A submaximal normalization of EMG signals in trunk muscle groups

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Abstract: The accuracy of control and strength of contraction for muscles of the trunk, the muscles between our neck and groin, can vary significantly with conditions like hemiparesis, multiple sclerosis, or low back pain. Such medical conditions can contribute to an inability of our trunk muscles to perform at full capacity. A typical normalization method for applied physiologists includes finding a given muscle's maximum voluntary isometric contraction (MVIC), and many individuals with muscle weakness or control-limiting conditions are unable to efficiently participate in this method. To properly assess the severity of muscle weakness or loss of control, there is a need for research on normalizing EMG signals produced from contractions in trunk muscles at a fraction of an individual's MVIC. In order to contribute to this normalization, healthy participants in this study performed a muscle contraction task based on a submaximal MVIC. Participants attempted to reach and hold a contraction for a specific muscle group (i.e., deltoids, pectoralis major, external obliques, and latissimus dorsi) at a target contraction level defined as 25%, 12%, and 6% of their MVIC. The objective of this study was to characterize normalization of EMG signals from trunk muscle contractions with variability and offset error. The standardized measures supported the use of the 25% and 12% contraction levels as submaximal EMG signal normalization. In future studies, the 6% contraction level and the external obliques potentially require refinement in contraction maneuvers for a more accurate normalization. Nevertheless, future experiments may use the results of this study as a submaximal reference point within healthy populations acting as a measure of comparison for patients demonstrating muscle weakness.

Keywords
trunk, maximum voluntary isometric contraction, EMG, normalization

1. Introduction

Trunk muscles are necessary for balance (Ryerson et al., 2008) acting as a cushion for our bones and protection from unexpected perturbations. Several techniques within the applied physiology field are used to assess the strength and control of trunk muscles. Recording and interpreting muscle contractions due to a specific maneuver (extension, flexion, abduction, etc.) acts as a primary method for characterizing strength of a muscle group. However, the precision of control and strength of contraction can vary depending on factors such as physical fitness, inherited conditions, etc. Several conditions demonstrate the inability of our torso muscles to perform at full capacity. Individuals with low back pain (Radebold et al., 2001; Cholewicki et al. 2005; Chang et al., 2015) and several other medical conditions (Ryerson, et al., 2008; van der Burg et al., 2006; Chow and Stokic, 2011; Santos et al., 2016.) consistently demonstrate a lack of strength and control of their trunk muscle groups. To understand the severity of muscle weakness, a normalization, or a reference, should be available to act as a point of comparison, especially in healthy populations.

Within the applied physiology field, one of the most common procedures used to record the contraction of different muscle groups is surface electromyography (EMG). For records of a given muscle group contraction, surface electromyography requires placement of an EMG electrode onto the surface area above the targeted region. However, interpretation of EMG signals can vary greatly due to several factors including EMG placement (Jensen et al., 1993; Kasprisin & Grabiner, 1998), skin temperature (Winkel & Jørgensen, 1991), and electrical signals from adjacent muscles (Hansson et al., 1992). As multiple research studies have encountered an increased variability in their results due to these factors, several studies have declared the importance of a normalization method to combat such discrepancies. A study by Lehman & McGill (1999) confirms this assertion by researching the large variability in EMG signal interpretation and advocating for normalization methods for an improved inter-muscular and inter-subject comparison.

Delayed response time is a key component for assessing trunk muscle stability. The term "reflex latency" describes the delay period in which trunk muscles are activated to prevent lumbar instability after an unforeseen disturbance (Santos et al., 2011). However, this delay period can increase due to injury and result in insufficient control of the trunk muscles (Cholewicki et al., 2005). Cholewicki et al.'s (2005) study found a significant correlation between the likelihood of injury to the lower back and a delayed muscle reflex response. A study by Radebold et al. (2001) also considers a delayed muscle response. However, their study assessed the delay in response time for subjects experiencing lower back pain in comparison to Cholewiki et al.'s (2005) study which assessed the delay using sudden trunk loading in athletes with a previous lower back injury. The results of Radebold et al.'s (2001) study found that subjects with chronic lower back pain performing isometric trunk exercises consequently had poor posture control (i.e., a longer reflex response time). For weaker muscle groups identified in my proposed study, the amplitude for contractile strength is predicted to be lower and a pronounced reflex latency may be evident in these groups.

In addition to reflex latency, assessment of muscle stability can take form in various other methods. A typical normalization method used by applied physiologists is discernment of a muscle group's maximum voluntary contraction (MVC). However, there are inconsistencies in the literature regarding the maneuver that produces the highest activation for a particular muscle group. One study searched for the maximum EMG activity in different cardinal planes for healthy patients and back-pain patients, and they found a maneuver (i.e., trunk flexion, lateral flexion, axial rotation, extension) in one common direction that produced the maximum EMG activity for most muscle groups (i.e., rectus abdominis, external and internal oblique, and multifidus, respectively) aside from latissimus dorsi and iliocostalis lumborum (Ng et al., 2002). However, a different study assessing EMG normalization in females found that several different MVC maneuvers (i.e., upper/lower trunk flexion/extension) should be performed to find maximum EMG electrical activity for rectus abdominis, external and internal obliques, in addition to latissimus dorsi (Vera-Garcia et al., 2010). Supporting the lack of consensus on the best maneuver for MVC, one study found it difficult to reach a consensus on a maneuver producing maximum contraction level for all participants but found one submaximal maneuver that produced the highest muscle activation and lowest inter-subject variability.

While MVC is a widely used normalization method, some research studies have considered a more reliable normalization method can be found in submaximal MVCs. Similar to studies by Vera-Garcia et al. (2010) and Ng et al. (2002), a unanimous maneuver was not found for MVC in Biviá-Roig et al.'s (2019) study. However, their study was able to discern a common maneuver for subjects performing at a submaximal MVC. In a study by Yang and Winter (1983), investigators also found submaximal contractions as a reference point for normalization were more reliable, less variable between subjects, in comparison to a typical MVC value. As opposed to a comparison, another study attempts to subdue the subjectivity associated with MVCs utilizing a more mathematical approach: a set of submaximal contractions and a predicted maximal contraction (Marras and Davis, 2001). Due to its reliability and attainability for those with limited muscle control, these research studies focus on submaximal MVCs making it a logical candidate for EMG normalization.

The objective of this study was to normalize EMG signals in healthy individuals at a submaximal MVC for four trunk muscle groups: the deltoids, the pectoralis major, the latissimus dorsi, and the external obliques. The normalization was characterized by variability during a sustained muscle contraction at a targeted submaximal MVC level. The results of this study have the potential to serve as reference information in healthy individuals. More targeted innovations for improvement of postural control can be made for regions associated with muscle weakness (i.e., limited strength and control).

2. Materials and Methods

2.1. Subjects

Seven healthy young adults (four females and three males) between the ages of 18 and 23 participated in this study.

2.2. EMG Placement

The desired muscles (deltoids, latissimus dorsi, pectoralis major, and external obliques) were identified and prepared using Webcol™ alcohol prep wipes. Three Ambu® BlueSensor N EMG electrodes were used for each muscle group for the duration of the experiment: two were placed two centimeters apart longitudinally along the belly of each muscle group and one was placed on the superficial portion of bone acting as a ground. EMG placement for each muscle group was:

- *Deltoid:* halfway between deltoid the tip of the acromium and deltoid tubercle
- *Latissimus Dorsi:* three fingerbreadths distal to and along posterior axillary fold
- *Pectoralis Major:* anterior axillary fold
- *External Oblique:* midway along the anterior superior iliac spine, cephalad to the iliac crest

2.3. Collection of Maximum Voluntary Isometric Contraction (MVIC)

Research assistants gave verbal instruction for participants to perform the maximum voluntary isometric contraction (MVIC) of a given muscle group. Participants were sitting upright on a chair. Their posterior rested on the back of the chair and their feet were parallel to the ground for the duration of the MVIC task (Fig. 1a). MVIC value was calculated using filtered processing in LabView.

(a)

(b)

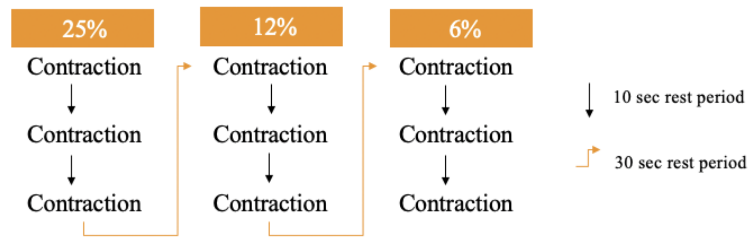

Figure 1. (a) Sagittal view displaying the position of participants during collection of MVIC and recording of contraction attempts. (b) Procedure for contraction tasks with submaximal target level (orange boxes). Each contraction attempt (‘Contraction’) is held for ten seconds. Subsequently, a ten-second rest period (black arrow) occurs before transitioning to the second contraction attempt. An additional ten-second rest period occurs before attempting the last contraction. A thirty-second rest period (orange arrow) takes place before shifting to a lower target contraction level.

2.4. Recording Contraction Levels

Participants were instructed to perform an isometric contraction task including three contraction periods, two short rest periods, and one long rest period before transitioning to a lower contraction level (Fig. 1b). Participants performed at 25%, 12%, and 6% of their MVIC, defined as target contraction levels for each participant. Participants contracted a given muscle group three times for 10 seconds at the target contraction level. Ten-second rest periods occurred after each of the first and second task attempts, and a 30-second rest period occurred after the third attempt. A lower target level was attempted by the participant after the 30-second rest period concluded. Participants performed the task for all three target contraction levels with visual feedback. This procedure was replicated across each of the specified muscle groups.

2.5. EMG Signal Processing

Raw EMG signals from muscle contraction were filtered within each task for all participants. The raw signal was amplified in differential mode by an electromyographic pre-amplifier for Ag/AgCl (DC power supply: ± 5 V @ 2.5 mA, differential gain: x300±2% @ 200Hz, C.M.R.R. at 65Hz:100 dB, bandwidth (-3dB): 10Hz to 2kHz, noise: less than 2μV RMS, input impedance: >100MΩ). With a time constant of 0.09665 seconds, low frequency cutoff band pass filtering (‘DC Remove’) on Spike 2 removed the DC offset characteristically associated with signal noise due to movement, perspiration, etc. Full wave rectification (‘Rectify’) and digital low pass filtering (‘Smooth’) at a time constant of 0.15 seconds produced the final EMG signal output.

2.6 Statistical Analysis
A given participant performed three contraction attempts for each target contraction level (25%, 12%, 6%). The mean contraction value or a ten second attempt towards the target level was calculated and averaged with Spike2.

2.6.1. Offset Error
The offset error was defined as the fraction in which a contraction attempt was not at the target contraction level. Offset error was calculated using the formula:

$$Offset\ Error\ = \frac{|Target\ Contraction\ Level\ -\ Mean\ of\ Contraction\ Attempt|}{|Target\ Contraction\ Level|} \cdot 100$$

The overall offset error was found by averaging the seven offset errors calculated from each participant for one target contraction level in a muscle group (e.g., 25% in deltoids or 12% in latissimus dorsi).

2.6.2. Variability: Standard Deviation (SD) & Coefficient of Variation (CV)
For a given participant, the SD was defined as the average deviation from the mean across the participant's three attempts towards their target level. The CV was calculated as the ratio between the SD and the mean. The overall value for each standardized measure (SD and CV) was found by averaging their particular set of seven values (i.e., due to seven total participants) for a target contraction level in one muscle group.

3. Results

Figure 2. Offset Error

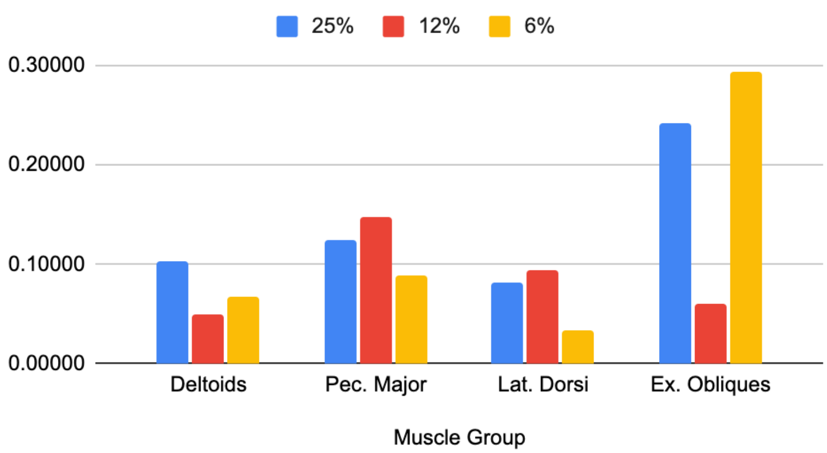

Figure 2. Mean percent of contraction attempts deviating from the designated target levels during the ten-second contraction. Each bar represents the mean from a set of seven data points indicative of each

participant in the study. Pec. Major = Pectoralis major. Lat. Dorsi = Latissimus Dorsi. Ex. Obliques = External Obliques.

3.1. Offset Error

The 12% contraction level produced the lowest offset error for the deltoids. The 25% and 12% contraction levels of the pectoralis major produced higher offset values relative to the remaining values on the graph. Additionally, the 6% contraction level had the lowest offset error for the pectoralis major. The 6% contraction level had the lowest offset error for the latissimus dorsi. The 12% contraction level had the lowest offset error for the external obliques. The external obliques produced the high offset error values in their 25% and 6% contraction levels.

Figure 3. Standard Deviation

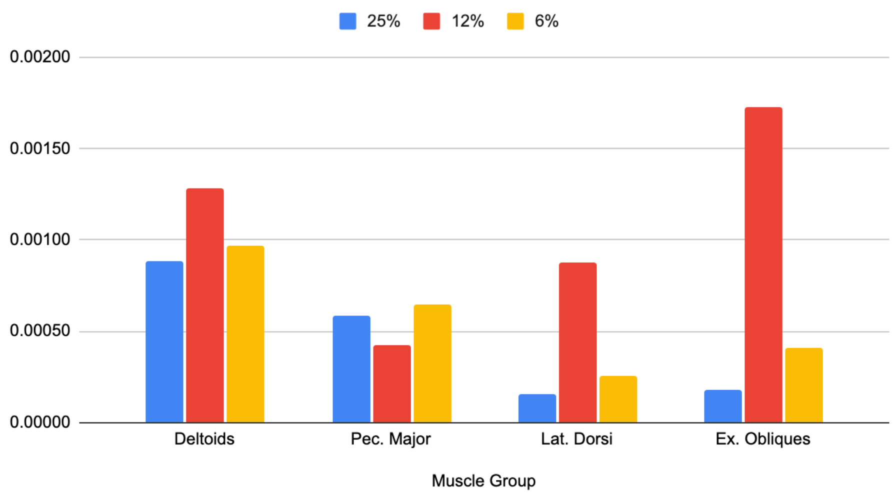

Figure 3. Displays the mean deviation from a set of three contraction attempts across participants. Each bar represents the mean from a set of seven data points indicative of each participant in the study. Pec. Major = Pectoralis major. Lat. Dorsi = Latissimus Dorsi. Ex. Obliques = External Obliques.

3.2. Standard Deviation

The 25% contraction level had the lowest standard deviation for the deltoids (SD = 0.0009). The 12% contraction level had the lowest standard deviation for the pectoralis major (SD = 0.0004). The 6% contraction level had the lowest standard deviation for the latissimus dorsi (SD = 0.0002). The 6% contraction level had the lowest standard deviation for the external obliques (SD = 0.002). The highest standard deviation values produced were by the 12% contraction level in the external obliques and the deltoids. The lowest values produced were by the 25% contraction level of the latissimus dorsi and the external obliques.

Figure 4. Coefficient of Variation

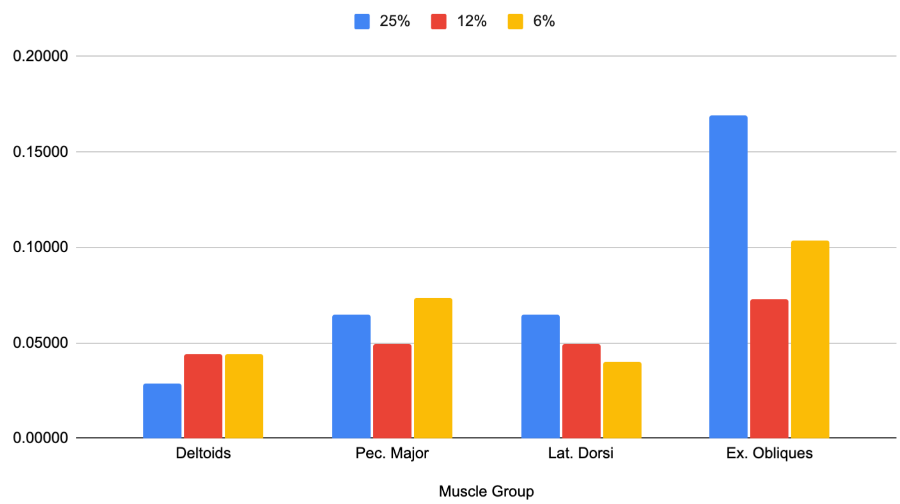

Figure 4. Displays the values for the mean ratio of standard deviation to mean across participants for a given contraction level. Each value represents the mean from a set of seven data points indicative of each participant in the study. Pec. Major = Pectoralis major. Lat. Dorsi = Latissimus Dorsi. Ex. Obliques = External Obliques.

3.3. Coefficient of Variation (CV)

The 25% contraction level had the lowest CV for the deltoids. The 12% contraction level had the lowest CV for the pectoralis major. The 6% contraction level had the lowest CV for the latissimus dorsi. The 12% contraction level had the lowest CV for the external obliques. While the 25% contraction level for the deltoids produced the lowest CV, the 25% contraction level for the external obliques produced the highest CV for this study.

4. Discussion

4.1. Standardized Measures

Offset error is a measure of a participant's inaccuracy during a contraction attempt. A higher offset error may indicate less control or increased difficulty when attempting to reach the target contraction level. The external obliques produced excessively high levels of contraction levels, and this may have been due to outliers in the data collected. Additionally, many participants were not familiar contracting their external obliques in comparison to the other muscles relevant to the study. The pectoralis major produced the second highest set of values for offset error. With a high inaccuracy relative to additional muscles observed in the study, a different maneuver for muscle contraction may be necessary to refine the accuracy of this task and permit an improved assessment of these values. The standard deviation provides a perspective on the variability across contraction attempts and across subjects. The high standard deviation produced by the 12% contraction level in the external obliques is consistent with limitations in control seen in the additional results of this study. With the majority of participants, the deltoids and the latissimus dorsi acted as the stronger trunk muscles with a higher MVIC than the external obliques or the pectoralis major. The weakness within the latter two muscles is supported by their higher offset errors (Fig. 2) and higher CV (Fig. 4).

4.2. Challenges in Implementation

While a submaximal contraction level has demonstrated potential as a reliable normalization method, I believe there lies a threshold where a submaximal level is not feasible. If the target contraction level is excessively low the results may not be as beneficial to a normalization study attempting to track accuracy towards a target contraction level. One of the primary concerns during the experiment included the few events in which the target contraction level fell below the ground level for muscle activity. Such instances primarily occurred during the six percent target contraction level of the external obliques or the six percent contraction of the pectoralis major. MVICs for both muscles were consistently lower in comparison to the additional two relevant muscles observed in this study. With previous studies experiencing significant variation in EMG signal interpretation, this unattainable contraction level could be a result of EMG electrode placement. As EMG is a relative measure, the muscle activity may have been misinterpreted initially if the ground electrode was not placed properly on the superficial region of the intended connective tissue (i.e., bone). In the future it may be important to consider a slightly larger contraction level than the six percent to ensure results are contributing new insights

4.3. Future Research

As external obliques were consistently in the extremes of the data set, a consideration for change may be found in the procedural portion of the study. Several researchers have found difficulty in deciding a maneuver (trunk flexion, extension, etc.) that best demonstrates a participant's MVIC (Vera-Garcia et al., 2010; Ng et al.; Biviá-Roig et al., 2019). Potentially additional studies focusing on a preferred maneuver for specified trunk muscle groups could prove beneficial to the normalization of EMG signals for a submaximal MVIC. A particular maneuver for a muscle contraction could drastically alter the offset error, SD, and CV values found in the results of this study. However, a study by Finucane et al. (1998) has demonstrated results of good-to-high reliability with non-normalized EMG measures of submaximal contractions. Therefore, submaximal contractions independently may be a point of research to consider.

With a small sample size, this experimental procedure should be replicated with a larger subject population to improve its reliability. An extension of this study could observe how a difference in sex may contribute to a change in the normalized EMG signals observed in this study. Additionally, this experiment could be adapted to function as a training regimen with an objective of refining the movements of the relevant trunk muscles. Implementing a nonvisual feedback component to the original procedure would demonstrate a similar characteristic to training tasks in other studies. Several studies found core strength training should take place over the course of three weeks or more to demonstrate significant improvement (DeMichele et al., 1997; Howe et al., 2011), and this should be a consideration for the timeline of this potential study.

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