hand about the wrist through a full range of motion until fully flexed while the researcher applied resistance to the palm of participant's hand.	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upward). Starting in full wrist flexion, participant instructed to extend the hand about the wrist through a full range of motion until fully extended while the researcher applied resistance to the dorsal aspect of the participant's hand.
Elastic band (ELAS)	Participant stood with one foot on the distal end of the elastic band and hand grasping the proximal handle of the band in a position such that there was resistance in the band when the arm was at their side and forearm fully flexed (i.e., hand almost touching shoulder) with the palm facing towards the body. Participant allowed the band to pull the forearm into 90º of flexion, at which point they were instructed to rapidly flex the forearm against the band resistance until fully flexed.	Participant stood with one foot on the distal end of the elastic band and hand grasping the proximal handle of the band with the arm in 180º of shoulder flexion and forearm fully extended (i.e., hand straight above the head) with the palm facing forward. Participant allowed the band to flex their forearm to 90° (i.e., until hand was at head level), at which point they were instructed to return the forearm to the full extension against the band resistance.	Participant seated with the forearm flexed at 90° resting on the table in supination (i.e., palm facing upward). The dominant hand held the handle of the band while the opposite hand held the free end of the band in a position that applied maximum resistance when the wrist was fully flexed. Participant allowed the band to pull the hand into full extension, at which point they were instructed to return the hand to the fully flexed position against the band resistance.	Participant seated with their forearm flexed at 90° resting on the table in pronation (i.e., palm facing downward). The dominant hand held the handle of the band while the opposite hand held the free end of the band in a position that applied maximum resistance when their wrist was fully extended. Participant allowed the band to pull their hand into full flexion, at which point they were instructed to return the hand to the fully extended position against the band resistance.
Un-resisted (UNRES)	Participant seated with forearm fully extended (i.e., at the side) and palm facing forward. Participant instructed to rapidly flex the forearm about the elbow into full flexion (i.e., hand almost touching shoulder).	Participant seated with forearm fully flexed (i.e., hand almost touching shoulder) and palm facing the body. Participant instructed to rapidly extend the forearm about the elbow into full extension (i.e., at the side).	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upwards). Starting full wrist extension, participant instructed to rapidly flex the hand about wrist into full flexion.	Participant seated with forearm flexed at 90° resting on the table in supination (i.e., palm facing upwards). Starting full wrist flexion, participant instructed to rapidly extend the hand about the wrist into full extension.

Elbow flexion=biceps brachii (BB), brachioradialis (Br); elbow extension=long head of triceps brachii (Tr), anconeus (An); wrist flexion=flexor carpi ulnaris (FC); wrist extension=extensor carpi ulnaris (EC).

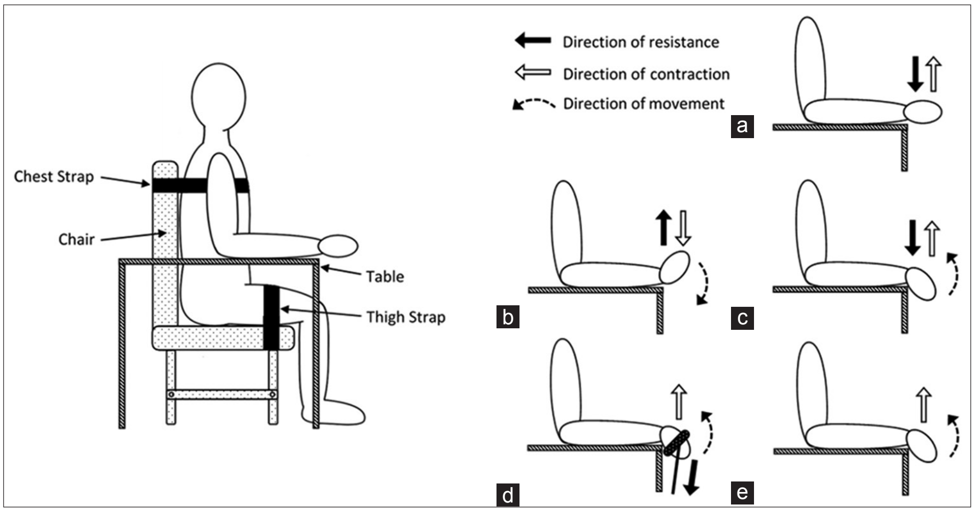

Figure 1. Schematic diagram illustrating an example of the standard seated position and the direction of resistance, contraction, and movement used to collect wrist flexion MVCs: (a) isometric (ISO), (b) eccentric (ECC), (c) concentric (CON), (d) elastic band (ELAS), and (e) un-resisted (UNRES) protocols

and CON MVC protocols, as per the EMG normalization methods employed in previous studies (Hoozemans & van Dieen, 2005; Holmes & Andrews, 2006; Burkhart & Andrews, 2010; Burkhart & Andrews, 2013, Lattimer et al., 2016). Resistance was applied by the same researcher for all MVC trials. For the ELAS MVC protocols, two elastic exercise bands (Slastix Toner Resistance Tubing, Power Systems, Knoxville, TN) with different resistances (medium: ~5.9 kg; heavy: ~8.6 kg) were used by participants. Band resistance was self-selected by the participants after trying each prior to data collection. In general, all female and smaller male participants (<70 kg body mass) used the medium band; all other male participants used the heavy band. No resistance was applied to the participant during the UNRES MVC protocols. Both the ELAS and UNRES MVC protocols consisted of three contractions within each of the three five-second trials.

Data Analysis and Statistics

Mean (of two second windows for ISO, one second windows for ECC, CON, ELAS, and UNRES) and peak (maximum value for ISO, ECC, CON and mean of three maximum values for ELAS and UNRES) muscle activation levels from each trial for each protocol were extracted from the filtered and full wave rectified data and subsequently normalized to ISO. One-way ANOVAs were initially used to determine if any significant differences occurred between trials. A four-way (two muscles x five MVC protocols (ISO, ECC, CON, ELAS, UNRES) x two data reduction methods (mean, peak) x two sexes (male, female)) mixed repeated measures ANOVA, where sex was the between-participant factor, was used for statistical analysis. The muscles that were included in the ANOVAs depended on the motion being assessed. For example, only BB and Br were compared for the elbow flexion trials, and only Tr and An were compared for the elbow extensions trials. All statistical analyses were performed with IBM SPSS statistical software, V.19 (SPSS Inc., Chicago, Illinois) and alpha was set at 0.05. Post-hoc analysis was performed with a Bonferroni adjustment and effect sizes and power were also calculated.

RESULTS

There were no significant peak muscle activation differences between the three MVC trials executed within each five-second protocol. Therefore, all subsequent statistical analyses were performed on the average value from the three trials. With respect to elbow flexion, there was a significant main effect ($p < 0.001$; $\eta^2 = 0.447$; power = 1.00) of MVC protocol that affected the BB and Br in an identical manner, in which the ECC and CON were the only MVC protocols to elicit significantly greater muscle activation than the ISO protocol (Figure 2). The CON protocol generated the largest level of muscle activation overall, approximately 45% greater than all other MVC protocols. The ECC protocol produced muscle activation levels that were approximately 30% greater, compared to the other protocols, with the exception of the CON protocol (Figure 2). No significant interactions or main effects were found for data reduction method (mean vs. peak), sex, or muscle.

For elbow extension, there was a significant main effect, for both the Tr and An, of MVC protocol ($p < 0.001$; $\eta^2 = 0.493$; power=1.00), such that the UNRES protocol resulted in significantly lower levels of muscle activation compared to all other conditions (Figure 3). Furthermore, the ELAS protocol produced significantly greater muscle activation levels compared to the ISO and UNRES protocols, but significantly lower compared to ECC and CON protocols. In addition, the ECC and CON protocols resulted in approximately 42% greater muscle activation compared to the ISO protocol (Figure 3). A significant interaction was present for data reduction method by MVC protocol ($p = 0.035$; $\eta^2 = 0.18$; power =0.951), where the normalized EMG values were significantly different between the mean ISO (1.00 ± 0.00) and ECC (1.92 ± 0.24), ISO (1.0 ± 0.00) and CON (1.84 ± 0.28), and CON (1.84 ± 0.28) and UNRES (0.59 ± 0.09) protocols. This is in contrast to the significant differ-

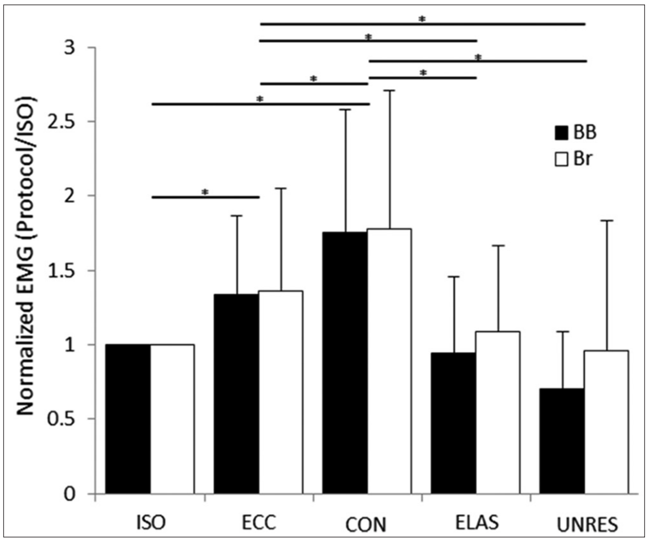

Figure 2. Comparison of the mean (SD) normalized muscle activation levels between protocols for the Biceps Brachii (BB) and Brachioradialis (Br) (*$p < 0.05$).

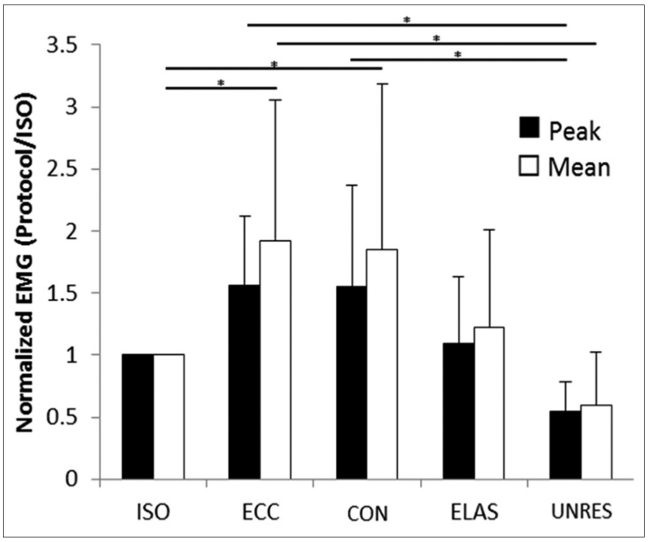

Figure 4. Protocol by data reduction interaction effect on the mean (SD) normalized muscle activation for the elbow extensors (*$p < 0.05$).

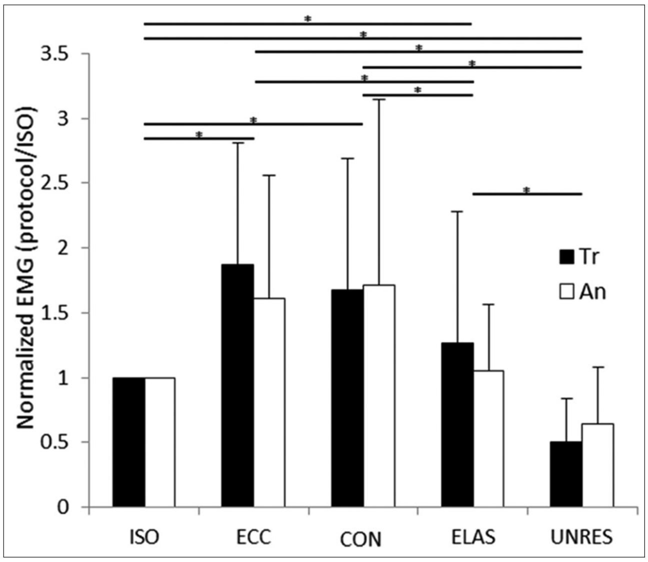

Figure 3. Comparison of the mean (SD) normalized muscle activation levels between protocols for the Triceps Brachii (Tr) and Anconeus (An) muscles (*$p < 0.05$).

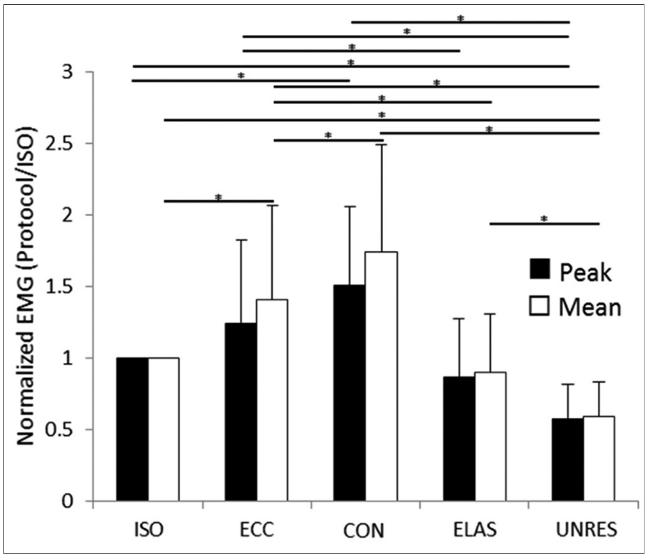

Figure 5. Protocol by data reduction interaction effect on the mean (SD) normalized muscle activation for the wrist flexors (*$p < 0.05$).

ences found for the peak value between ECC (1.36 ± 0.12) and UNRES (0.54 ± 0.05) protocols, as well as between CON (1.54 ± 0.17) and UNRES (0.54 ± 0.05) protocols. However, there were no significant differences between the mean and peak values for any of the MVC protocols (Figure 4).

For wrist flexion (which activated the FC), there was a significant ($p < 0.001$; $\eta^2 = 0.822$; power =1.00) data reduction method by MVC protocol interaction. The muscle activation levels for ISO protocol was significantly lower than the ECC protocol when considering the mean values only (1.00 ± 0.00 vs. 1.43 ± 0.121), while ISO protocol was significantly greater than the ELAS protocol for the peak value only (1.00 ± 0.00 vs. 1.25 ± 0.103) (Figure 5). Moreover, when compared to the CON and UNRES protocols, the ISO protocol produced significantly less and significantly greater muscle activation, respectively, for peak and mean values. Both the ECC and CON protocols resulted in significantly greater values compared to the ELAS and UNRES protocols for both data reduction methods by approximately 52% (Figure 5).

A significant interaction was found for data reduction method by MVC protocol ($p = 0.002$; $\eta^2 = 0.342$; power = 0.961) for the wrist extension (which activated EC) normalized EMG (Figure 6). There was a significant difference between the mean ISO (1.00 ± 0.00) and ECC (1.41 ± 0.137) protocols, and the ECC (1.41 ± 0.137) and CON (1.74 ± 0.156) protocols (Figure 6). In comparison, there were significant differences for both the peak and mean values between multiple pairs of MVC protocols (ISO and CON, ISO and UNRES, ECC and UNRES, CON and UNRES, and ELAS and UNRES), such that the CON protocol produced muscle activations greater than ISO protocol, while the ELAS and UNRES protocols all had values less than the ISO protocol (Figure 6).

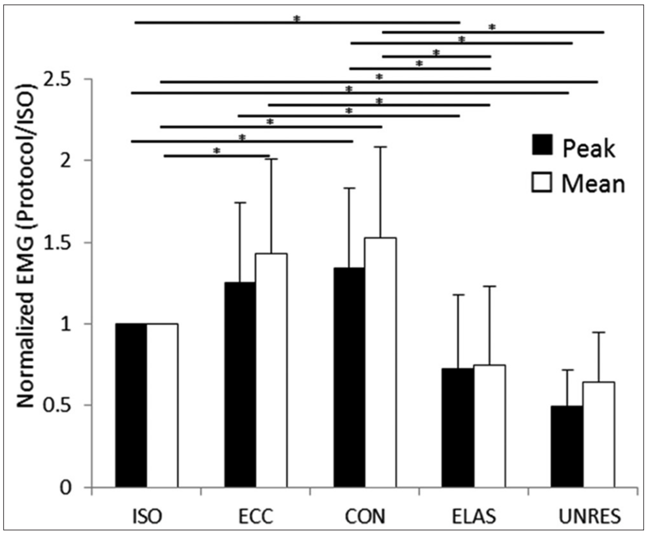

Figure 6. Protocol by data reduction interaction effect on the mean (SD) normalized muscle activation for the wrist extensors (*$p < 0.05$).

DISCUSSION

The results of this study demonstrated that ECC and CON MVC protocols consistently produced higher muscle activation levels, across all of the muscle groups tested in the upper extremity, compared to standard ISO protocols that are more commonly used to normalize EMG in biomechanical studies. However, in three of the four muscle groups that were analyzed (elbow extensors, wrist flexors, and wrist extensors) these differences were dependent on the data reduction method (i.e., mean vs. peak) that was used to obtain the final values for normalization. In contrast to this, the ELAS and UNRES contraction protocols either produced similar or lower muscle activation levels in comparison to the ISO protocol, and always lower activation than the ECC and CON protocols. The greater muscle activation levels reported here for dynamic MVC protocols, compared to an isometric protocol, are consistent with the results of previous studies (e.g., Rouffet & Hautier, 2008; Ball & Scurr, 2010; Suydam et al., 2017). However, the importance of the results of the current study go beyond providing additional support for the use of dynamic MVC protocols for normalizing EMG activity during sport and recreation-related tasks. To the authors' knowledge, this is the first study to highlight comparable outcomes for muscles of the upper extremity, rather than the lower extremity, the focus of previous work to date.

The increase in muscle activation levels experienced by the MVC protocols for the ECC and CON muscle actions specifically in the current study can be described by the physiological underpinnings of the neuromuscular system. This includes the rapid recruitment and de-recruitment of motor units (Farina, Merletti, & Enoka; Farina, 2006) that occurs during dynamic (i.e., ballistic) motions that are not present during isometric contractions (Nakazawa, Kawakami, Fukunaga, Yano, & Myashita, 1993). Furthermore, fast twitch motor units, having low fatigue resistance, are recruited during dynamic actions (Winter, 2009), and will activate initially, followed by a reduced effect on muscle activation levels as the contraction continues (Adams, Harris, Woodard, & Dudley, 1993; Enoka & Fuglevand, 1993; Winter, 2009). On the other hand, isometric MVCs are a voluntary action and are performed by exerting maximal effort with a fixed external load over a period of time and involve slower motor units with longer motor unit action potentials (Winter, 2009).

An interesting finding was that for all muscles, the CON protocols generally produced greater muscle activation than the ISO protocols, and in some cases, significantly more activation than the ECC protocols. This trend would appear to partially support the tension-velocity relationship of muscle, in which eccentric contractions, at any velocity, produce a greater force (as a result of greater muscle activation) than isometric or concentric contractions. However, even though Westing, Cresswell, and Thorstensson (1991) confirmed the torque-velocity relationship (i.e., eccentric contractions producing greater torque than concentric contractions), they found that concentric contractions generated greater levels of muscle activation in the knee compared to eccentric contractions. This was attributed to an inability to voluntarily activate the muscles at maximal levels under high tension consistent with eccentric contractions (Westing et al., 1991). The results presented here are further supported by Coburn et al. (2005) who reported a higher level of muscle activation in the knee extensors in response to concentric contractions (compared to isometric contractions), despite a higher production of force when the muscles were contracted isometrically.

A limitation of the current study was that the dynamic protocols were novel movements for the participants, and consequently, there were some cases in which a few MVC trials (approximately two or three) had to be repeated in order to obtain consistent movements between participants. As a result, it is possible that performing these additional MVC trials induced a small learning effect, which could have contributed to the differences observed between the MVC protocols. However, while it could be argued that adequate training be included in the MVC protocols to ensure that participants are completely informed of all movement tasks prior to data collection, as demonstrated by Frost, Gerling, Markic, and Brown (2012), MVC performance and within-day reliability of muscle activations does not significantly improve over repeated-day familiarization for both resistance-trained and non-resistance-trained populations.

CONCLUSIONS

In conclusion, to the author's knowledge, this is the first study to compare isometric and dynamic MVC protocols in muscles of the upper extremity crossing the elbow and wrist. The overall aim was to improve EMG normalization procedures for assessing the muscle activations associated with dynamic activities, as they are an integral aspect of human movement that occur in a variety of tasks (e.g., sport, recreation, rehabilitation, occupational, etc.). Ultimately, the results presented here provide additional evidence that utilizing dynamic concentric MVC protocols may provide a better indication of muscles' true maximal level of activation than traditionally obtained using isometric protocols for the same muscles.

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