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Reliability of and Correlation Among Electromyographic Normalization Procedures for Biceps Brachii Muscle: A Comparison of Maximal and Submaximal Isometric Voluntary Contractions

Biceps Brachii Kası için Maksimal ve Sabit Yük Altında Submaksimal Kasılmalara Göre Elektromiyografik Normalizasyon Yöntemlerinin Güvenilirliği ve Korelasyonu

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ABSTRACT

Normalization of surface electromyography (sEMG) signal amplitude is considered as a necessary operation to enable comparable data on different muscles, individuals, and sessions. Previous studies usually suggested using the maximal contraction normalization procedure. However, that procedure might not always be possible or the best method in some sEMG studies. The purpose of this study is therefore twofold. The first is to investigate reliability of two different constant load normalization procedures (with and without feedback) at different constant-force submaximal contractions. The second is to investigate correlation of normalization factors obtained from maximal voluntary and standardized submaximal tasks. 18 young healthy participants took part in the study. Subjects performed three muscle contraction tasks, namely, (i) maximal voluntary contraction (MVC) task: isometric maximal contraction of biceps brachii muscle, (ii) force matching task (FM): matching 2.5 kg, 5.0 kg, 7.5 kg and 10.0 kg force with visual feedback, and (iii) load holding (LH) task: holding 2.5 kg, 5.0 kg, 7.5 kg and 10.0 kg weights without visual feedback. sEMG amplitude normalization factors were examined for three tasks. The results of the study suggested that the reliability of sEMG amplitude normalization factors from FM and LH tasks for four target forces or loads were high (intraclass correlation (ICC): 0.863-0.958) to very high (ICC: 0.970-0.995). Due to some limitations of the MVC maximal contraction normalization procedure, normalization to the maximal might not always be possible or the best method for some sEMG studies. In such cases, submaximal isometric load holding tasks could be an alternative to the MVC task for biceps brachii muscle.

Keywords: *Biceps brachii, Normalization, Electromyography*

ÖZ

Yüzeyel elektromiyografi (yEMG) sinyal genliğinin normalleştirilmesi, farklı kaslar, bireyler, seanslar arasında karşılaştırılabilir veriler sağlamak için gerekli bir işlem olarak kabul edilir. Önceki çalışmalar genellikle maksimal istemli kasılma normalizasyon yöntemini kullanmayı önermiştir. Ancak, bu yöntem bazı yEMG çalışmalarında her zaman mümkün ya da en iyi yöntem olmayabilir. Bu çalışmanın iki temel amacı vardır. Birincisi, farklı yükler altında iki farklı submaksimal izometrik kasılma normalizasyon prosedürünün (görsel geri beslemeli ve geri beslemesiz) güvenilirliğini araştırmaktır. İkincisi, maksimal istemli kasılma ve submaksimal izometrik kasılma görevlerinden elde edilen normalizasyon değerleri arasındaki korelasyonu araştırmaktır. Bu deneysel çalışmaya 18 genç sağlıklı katılımcı gönüllü olarak katılmıştır. Denekler üç kas kasılması görevi gerçekleştirdiler. Bunlar sırasıyla şöyledir: (i) maksimal istemli kasılma görevi: biseps brachii kasının izometrik maksimal istemli kasılması, (ii) kuvvet eşleştirme görevi: 2.5 kg, 5.0 kg, 7.5 kg ve 10.0 kg yük ve görsel geri bildirim ile, (iii) yük tutma görevi: görsel geri bildirim olmadan 2,5 kg, 5,0 kg, 7,5 kg ve 10,0 kg ağırlıkları tutmak. yEMG genlik normalizasyon değerleri üç görev için incelenmiştir. Çalışmanın sonuçları, kuvvet eşleştirme ve yük tutma görevlerinden elde edilen normalizasyon değerlerinin güvenilirliğin yüksek (güvenirlik katsayısı 0.863 ve 0.958 arasında) ya da çok yüksek (güvenirlik katsayısı 0.970 ve 0.995 arasında) olduğunu göstermiştir. Maksimal istemli kasılma normalizasyon yönteminin bazı sınırlılıkları nedeniyle, bazı yEMG çalışmaları için maksimale göre normalizasyon her zaman mümkün ya da en iyi yöntem olmayabilir. Bu gibi durumlarda, submaksimal izometrik yük tutma görevi, biceps brachii kası için maksimal istemli kasılma görevine tekrarlanabilir bir alternatif olabilir.

Anahtar Kelimeler: *Biseps brachii, Normalizasyon, Elektromiyografi*

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INTRODUCTION

Variations in amplitude of surface EMG (sEMG) signals are linked to many intrinsic and extrinsic factors such as thickness of the subcutaneous tissue, electrode location, muscle fiber composition (De Luca, 1997, Merletti and Parker, 2004). To reduce the impact of such variability sources on the interpretation of sEMG signals, normalization of sEMG amplitude is usually considered as a necessary operation (Staudenmann et al., 2010), which facilitate comparable data on different muscles, individuals, sessions, and studies (e.g. Besomi et al., 2020). Normalization of sEMG amplitude signals is typically performed by dividing the sEMG amplitude signals during the studied task (e.g. walking, cycling, rowing) by a reference sEMG amplitude value obtained from the same muscle in the same experimental data collection session (Halaki et al., 2012). Motivated by this necessity, extracting the most representative, physiologically meaningful, and repeatable denominator for the normalization equation has long been a topic for a considerable body of research on electromyography (e.g., Burden, 2010; Halaki et al., 2012; Besomi et al., 2020).

Normalization procedures of the sEMG amplitude values yield information on the magnitude of muscle activation with respect to a reference value, and there are several approaches based on isometric, isokinetic, or dynamic actions to perform normalization procedures in the literature (e.g. Burden, 2010). Specifically, two common isometric action EMG normalization methods are based on reference electrical activity of muscle during a standardized isometric submaximal reference voluntary contraction (RVC) and maximal electrical activity of muscle during an isometric maximal voluntary contraction (MVC) (Mirka, 1991; Merletti and Parker, 2004; Besomi et al., 2020). Despite the common usage, both methods, however, have several limitations (e.g., Hug and Tucker, 2017). For instance, the area of signal recording under the sEMG electrode would differ when the muscle length changes during isometric contractions due to muscle tendon interaction which induce nonisometric behavior of muscle fascicles during isometric contractions on the joint level (Ito et al., 1998). As a result, different maximal values might be observed at different joint positions and at different instants of contraction during an MVC task within the same subject (Pieter Clarys et al., 2010). In fact, if simultaneous recording of force output is not readily available, the researchers or clinicians might not be able to choose the best representative interval for normalization factor estimation (Soylu and Arpinar-Avsar, 2010). Therefore, several studies investigated the most representable time interval for the amplitude analysis of sEMG signal on time domain based on the force output during an MVC task (Buckthorpe et al., 2012, Soylu and Arpinar-Avsar, 2010). There are also issues with the RVC normalization procedures, for instance, visual feedback on the force output is necessary for successfully producing a constant level of contraction. On the other hand, force level and the availability of visual feedback (Tracy et al., 2007; Baweja et al., 2009; Athreya et al., 2012) have been shown to alter force fluctuations during submaximal isometric contractions. It is possible that the variability in sEMG signal during submaximal isometric contractions might be partially linked to fluctuations in force output. For instance, Tracy et al. (2007) have shown that in the presence of visual feedback, visuo-motor corrections contribute to force fluctuations. Removal of visual feedback has been shown to reduce force fluctuations and muscle activity during constant isometric contractions (Baweja et al., 2009 and 2011). The results of those studies demonstrated that removal of visual feedback has been a facilitator since it could reduce force fluctuations during constant isometric contractions.

A recent consensus article on EMG normalization presented six approaches as MVC in same task, standardized isometric MVC, standardized submaximal task, peak or mean EMG amplitude in task, non-normalized, and maximal M-wave (Besomi et al., 2020). Obtaining normalization factors based on the maximal EMG amplitude during an MVC task is often recommended method since it provides a reference that is shown to be repeatable (Burden, 2010) and normalization to with respect to this reference might be read as a percentage of the maximal potential capacity of the muscle under investigation (Burden, 2010; Besomi et al., 2020). However, MVC normalization may not be implemented or the best method for some analyses (Burden, 2010). For instance, due to pain, discomfort, risk of injury, fatigue, being novice in attaining maximal effort, or some other limiting conditions, participants might be unable or unwilling to perform a maximal effort in an MVC task which imply a bias towards higher resulting normalized values for magnitude of muscle activation (Besomi et al., 2020). If MVC task cannot be performed due to those aforementioned conditions, standardized submaximal tasks could be an alternative method for EMG normalization (Burden, 2010). For instance, Dankaerts et al. (2004) compared reliability of normalization factors obtained from submaximal and maximal voluntary isometric contractions. The results of the study indicated that both methods showed excellent intra-day reliability. Apart from differences in EMG normalization approaches by task, availability of visual feedback is another design variable in EMG normalization studies. Although, a number of studies have investigated the effects of providing force production feedback on reliability of normalization factors obtained from maximal voluntary contractions (e.g. Fischer et al., 2010), few studies have investigated the impact of feedback on reliability of normalization factors obtained from submaximal voluntary contractions.

This study aims to study normalization factors calculated from sEMG record in relation with force output. It was hypothesized that if an RVC procedure performed in the absence of visual feedback such as carrying a constant load at a static position, it could improve reliability of the normalization procedure. Moreover, if the normalization factors obtained from the RVC procedures had good correlation with the MVC procedure, the common procedure in sEMG amplitude normalization, constant-force contraction normalization procedure without feedback could be an alternative for some sEMG studies. Therefore, the purpose of this study has two folds: i) to investigate reliability of two different constant load normalization procedures (with and without feedback) at different constant-force contractions, and ii) to investigate correlation between MVC and RVC normalization factors.

MATERIALS and METHODS

Subjects and sEMG Measurements: Eighteen healthy and physically active subjects volunteered to participate in the study by providing written consent approved by the University Ethics Committee. The mean ± SD age, body weight and body mass of the subjects were 22.8 ± 3.0 years, 176 ± 5 cm, 74.8 ± 9.4 kg respectively.

For sample size estimation, a priori statistical power analysis was performed using the G*Power 3.1 software (Faul et al., 2007) with the option of effect size specification as in Cohen (1988). With an alpha = 0.05, power = 0.80, and effect size f(V) = 0.8, the projected sample size needed was 15 subjects for repeated measures ANOVA within-factors design.

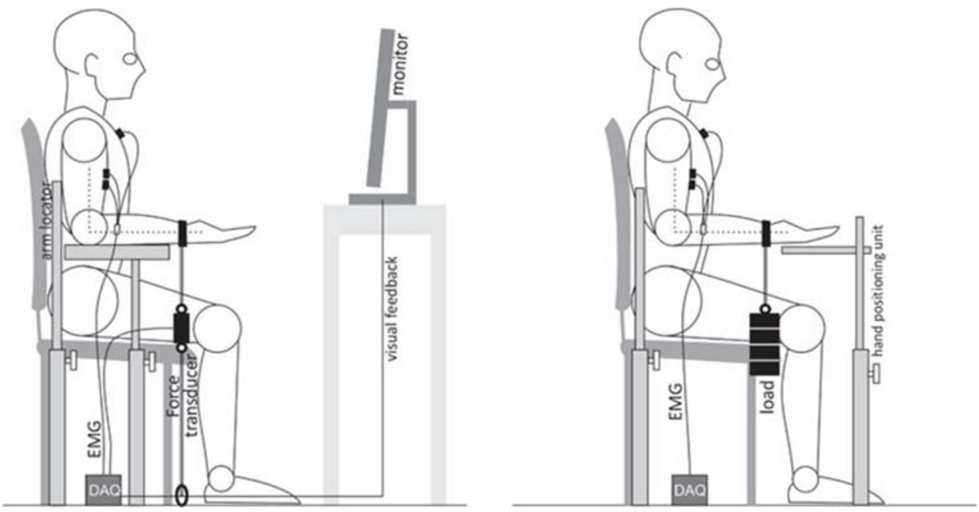
sEMG measurements were performed on biceps brachii muscle of the dominant arm during the experimental procedures. To collect sEMG data, Biovision EMG amplifiers and electrodes were used. The electrodes were placed following SENIAM recommendations as on the line between the medial acromion and the fossa cubit at one third from the fossa cubit along the line between the acromion and the fossa cubit (Hermens et al., 2000). Before attaching surface electrodes, measurement sites were shaved and cleaned with alcohol by lightly abrading the skin. Ag/AgCl electrodes with center-to-center distance of 2 cm were placed longitudinally along the muscle belly. Reference electrode was placed on the upper part of the sternum. Pass band of EMG amplifier, sampling rate, maximum inter-electrode impedance and minimum CMMR were 10–500 Hz, 2000 Hz, 5 KΩ (at DC) and 100 dB (at 50 Hz) respectively. The EMG signal were then digitally filtered with a fourth-order zero-lag Butterworth bandpass filter with the cut-off frequencies of 20 Hz and 400 Hz (Martinek et al., 2021).

Experimental Procedures:

MVC measurements: For each subject, force was measured during the MVC trials. Subjects sat on a chair with back supported, dominant arm positioned with the upper arm perpendicular to the ground, elbow flexed at 90 degrees and forearm supported by armrest in supine position. A force transducer (Biovision, Germany) was fixed on one end to the ground and on the other attached to subjects' right wrist by means of a non-elastic cable and a wrist band (Figure 1). The subjects were instructed to pull the cable up by gradually increasing force to reach maximal level of exertion within two seconds and to maintain the same level for the subsequent eight seconds (Soylu and Arpinar-Avsar, 2010). Four trails were performed with two minutes rest in between. No force feedback was provided to reduce possible sudden increases in the magnitude of force (Fischer et al., 2010).

Figure 1

The Experimental Setup (Left: During The MVC and FM Tasks; Right: During The LH Tasks)



RVC measurements: The experimental setup for isometric RVC tasks consisted of two different constant-force contraction experiments, namely, force matching (FM) and load holding (LH) tasks. Each task was repeated four times for each of four different absolute target forces or loads, i.e., 2.5 kg, 5.0 kg, 7.5 kg and 10.0 kg force. The trials were in random order with two minutes rest in between. The block randomization approach was used to determine the order of target forces or loads, i.e., the subjects completed all four trials for one of the target forces or loads before passing on the next one. The trials of FM task were performed on the dominant arm with the same setup used in the MVC task. Additionally, a computer screen was placed about one meter away from the subject's eye level to provide visual feedback using a custom program written in MATLAB. The subjects were asked to move a bar displayed on the computer screen by pulling the cable attached to the force transducer and to match the line which represents the target force for that trial. The subjects were expected to maintain the force level at the target for eight seconds. The target lines were displayed on the same screen and at the same feedback resolution.

For the LH tasks, the armrest and force transducer were removed from the setup, instead, a steel cable that fastened to a hanging load was connected to the subjects' wrist. The subjects were instructed to keep their hand parallel to forearm in supine position as stable as possible and in parallel with the adjacent hand positioning unit. Whenever the subjects were positioned properly, the load was gently released by one of the experimenters. The subjects were instructed to stabilize the load within two seconds and to maintain the same level for the subsequent eight seconds. The arm position of the subject was visually checked during the trials to detect any unwanted movement of the arm or unintended contact of the hand with the unit. No such errors were noted during data acquisition.

Analysis of force and sEMG signals: First, a distinctive two seconds long force plateau from the force recordings was determined for each trial (Soylu and Arpinar-Avsar, 2010). Then, to calculate sEMG amplitude normalization factors, root mean square (RMS) values of the sEMG signals (Hermens et al., 2000) were estimated for each trial over the previously established two seconds long force plateau of each trial. The force fluctuations during the MVC and FM tasks were also quantified over the two second periods of force plateau of each trial by means of standard deviation (SD) and coefficient of variation (CV) which was equal to (SD/mean value of the force signal over the force plateau)*100. For the FM tasks, after reaching the target forces, ±5% CV values were used to determine plateau. For the MVC tasks, the procedure which was described in Soylu and Arpinar-Avsar (2010) in detail has been used, and it was based on first detecting the peak force, then searching a plateau of two second period after the peak force.

Statistical Analysis: The normality of the distribution of the data was checked using the Lilliefors test for normality. Intraclass correlation coefficients (ICCs) (2-way random effects, absolute agreement among measurements, ICC(2,4) (McGraw and Wong, 1996)) with 95% confidence interval were calculated to assess the intra-session reliability of the sEMG normalization factors obtained in MVC, and LH and FM tasks for four target forces or loads. To assess ICC values, have adopted Munro's correlation strength categories as 0.00−0.25: little, if any; 0.26−0.49: low; 0.50−0.69: moderate; 0.70−0.89: high; 0.90−1.00: very high level of strength of reliability coefficients (Carter and Lubinsky, 2016). Pearson correlation coefficients were also calculated to determine the relationship among the sEMG amplitude normalization factors obtained in the MVC and LH tasks as well as MVC and FM tasks for each target loads or forces, namely, 2.5 kg, 5.0 kg, 7.5 kg and 10.0 kg force. To also assess Pearson correlation coefficients, Munro's correlation strength categories were used. The statistical analysis was performed using SPSS (version 23, IBM, Inc). Significance level was set at $p < 0.05$.

RESULTS

The mean value of the force signal over the force plateau was 179.0 ± 8.9 N (range: 167.6 to 200.2 N) in the MVC task. The reliability of sEMG amplitude normalization factors for the MVC task could be considered very high according to Munro's classifications (Table 1). The ICC values of sEMG amplitude normalization factors for the FM tasks were 0.894, 0.863, 0.958, and 0.945 for 10.0, 7.5, 5.0, and 2.5 kg target forces respectively (Table 1). The ICC values of sEMG amplitude normalization factors for the LH tasks were 0.985 0.995, 0.985, and 0.970 for 10.0, 7.5, 5.0, and 2.5 kg target loads respectively (Table 1). All those ICC values could be considered high to very high level of strength of reliability coefficients according to Munro's classification (Carter and Lubinsky, 2016). If the ICC values were averaged over the task, then the order was as MVC > LH > FM. Among the LH and FM tasks for four target loads or forces, the highest ICC value was for the LH task with 7.5 kg load.

Table 1

Intraclass Correlation Coefficients (Iccs) for Semg Amplitude Normalization Factors Obtained in Maximal Voluntary Contraction (MVC), and Load Holding (LH) and Force Matching (FM) Tasks for Four Target Loads or Forces

n=18	Load	ICC	Lower and upper bounds
FM	10.0 kg	0.894	0.693-0.964
	7.5 kg	0.863	0.593-0.954
	5.0 kg	0.958	0.876-0.986
	2.5 kg	0.945	0.835-0.981
LH	10.0 kg	0.985	0.954-0.995
	7.5 kg	0.995	0.980-0.998
	5.0 kg	0.985	0.954-0.995
	2.5 kg	0.970	0.902-0.991
MVC	maximal	0.996	0.989-0.999

Table 2 presented the force fluctuations over the force plateau during MVC and FM tasks across subjects by means of SD and CV. For the MVC task, the force fluctuations were the largest as 0.52 kg with a CV value of 4.90% (Table 2). For the FM tasks, the highest force fluctuations were observed for 10.0 kg target force as 0.22 kg with a CV value of 2.67%. In terms of CV, the highest value was experienced for the 2.5 kg force matching task as 4.01%.

Table 2

The Force Fluctuations Over The Force Plateau During The Force Matching (FM) and Maximal Voluntary Contraction (MVC) Tasks By Means of Standard Deviation (SD) and Coefficient of Variation (CV)

n=18		SD (kg)	CV (%)
FM	2.5 kg	0.06	4.01
	5.0 kg	0.10	2.21
	7.5 kg	0.18	2.13
	10.0 kg	0.22	2.67
MVC	maximal	0.52	4.90

Table 3 showed Pearson correlation coefficients of the sEMG amplitude normalization factors among the MVC and LH tasks (highlighted with grey shading) together with MVC and FM tasks (no highlight) of each target loads or forces, specifically, 2.5 kg, 5.0 kg, 7.5 kg and 10.0 kg force. Significant and high level (according to Munro's classifications) of correlations were observed between the 10.0 kg target force of FM and MVC tasks. Among the LH and MVC tasks, however, the highest value of Pearson correlation coefficient was realized between the 7.5 kg target load and MVC tasks (very high level according to Munro's classifications).

Table 3

Pearson Correlation Coefficients Among The Semg Amplitude Normalization Factors For The Maximal Voluntary Contraction (MVC) and Load Holding (LH) Tasks (Highlighted With Grey Shading, Upper Triangular) Together With MVC and Force Matching (FM) Tasks (No Highlight, Lower Triangular) of Each Target Loads or Forces

	MVC	10.0 kg	7.5 kg	5.0 kg	2.5 kg	
MVC	1	0.751*	0.787*	0.773*	**0.850****	LH
10.0 kg	**0.812****	-	**0.949****	**0.861****	**0.925****	
7.5 kg	0.551	0.695*	-	0.746*	**0.905****	
5.0 kg	0.669*	0.690*	0.761*	-	**0.914****	
2.5 kg	0.296	0.454	0.627*	0.728*	-	
FM						

*, **: Correlations are significant at the level of 0.05 and 0.01 respectively

DISCUSSION

The purpose of this study was twofold. The first was to investigate reliability of two different constant load normalization procedures (with and without feedback) at different constant-force submaximal contractions. The second was to investigate correlation between MVC and RVC normalization factors. Reliability of such procedures are crucial since a normalization procedure, in general, converts a signal into a scale relative to a known and repeatable value (Halaki et al., 2012). The results of the current study indicated that reliability of sEMG amplitude normalization factors from FM and LH tasks for four target forces or loads were high to very high according to Munro's classification (Carter and Lubinsky, 2016). On average, the ICC values were higher for the LH than the FM tasks. When the force fluctuations were quantified with CV, the lowest force fluctuations were attained for the FM task with 7.5 kg force. In terms of correlations, significant and highest level of correlations were observed between the 7.5 kg target load of LH and MVC tasks.

Considering the limitations of MVC maximal contraction normalization procedure (e.g., Halaki et al., 2012; Hug and Tucker, 2017), normalization to the maximal might not always possible or the best method for some analyses (Besomi et al., 2020). In some experimental designs, holding a constant load may be an affordable alternative as the results of the current study yielded high to very high reliability and significant and high to very high of correlations with the normalization factors obtained in the MVC task. Also, for some groups, holding a load of 5.0 to 7.5 kg would be more preferable in terms of favoring participants' comfort in the data collection sessions.

Another important consideration is that both MVC and visually guided RVC tasks inevitably result in force fluctuations in order to function at the muscle's maximal potential or to maintain a steady force level. Even though, visual feedback has been shown to increase the reliability of submaximal contractions for the purpose of EMG normalization procedures (Burnett et al., 2007), it introduces considerable force fluctuations at submaximal contractions (Athreya et al., 2012). In a supportive way, Baweja et al. (2009) have reported that force fluctuations were lower when the visual feedback had removed. In our study, the lowest force fluctuations were observed for the FM task with 7.5 kg force (2.67% vs. 4.90% for MVC task).

The force fluctuations in the MVC task was higher than the force fluctuations in the FM tasks. In healthy subjects, force fluctuations could be driven by tuning the level of muscle contraction actively in the presence of visual feedback which could be linked to physiologic factors such fatigue (Hunter et al., 2004) or aging (Tracy et al., 2007). It has been suggested that when visual feedback is available, matching of a target force requires continuous control of muscle activity which leads to increased role of the motor cortex during persistent performance adjustments (Kazennikov and Levik, 2009). Compatible with this mechanism, Baweja et al. (2009 and 2011) showed increased EMG activity especially at higher force levels in the presence of visual feedback. That neuromuscular control strategy might explain the increased force fluctuations during MVC and FM tasks. In contrast, holding a constant load without visuomotor corrections could be argued to be predominantly controlled by subcortical structures (Donoghue et al., 1998).

Certain limitations affected our study. First main limitation was that only intra-day reliability was assessed in this particular study. Another possible output of reliability studies is the inter-day or test-retest reliability which reflects consistency of test measures over time. Future studies may investigate inter-day reliability of the normalization procedures applied in this study. Second limitation of the study was that the subjects were healthy young ones. As reliability is a population-specific quality, the results of this study cannot be directly applicable to patient or elderly populations. Further studies may examine a subject group with elderly individuals and/or patients with musculoskeletal disorders who might particularly struggle with maximal contractions of the normalization procedure. Third, in the experiments, all subjects were tested with the same set of loads regardless of their maximal voluntary contraction forces. Future studies may take individual strength differences into account by introducing relative loads with respect to subjects' maximal forces attained in the MVC tasks.

CONCLUSION

In conclusion, sEMG amplitude normalization factors from the force matching and load holding tasks could be deemed reliable to be used in normalization procedures. When compared to the force matching tasks (with visual feedback on force output), the reliability of the load holding tasks (without visual feedback on force output) were higher. Significant and high level of correlations were observed between the load holding and MVC tasks. Those findings provided support for using submaximal isometric load holding tasks to obtain normalization factor for biceps brachii muscle as an alternative to the MVC task.

Yazar Katkısı (Author contributions):

1. **Pinar Arpinar-Avsar:** Idea, Design, Supervision, Data Collection and Processing, Analysis/Comment, Writing, Critical Review
2. **Hüseyin Çelik:** Data Collection and Processing, Analysis/Comment, Writing, Critical Review

Etik Kurul İzni ile İlgili Bilgiler

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