Surface electromyographic amplitude normalization methods: A review

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ABSTRACT

The electromyogram is the summation of the motor unit action potentials occurring during contraction measured at a given electrode location. The voltage potential of the surface electromyographic signal detected by electrodes strongly depends on several factors, varying between individuals and also over time within an individual. Thus, the amplitude of the EMG signal itself is not useful in group comparisons, or to follow events over a long period of time. The fact that the recorded electromyographic amplitude is never absolute is mainly because impedance varies between the active muscle fibers and electrodes and its value is unknown. The EMG signal is highly variable and is dependent upon many factors. Thus, the amplitude of the temporally processed electromyography can only be used to assess short-term changes in the activity of a single muscle from the same individual when the electrode setup has not been altered. To allow comparison of activity between different muscles, across time, and between individuals, the EMG signal should be normalized, i.e. expressed in relation to a reference value obtained during standardized and reproducible conditions.

Notwithstanding the importance of electromyographic amplitude normalization, studies on functional activities, such as gait, do not seem to show a uniform methodology. Taking this into account, the main purpose of this chapter is to review and discuss different normalization procedures to relate the most appropriate method for specific situations, based on how the normalization method might influence data interpretation. In addition, this review supports the development of proper normalization procedures for biomechanical studies of functional activities like human gait.

Keywords: biomechanics, electromyography, isometric actions, dynamic actions, isokinetic actions, human gait

INTRODUCTION

Electromyography (EMG) is unique in specifying muscle activation. Specifically, surface EMG is a convenient index of muscle excitation and allows a description of muscular patterns (Bouisset & Do, 2008). Analysis of amplitude modulation is usually performed with the signal envelope (rectification and low-pass filtering) or by estimation of the average rectified or root-mean-square value with a sliding window (Campanini, Merlo et al., 2007). However, absolute EMG amplitude values are not reliable, due to many factors which can influence them (Farina, Merletti et al., 2004). Variance of the estimate can be substantially reduced with special techniques, such as signal whitening and multichannel processing (Campanini, Merlo, et al., 2007). Nevertheless, the main limitation in the interpretation of EMG amplitude results not from processing algorithms but from the masking effects of unwanted factors.

The use of amplitude modulation for the assessment of relative muscle activation during movement relies on two main requirements: 1) EMG amplitude should be directly related to the level of excitation sent to the muscle from the spinal cord (Bonato, 2001), and 2) amplitude should not be influenced by factors other than the excitation level (Bonato, Roy et al., 2001). Both requirements are difficult to satisfy during dynamic contractions: Amplitude is not directly related to the excitation level because of amplitude cancellation (Farina, Merletti, et al., 2004). Moreover, the relation between amplitude and excitation level depends on the pattern of motor unit activation (Fuglevand, Winter et al., 1993), electrode location in relation to innervations zones and tendon regions, and crosstalk. In dynamic contractions, volume conductor properties (Mesin, Joubert et al., 2006) and the relative position of the electrodes with respect to muscle fibers may vary over time; therefore, amplitude may be additionally influenced by geometrical factors, in a subject- and muscle-specific way. Quantitative comparisons of patterns of EMG amplitude during movement across muscles or subjects should consequently require analysis of the possible confounding factors.

IMPORTANCE OF NORMALIZATION PROCEDURES

The electromyogram is the summation of the motor unit action potentials occurring during the contraction measured at a given electrode location. This activity is often expressed in millivolts, but other units can be output by the acquisition device. EMG normalization is the process by which the electrical signal values of activity are expressed as a percentage of that muscle’s activity during a calibrated test contraction (Lehman & McGill, 1999). Aiming to improve absolute EMG reliability and to provide an expression of relative muscle activation, the normalization of EMG data requires the use of a standardized and reliable reference value against which experimental data are measured (Burden, Trew et al., 2003).

The amplitude and frequency characteristics of the raw EMG acquired using surface electrodes has been shown to be sensitive to many intrinsic and extrinsic factors (DeLuca, 1997). As such, the amplitude of the temporally processed EMG can only be used to assess short-term changes in the activity of a single muscle from the same individual when the electrode setup has not been altered (Mathiassen, 1997; Mathiassen, Winkel et al., 1995). To allow the comparison of activity between different muscles, across time, and between individuals, the EMG should be normalized (DeLuca, 1997; Knutson, Soderberg et al., 1994; Mathiassen, Winkel, et al., 1995; Mirka, 1991; Yang & Winter, 1984), i.e. expressed in relation to a reference value obtained during standardized and reproducible conditions (Mathiassen, Winkel, et al., 1995).

The fact that the acquired EMG amplitude is never absolute is mainly because the impedance varies between the active muscle fibers and electrodes and its value is unknown (Gerdle, Karlsson et al., 1999). The EMG is highly variable and is dependent upon electrode application and placement (Jensen, Vasseljen et al., 1993), perspiration and temperature (Winkel & Jørgensen, 1991), muscle fatigue (Hansson, Strömberg et al., 1992), contraction velocity and muscle length, cross talk from nearby muscles (McGill & Norman, 1986), activity in other synergists and antagonists (Mathiassen & Winkel, 1990), subcutaneous fat thickness, and slight variation in task execution (McGill, 1991), to name a few. It would be impossible to control all these modulators of EMG amplitude in a clinical setting. Therefore, when comparing amplitude variables between measurements, normalization of some kind is required, i.e. the EMG signal is converted into a scale that is common to all measurement occurrences. Normalization controls for the aforementioned variables and facilitates the comparison of EMG signals across muscles, between subjects, or between days for the same subject. By expressing the neural activity (EMG amplitude) as a percentage of the reference task, interpretation of the signal is moved into a framework of biological significance (Lehman & McGill, 1999).

AMPLITUDE NORMALIZATION METHODS

As already mentioned, because of the inherent variability of EMG signal, clinical interpretation of surface EMG requires the normalization of the EMG signal for physiological interpretation and for comparison between muscles and between subjects. Previous studies have used a number of different methods to produce reference EMG values for normalization purposes that can be repeated across participants and test days, including isometric, isokinetic and dynamic muscle actions (Burden, Trew, et al., 2003; Lehman & McGill, 1999; Yang & Winter, 1984), Figure 1.

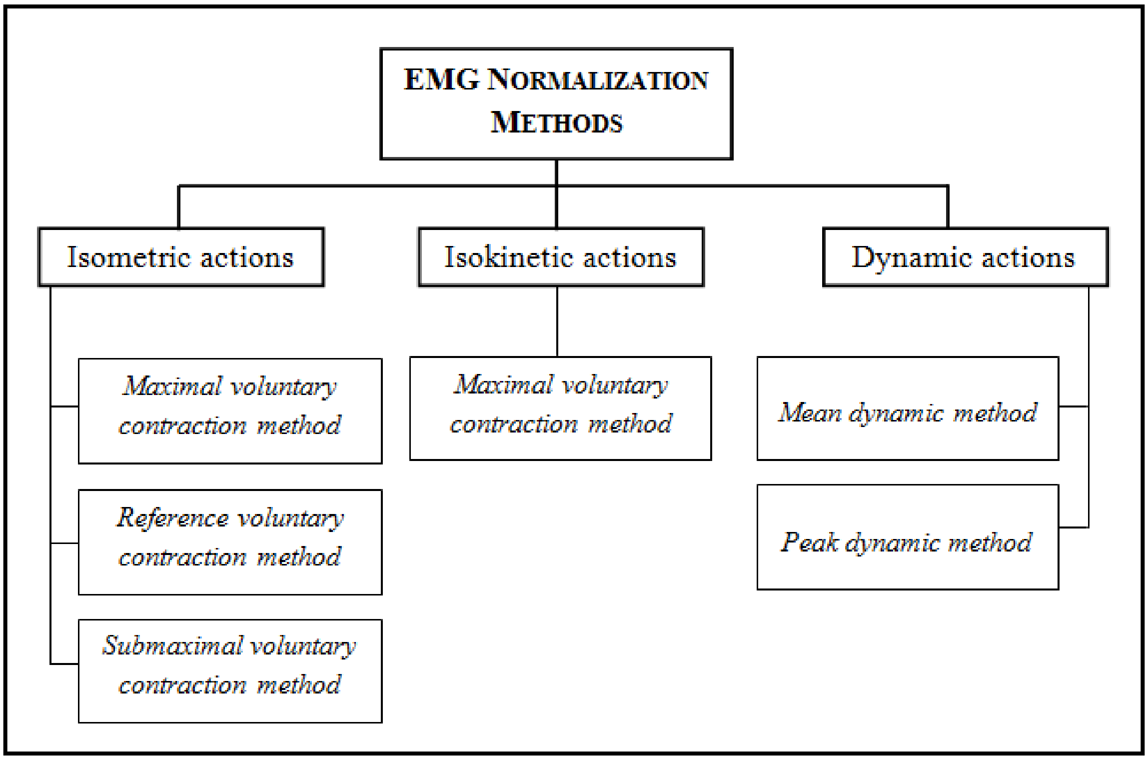

Figure 1: Usual electromyographic normalization methods.

a) Isometric actions

Maximal and submaximal voluntary contraction methods

Typically, EMG is expressed as a percentage of the maximum neural drive acquired while a subject performs an isometric maximal voluntary contraction (MVC) of the desired muscle. This is perhaps the most powerful strategy for physiologic interpretation in healthy people. However, maximal effort contractions are not usually possible for older patients or for patients with symptoms. Also, acquiring maximal electrical activity is not always achieved during an effort involving maximal force generation (Lehman & McGill, 1999).

The use of MVC has several technical concerns, which have an impact on the validity and reliability of the normalization protocol, associated with isometric testing. These concerns include the inertial effects at the onset of the test, and the patient fatigue, posture and motivation. Furthermore, normalization is not a measure of muscular tension, but is a measure of muscular activation expressed as a percentage of activity relative to the subject's MVC (Soderberg, 1992). Therefore, the EMG from an isometric MVC may not represent the maximum activation capacity of the muscle either at lengths other than those at which the MVC was performed, or under non-isometric conditions, as was shown by (Mirka, 1991). Additionally, the other major limitation of using the EMG from an MVC as the denominator in the normalization equation concerns the poor reliability of EMG signal that has been reported from such contractions (Clarys, 2000; Perry, 1992; Yang & Winter, 1983).

In spite of the aforementioned limitations, maximal isometric muscle actions are the suggested method of normalizing by SENIAM and Kinesiology’s guidelines and are the most widely employed normalization method (Burden, Trew, et al., 2003; DeLuca, 1997). Despite some studies demonstrating good EMG reliability between days (Hsu, Tang et al., 2002) and acceptable EMG reliability either between days or between weeks (Ball & Scurr, 2010), the majority of research has shown poor EMG reliability both within and between subjects and between sessions for isometric EMG levels of different muscles, particularly at maximal loads due to fatigue onset (Ball & Scurr, 2010; Bamman, Ingram et al., 1997; Heinonen, Sievänen et al., 1994; Yang & Winter, 1983), synergistic contribution and psychological factors (Enoka & Fuglevand, 1993; Miaki, Someya et al., 1999; Yang & Winter, 1983). Due to this instability of the EMG signal at near maximal levels, in (DeLuca, 1997) it is recommended that EMG amplitudes are normalized to force levels that are 80% of the maximum voluntary muscle action. Previous research has demonstrated that sub-maximal loads produced improved reliability between days compared to maximal loads for knee extensors and triceps (Rainoldi, Galardi et al., 1999; Yang & Winter, 1983).

All the aforementioned methods provide an output that relates the task EMG to the EMG obtained during a particular standardized event and, as such, were termed as bioelectric normalizations in (Mathiassen, Winkel, et al., 1995). An alternative manner of normalization involves translating the EMG that forms the denominator of the equation in the isometric methods into a force or torque variable. Typically, the EMG is related to a maximal contraction, or a submaximal contraction at a known level of force. One purpose of such biomechanical normalization methods is to generate an estimate of the physical load on the muscle under investigation (Marras & Davis, 2001; Mathiassen, Winkel, et al., 1995).

Reference voluntary contraction method

Controlled reference voluntary contractions (RVC) postures are interesting for clinical populations who are unable to attempt maximal efforts or who need an analogous controlled task for interpreting repeated tests. For example, standing upright holding 5 kg in the hands with the arms outstretched horizontally during each test session will produce a very similar low back moment day after day. Any change in un-normalized EMG amplitude could be due to any of the modulators and artifacts noted in the previous section. Any change in EMG amplitude (normalized to this RVC) indicates a true increase or decrease in the neural drive (Lehman & McGill, 1999).

b) Dynamic muscle actions

Peak dynamic and mean dynamic methods

Gait EMG signal was first normalized using a method that divided each point that constitutes the processed EMG by the peak value acquired from the same EMG. This method, subsequently referred to as the *peak dynamic method*, still appears to be popular among gait electromyographers (e.g. (Arendt-Nielsen, Graven-Nielsen et al., 1996; van Hedel, Tomatis et al., 2006)). In (Yang & Winter, 1984) a number of normalization methods are compared in an attempt to find the one which could provide a normal gait EMG template and, therefore, improve the use of electromyography as a diagnostic tool in gait analysis. Based on this rationale, the criterion for selecting the best method was the one that most reduced the inter-individual variability of the ensemble averaged EMG signal. The authors concluded that the *mean and peak dynamic methods* would help reduce the subject-specific and situation-specific conditions that may increase signal variance. They also pointed out that using these methods came at the expense of information inherent on the variance of the EMG signal. In (Ball & Scurr, 2010) it was found that squat jump and sprint provided reliable EMG amplitudes both between days and between weeks for all muscles of the triceps surae. However, dynamic tasks such as reaction tests (Horstmann, Gollhofer et al., 1988), sub-maximal running, one-leg hopping, drop jumps (Gollhoferl, Horstmann et al., 1990) and walking (Kadaba, Ramakrishnan et al., 1989) have shown poor EMG reliability between testing sessions.

c) Isokinetic actions

Electromyography amplitudes from an isokinetic muscle action have been proposed as an alternative to isometric muscle actions for EMG normalization to allow joint angle, torques and corresponding EMG amplitudes to be quantified (Kellis & Baltzopoulos, 1996; Mirka, 1991). Good EMG reliability has been shown between trials for isokinetic exercises for the knee extensors and flexors (Finucane, Rafeei et al., 1998; Larsson, 2003) and inappropriate reliability has been shown between isokinetic exercises for the triceps surae muscles (Ball & Scurr, 2010).

EMG AMPLITUDE NORMALIZATION DURING GAIT

Early investigations of dynamic tasks, including walking (Arsenault, Winter et al., 1986; Dubo, Peat et al., 1976), have used the EMG from an isometric MVC as the normalization reference value. However, it is generally recognized that the EMG from an isometric MVC is less reliable than the signal obtained from an isometric submaximal contraction (Yang & Winter, 1983), and that it might not represent the maximum activation capacity of the muscle (Enoka & Fuglevand, 1993). This has led to the evaluation and use of other reference values; in addition, some authors have expressed alternative aims for EMG normalization (Winter & Yack, 1987; Yang & Winter, 1983). As already mentioned, (Yang & Winter, 1984) compared four different normalization reference values to identify which one would result in the greatest reduction in inter-subject variability during walking. The use of either the mean or the peak linear envelope from the ensemble average of at least six strides reduced the inter-subject coefficient of variation in relation to the un-normalized data in all five lower limb muscles analyzed. In comparison, the inter-subject coefficient of variation was generally increased by using either 50% of the isometric MVC or the mean EMG per unit of isometric moment as the reference values. A reduced inter-subject coefficient of variation was also demonstrated for the biceps brachii during isotonic elbow flexions and extensions (Allison, Marshall et al., 1993) and for the gastrocnemius during a balancing task (Knutson, Soderberg, et al., 1994) by using the peak or mean ensemble value in comparison to the EMG from an isometric submaximal contraction (Allison, Marshall, et al., 1993) or MVC (Allison, Marshall, et al., 1993; Knutson, Soderberg, et al., 1994).

Although the peak and mean ensemble methods are the only feasible ways of normalizing EMG signal from patients with neurologic disorders (Yang & Winter, 1984), such methods tend to produce a normal EMG template for a particular task and, therefore, may remove the true biological variation within a group (Allison, Marshall, et al., 1993; Knutson, Soderberg, et al., 1994). While the isometric MVC method is the only one that aims to reveal the percentage of the maximum activation capacity of the muscle required to perform a specific task (Yang & Winter, 1984), generally, the other methods mentioned above lead to changes in the un-normalized data as a consequence of variations in load and velocity of movement (Allison, Marshall, et al., 1993).

In (Knutson, Soderberg, et al., 1994) the EMG activity of the gastrocnemius muscle was evaluated during gait using the MVC, mean dynamic method and peak dynamic method normalization in anterior cruciate ligament injured subjects. Data were compared statistically for the inter-class coefficient of variance (CV), variance ratio (VR) and intra-class coefficient of variance (ICC), being concluded that normalizing to MVC provided the most reproducible results based on the VR and ICC. However, this work did not identify how the normalization method might influence data interpretation and the justification for using the MVC method seems contradictory to that of (Yang & Winter, 1984) for rectus femoris, vastus lateralis, biceps femoris, tibialis anterior, and soleus muscles.

a) Mean dynamic method of normalization of the EMG signal during a full gait cycle

The mean dynamic method represents an average of both quiet and active periods during the gait cycle. Therefore, it may be more susceptible to systems with a low signal noise ratio, or it may represent baseline noise in movements that cause very phasic activation. This method, depicted in Figure 2, is more conservative as the overall variability in the signal may be reduced at the expense of true changes in activation level (Benoit, Lamontagne et al., 2003).

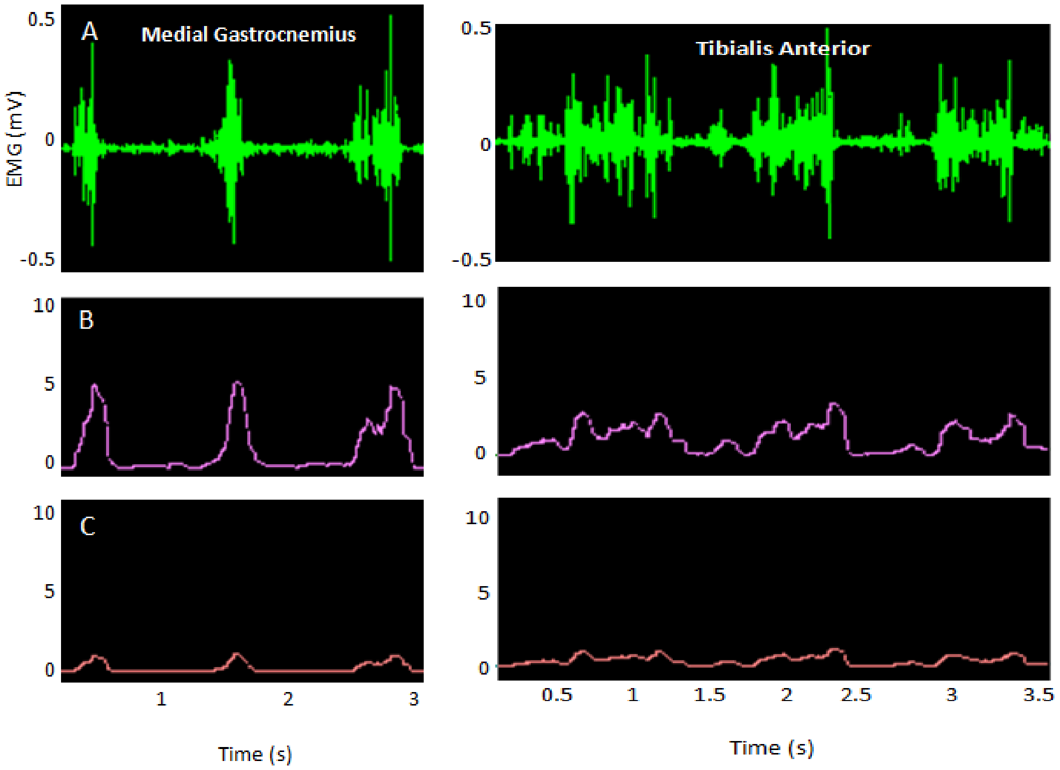

Figure 2: Raw EMG signal of medial gastrocnemius and tibialis anterior muscles obtained during gait at self-selected speed (A). The raw EMG signal was filtered and processed according to the root mean square (RMS) procedure and then normalized according to *mean dynamic* (B) and *peak dynamic* (C) methods.

b) Peak dynamic method of normalization of the EMG signal during a full gait cycle

When representing the percentage of the peak dynamic method of EMG signal during repeated gait cycles (Figure 2), the procedure indicates the periods during the gait cycle at which the muscle is most active. However, it does not indicate the muscle’s ability to activate. Therefore, the amount of activation cannot be related to any physiological measure and the patients’ inability to contract the muscle due to pain inhibition, and altered neuromuscular performance, may not be observed (Benoit, Lamontagne, et al., 2003).

c) Isometric maximal voluntary contraction method

Evidence suggests that the isometric maximal voluntary contraction (MVC) method best represents isotonic contractions at various speeds (Burden & Bartlett,

1999) and, with modeling, can estimate muscle forces during gait. However, adding to the disadvantages already mentioned, normalizing to isometric contraction does not represent dynamic contraction. The advantage of this technique is that normalization is based on the patients' ability to contract the muscle. Yet, this ability to perform a MVC is greatly affected by pain, and when the pain is inhibited with local analgesia postoperatively, there is an increase in the patients' ability to contract voluntarily the quadriceps to a maximal level (Arvidsson, Eriksson et al., 1986). The influence of pain-induced muscle inhibition would probably only affect the data when normalized to the MVC method. On the other hand, if the subject was unable to contract the muscle maximally during the MVC protocol, the relative amount of activation required during a cyclical movement such as gait might be represented by a change in the amount of activation recorded, and not merely by changes in temporal parameters. Although additional methods exist, such as using interpolated-twitch techniques (Rudolph, Axe et al., 2001) and using torque measurements to model the force output of the various muscle groups, these may not provide useful clinical information for rehabilitation purposes.

All normalization methods exposed present advantages and limitations, Table 1. Normalization by the isometric of MVC is unreliable (DeLuca, 1997) since muscle contraction during gait is mostly isotonic (Winter & Scott, 1991). The isokinetic MVC method has been used as a method to simulate with a higher degree of comparability to muscle contractions during gait. However, when compared to the isometric MVC method, it did not always produce satisfactory results, especially if one considers that it is better to have lower CV and lower VR, which represents the intra- and inter-individual variability of the EMG profile (Burden, Trew, et al., 2003). Another object of normalizing the EMG signal is to establish an average EMG profile to be a reliable template. Therefore, the peak dynamic method and the mean dynamic method have also been used (Winter and Yack, 1987; Yang and Winter, 1984), in addition to the two normalization methods referred above. Additionally, it has been reported that profiles obtained with these methods are close to one another, and that the mean method produces better results with respect to reliability, as already mentioned. However, it has also been noted that normalization by using the peak and mean methods, which do not use reference values obtained from reference exercises, intentionally removes the true biological variation within a normal group (Allison, Marshall, et al., 1993; Knutson, Soderberg, et al., 1994).

In (Nishijima, Kato et al., 2010), a different normalization method based on exercises under submaximal load (segment weight dynamic movement) is proposed. According to these authors, this method is as applicable as the isometric MVC method as a normalization method for establishing a gait EMG profile template. Moreover, for all of the eight muscles studied, the gait EMG peak amplitudes were lower than those obtained from the reference exercises of the segment weight dynamic movement method. Therefore, at least in terms of muscular activity level, being able to carry out the reference exercises may serve as a criterion of a person having a sufficient muscular activity level required for walking.

In Figure 3, the results of different EMG amplitude normalization methods are presented for rectus femoris (RF) activity during the propulsion phase of gait at self-selected speed. To access the EMG activity during isometric and isokinetic MVC the subject was positioned in closed kinetic chain on a quadriceps chair, under the following criteria: (i) hip and knee at 90º flexion; (ii) stabilization of the torso, the pelvis, right below the anterior superior iliac spine, and thighs; (iii) resistance applied 3 cm above the malleoli; (iv) arms crossed over the chest. Isometric MVC of RF muscle was performed by reaching maximal force as rapidly as possible and maintaining it for 3 seconds. Submaximal MVC was performed with 40% of isometric MVC and maintained for 3 seconds. Isokinetic MVC of the knee extensors was performed concentrically at 0.52 $rad \cdot s^{-1}$ interval up to 6.28 $rad \cdot s^{-1}$ between 90º and 0º of knee flexion. Reference contraction was obtained by asking the subject to hold a standardized load (3 kg). RF EMG activity during gait propulsion was expressed as a percentage of the peak RMS EMG from the isometric and isokinetic MVC, submaximal MVC and reference contraction. Dynamic repetitive movement exercises under the load of the segment weight (segment weight dynamic movement exercise (SWDM)) of the quadriceps femoris was performed with the subject seated with legs dangling and performed knee extension from lower-limb-dangling position to knee-extended position. Each SWDM exercise was repeated 15 times at 30 rep/min using a metronome. For each SWDM exercise, the peak amplitude during concentric contraction was measured in 12 trials, excluding the first 3 trials (where frequent EMG pattern variations were observed, probably due to the instability during initial periods of repetitive exercises), and the average value of 10 (excluding the highest and lowest values) was used as the 100% SWDM value. For mean dynamic method (MDM) and peak dynamic method (PDM), the RMS of EMG activity of propulsion was expressed as a percentage of the mean and the peak RMS of EMG activity of the intra-individual ensemble average,

$$X_{norm} = \frac{X - X_b}{X_{mean} - X_b} \tag{1}$$

and

$$X_{norm} = \frac{X - X_b}{X_{peak} - X_b}, \tag{2}$$

respectively, where X is the current value of the considered variable, X_{norm} is its normalized value, X_b is the baseline activity of RF muscle, X_{mean} and X_{peak} are the mean and maximum value observed along gait cycle.

As previously stated, the used normalization methods yield an output that is simply the ratio of the task EMG to the EMG used as the denominator in the normalization equation. As such, depending on the nature of the denominator, outputs from different normalization methods can differ in magnitude and pattern.

As depicted in Figure 3, different EMG normalization procedures lead to significant differences on the relative EMG amplitude developed during the activity assessed. Analyzing the normalized values of RF during propulsion it can be noted that this activity is extremely low when compared to the one obtained in maximal and submaximal contractions. However, this kind of normalization has a biological meaning since the values obtained during the activity are a percentage of the values obtained during maximal and submaximal contractions. The results show a higher magnitude of output from the MDM and PDM, which occurs as a result of using a smaller denominator in the normalization equation. Differences between these two methods are comprehensible taking into account the denominator values. Comparing MDM and PDM and the maximal and submaximal contraction methods, the first are more difficult to interpret as they are a percentage of the values obtained during the task. The RVC and SWDM normalization methods lead to relative values that are between the values obtained in the other methods and have more biological meaning than MDM and PDM.

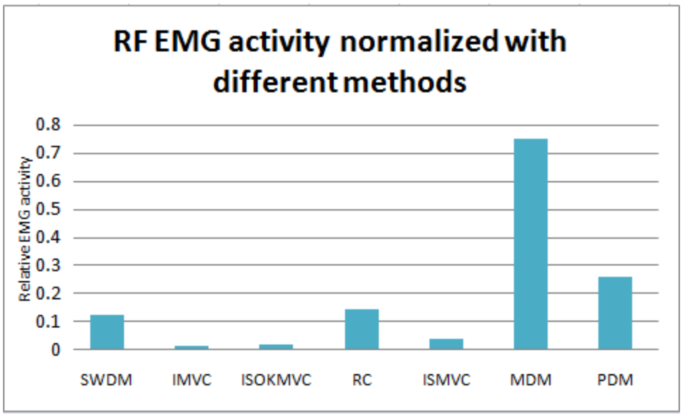

Figure 3: Relative EMG activity of RF obtained during gait propulsion at self-selected speed. Different normalization methods were used: segment weight dynamic movement (SWDM), isometric MVC (IMVC), isokinetic MVC (ISOKMVC), reference contraction (RC), isometric submaximal voluntary contraction (ISMVC), mean dynamic method (MDM) and peak dynamic method (PDM).

EFFECT OF NORMALIZATION METHOD ON INTER-SUBJECT VARIABILITY OF THE EMG SIGNAL

The use of normalization methods similar to the mean dynamic and peak dynamic methods has successfully reduced the inter-subject variability (Burden, Trew, et al., 2003; Winter & Yack, 1987; Yang & Winter, 1984). In addition, there is strong evidence that using the dynamic mean normalization reduces the inter-subject variability in relation to other normalization methods (Allison, Marshall, et al., 1993; Burden & Bartlett, 1999; Burden, Trew, et al., 2003; Knutson, Soderberg, et al., 1994; Yang & Winter, 1984) and the un-normalized EMG (Allison, Marshall, et al., 1993; Burden & Bartlett, 1999; Yang & Winter, 1984). Thus, if researchers or clinicians wish to retain the homogeneity of task-specific EMG signal for a group of individuals, they should avoid use of the peak dynamic method and, in particular, the mean dynamic normalization methods, as suggested elsewhere (Allison, Marshall, et al., 1993; Knutson, Soderberg, et al., 1994). According to (Burden, Trew, et al., 2003), normalization by mean dynamic method resulted in slightly more homogeneous pattern of gait EMG signal than the peak dynamic method. As to isokinetic maximal voluntary method, it should not be used in preference to the other methods, as is less reliable than un-normalized EMG signal or those normalized by the mean dynamic, peak dynamic or isometric maximal voluntary contraction methods (Burden, Trew, et al., 2003).

ABILITY OF NORMALIZATION METHOD TO DETECT CHANGES IN EXTERNAL FORCE

According to (Allison, Marshall, et al., 1993; Burden & Bartlett, 1999; Burden, Trew, et al., 2003), the isometric and isokinetic MVC methods reflect the increase in EMG that occurs in response to increments in external force. Unlike the MVC methods, the dynamic mean and dynamic peak normalization methods are not designed to provide the percentage of the maximal activation capacity of the muscle required to perform the isotonic contractions. Hence, it is unsurprising that the output of the mean dynamic normalization, and in particular the mean dynamic normalization methods, were unable to reflect the increase in EMG that occurred in response to the increase in force (Burden & Bartlett, 1999). This disagrees with the findings of (Allison, Marshall, et al., 1993) stating that normalization methods using either the mean or the peak EMG from the ensemble average were able to distinguish between load and no-load conditions for the same muscle.

CONCLUSION

Different electromyography amplitude normalization methods have been described. We reviewed several studies that focus on comparing the different methods. Isometric and dynamic methods seem to be the most recommended. However, both present advantages and limitations, being important to understand clearly the purpose of the electromyographic study and the implications of the method adopted on the interpretation of the results attained. Table 1 summarizes the main topics discussed in this chapter concerning EMG signal normalization procedures and interpretation.

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Table 1: Advantages, disadvantages/limitations and interpretation of normalization methods.

Normalization method		**Advantages**	**Disadvantages/Limitations**	**Data interpretation**
Isometric method	*MVC method*	Perhaps the most powerful strategy for physiologic interpretation in healthy people.	○ Poor reliability. ○ Is affected by inertial effects at the onset of the test, patient fatigue, patient posture, synergistic contribution, patient motivation, pain, neuro-muscle-skeletal dysfunctions and neurologic conditions. ○ May not represent the maximum activation capacity in other lengths or under non-isometric conditions.	Represents the percentage of the maximum neural drive acquired while a subject performs an isometric MVC of the desired muscle. Any change in EMG amplitude indicates a true increase or decrease in the neural drive.
	Submaximal voluntary method	Resolves the instability of the EMG signal at near maximal levels.	○ Inter-subject coefficient of variation generally increases by using either 50% of the isometric MVC. ○ Values can be lower than the obtained during the activity. ○ Is affected by inertial effects at the onset of the test, patient fatigue, patient posture, synergistic contribution, patient motivation, pain, neuro-muscle-skeletal dysfunctions and neurologic conditions. ○ Does not represent a dynamic contraction.	Percentage of the maximum neural drive acquired while a subject performs an isometric submaximal voluntary contraction of the desired muscle. Any change in EMG amplitude indicates a true increase or decrease in the neural drive.
	RVC method	Helpful for clinical populations who are unable to attempt maximal efforts or who need a similar controlled task for interpreting repeated tests.	○ Is affected by inertial effects at the onset of the test, patient fatigue, patient posture, synergistic contribution, pain, neuro-muscle-skeletal dysfunctions and neurologic conditions. ○ Does not represent dynamic contraction.	Any change in normalized EMG amplitude indicates a true increase or decrease in the neural drive.
Isokinetic actions	*Isokinetic MVC method*	Has been used as a method to simulate with a higher degree of comparability muscle contractions obtained in dynamic activities.	○ Is less reliable than the other normalization methods.	Represents the percentage of the maximum neural drive acquired while a subject performs an isokinetic MVC of the desired muscle. Any change in EMG amplitude indicates a true increase or decrease in the neural drive.
Dynamic muscle actions	*Mean dynamic method*	Reduces the inter-subject variability in relation to other normalization methods. Helpful for clinical populations that are unable to attempt maximal efforts.	○ Tends to produce a normal EMG template for a particular task and, therefore, may remove the true biological variation within a group. ○ It may be more susceptible to systems with a low signal to noise ratio or represent baseline noise in movements that cause very phasic activation. ○ It does not give an indication of what this activity level means with respect to the muscle's ability to activate.	Represents a percentage of the average of both quiet and active periods during the activity.
	Peak dynamic method	Reduces the inter-subject variability in relation to other normalization methods. Helpful for clinical populations that are unable to attempt maximal efforts.	○ Tends to produce a normal EMG template for a particular task and, therefore, may remove the true biological variation within a group. ○ It does not give an indication of what this activity level means with respect to the muscle's ability to activate.	Indicates at what periods during the activity the muscle is most active.

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