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An Algorithm for Defining the Onset and Cessation of the Flexion-Relaxation Phenomenon in the Low Back Musculature

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Abstract

The flexion-relaxation phenomenon (FRP) in the low back provides insights into the interplay between the active and passive tissues. Establishing a reliable algorithm for defining the lumbar angle at which the muscles deactivate and reactivate was the focus of the current paper. First, the EMG data were processed using six different smoothing techniques (no smoothing, moving average, moving standard deviation, Butterworth low pass filter at 0.5Hz, 5Hz, and 50Hz) herein called the processed EMG (pEMG). The FRP points were then defined using four thresholds (pEMG less than 3% MVC, pEMG less than 5% MVC, pEMG less than 2 times FRP pEMG, and pEMG less than 3 times FRP pEMG). Finally, a duration requirement was tested (no duration requirement, pEMG data must maintain threshold requirement for 50 data points). Each combination of smoothing, threshold, and duration were applied through a computer program to each muscle for all trials and established an EMG-off and EMG-on angle for each muscle. These estimates were compared to the gold standard of expert-identified EMG-off and EMG-on angles and the root mean square error (RMSE) between this gold standard and the predictions of the algorithms served as the dependent variable. The results showed that the most important factor to produce low values of RMSE is to utilize a Butterwort low pass filter of 5Hz or less and, if this is employed, there is no value to a duration requirement. The results also suggest that using the “3 times FRP pEMG” threshold technique may provide further improvements in these predictions.

1. Introduction

The flexion-relaxation phenomenon (FRP) has been explained as a synergistic load-sharing mechanism between active tissues (i.e., muscles) and passive viscoelastic tissues (e.g., ligaments, tendons, intervertebral discs, etc.) in the low back (Schultz et al., 1985). This myoelectric silence period often shows interesting alterations depending on the low back condition. The initiation and cessation of the EMG silence could be affected by the coordination of trunk and hip movement (Gupta, 2001), trunk velocity (Sarti et al., 2001), stretched passive tissues in low back (Solomonow et al., 2003a; Shin et al., 2009), low back muscle fatigue (Descarreaux et al., 2008), low back pain (Alschuler et al., 2009) and gender (Solomonow et al., 2003a). The results suggest that the FRP may be a worthwhile topic for discovering the underlying control mechanism and dysfunction in the low back. In those FRP studies, the 'FRP initiation lumbar flexion angle (EMG-off)' and 'FRP cessation lumbar flexion angle (EMG-on)' are the most common parameters employed to test hypotheses (Neblett et al., 2003). However, there has been no common agreement to define the EMG-off and -on angle of FRP when employing computer-based algorithm (Table 1).

Previous studies have employed a visual inspection method that is subjective and time-consuming (Dickey et al., 2003; Descarreaux et al., 2008; Gupta, 2001). A few studies attempted computer-based methods using various smoothing techniques and thresholds (Olson et al., 2004; Shin et al., 2009). The absolute-reference threshold using maximum voluntary contraction (MVC) is commonly employed (McGill and Kippers, 1994; Shin et al., 2009). The method usually determines a threshold such as 5% integrated EMG (IEMG) of MVC, and then uses the threshold for all experimental trials to find the EMG-off points. The method may increase objectivity of the analysis for EMG-off points, but the MVC trials can be potentially affected by the individual motivation and ability to perform the maximal exertions (e.g., low back patients). In other words, the absolute-reference threshold using MVC itself introduces variability (Mathiassen et al., 1995). Also, the absolute-reference is employed for all trials without modification, so it cannot sensitively interact with the characteristic of each trial such as changes in muscle activation pattern. A self-reference (i.e. within trial) method using EMG data from each experimental trial may address some of these concerns. The goal of this study was to examine computer-based algorithms for defining the lumbar flexion angles at which the myoelectric silence occurs during the trunk flexion motion (EMG-off) and the lumbar flexion angle at which the myoelectric activity reappears during the trunk extension motion (EMG-on).

Table 1. Summary of criteria to define onset and cessation of FRP

Authors	Threshold	Signal processing	Method
McGill and Kippers (1994)	3% of MVC	Low pass filtered at 2 Hz using Butterworth filter	Reference-based
Gupta (2001)	Abrupt changes	N/A	Visual inspection
Sarti et al. (2001)	Abrupt changes	100 ms moving average	Visual inspection
Dickey et al. (2003)	1% of MVC	Low pass filter at 6 Hz; Down-sampled to 20.5 Hz (Smoothing)	Visual inspection
Solomonow et al. (2003a)	N/A	100 ms moving average	Visual inspection
Olson et al. (2004)	5% of peak EMG during extension	Low pass filtered at 0.5 Hz using Butterworth filter	Reference-based
Olson et al. (2006)	N/A	Low pass filtered at 10 Hz using Butterworth filter	Visual inspection
Descarreaux et al. (2008)	N/A	10-450 Hz bandpass Butterworth filter	Visual inspection
Shin et al. (2009)	3% of MVC	Low pass filtered at 3 Hz using Butterworth filter	Reference-based

2. Methods

2.1 Subjects

This study employed a sample of recordings of EMG activity captured for previously published FRP study involving eight male participants with average age 26.2 (SD 2.9) years, height 178.2 (SD 5.0) cm and total body mass 70.6 (SD 5.3) kg (Ning et al., 2011). All procedures in the study were reviewed and approved by the Institutional Review Board for the Use of Human Subjects in Research.

2.2 Data Collection

Surface electromyography (Model: Bagnoli, Delsys Inc., Boston, MA) employing four bipolar surface EMG electrodes (Model DE 2.1 active, single differential electrodes) was placed bilaterally over the L4 paraspinals (2 cm lateral from L4 spinous process) and L3 paraspinals (4 cm lateral from L3 spinous process) (collected at 1024 Hz). The muscles were selected to investigate possible differences in the best algorithm for muscles with somewhat different functions.

Trunk kinematics data were collected using a magnetic field-based motion tracking system (Model: Motion Star (tethered model), Ascension Technology Corporation, Burlington, VT). Two sensors were secured to the skin over the T12 and S1 vertebrae and used to calculate lumbar flexion angle, defined as the difference between the T12 and S1 sensors in the sagittal plane (collected at 102.4 Hz). Data acquisition software (MotionMonitor Version 7.72, Innovative Sports Training, Chicago, IL) was used to collect and synchronize EMG and kinematics data. A lumbar dynamometer (Model: Kin/Com (hydraulic), Chattanooga Group, Inc., Chattanooga, TN) was used in conjunction with the asymmetric reference frame to provide static resistance and control of trunk flexion angle during the trunk muscle maximum voluntary contraction (MVC) exertions (Mirka and Marras, 1993).

Before the experimental trials, two MVCs in a 20 degree trunk flexion posture were collected, and used to calculate the 3% and 5% IEMGs of the MVCs (see next section). The subjects were then asked to perform five slow, controlled, sagittally symmetric trunk flexion-extension trials. In all conditions the pace of the motion was set as: seven seconds to move from upright to full flexion; six seconds of maintaining full flexion posture (including an exhale); and another seven seconds to move from full flexion to the upright posture. A metronome was used to assist the participants in maintaining the appropriate pace during the flexion-extension motion. An external trigger was used to indicate the timing of the full flexion posture, required in the data analysis process.

2.3 Computer-based FRP determination

A total of 160 EMG signals (8 subjects × 5 repetitions × 4 muscles (both right and left L3 and L4 paraspinals)) provided the data set on which we tested the effects of the forty-eight different combinations of the levels of the three independent variables: smoothing techniques (6 levels), threshold metrics (4 levels) and duration requirements (2 levels) (Table 2). Prior to implementing the computer-based algorithms a basic EMG processing procedure was conducted. The EMG data from the four muscles were filtered using a low-pass filter of 500 Hz, a high-pass filter of 10 Hz and the signal was notch filtered at 60 Hz (power supply noise) and 102.4 Hz (motion tracking system) and their harmonics up to 500 Hz. Each of these filtered EMG signals were then processed using all 48 processing techniques and these techniques are described in more detail below.

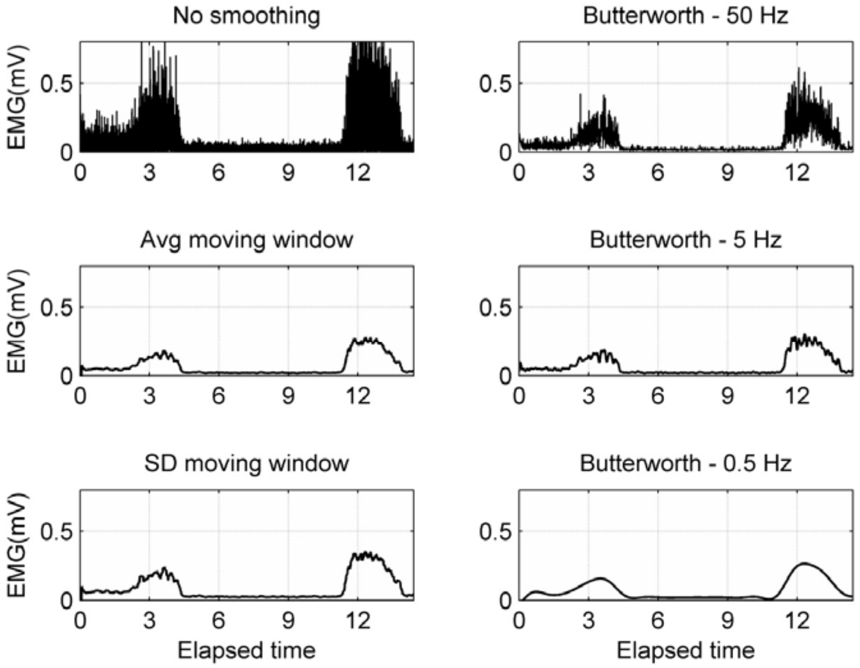
First, the ‘smoothing’ techniques considered in this study were those that have been used in previous studies and graphical presentations of the six techniques are shown in Figure 1. For five of the six techniques (all except moving standard deviation (SD) technique) the signals were first rectified. In the no-filter condition this was the end of the signal processing. In three of the smoothing conditions a fourth order, zero lag Butterworth low pass filter (dual pass) was applied on the rectified EMG signal (0.5, 5 and 50 Hz). The EMG data were filtered in the forward direction first, and the filtered sequence was then reversed and run back through the filter (dual pass). This method has been shown to provide precise zero phase distortion (Mitra, 2001). The last two smoothing conditions employed moving windows of size 256 data points where the window was centered about each sample to minimize possible phase distortion. The moving average (MAV) technique simply averaged the values in the window of the rectified data. The moving SDs (MSD) technique simply quantified the standard deviation of the values in the window of the unrectified data. The techniques created a series of averages or SDs of moving subsets of the full data set, and finally generated what we will call herein the processed EMG (pEMG) profile. Figure 1 represents pEMGs of all six types of data smoothing techniques. Thus, for our analysis the five levels of the independent variable ‘smoothing’ are: “None”, “50 Hz”, “5 Hz”, “0.5 Hz”, “MAV”, and “MSD”.

Second, the ‘threshold’ was defined as the point at which the magnitude of pEMG signals met the predetermined values (i.e., thresholds). Two categories of threshold were used: absolute-reference threshold and self-reference threshold were tested. The absolute-reference threshold makes use of data collected during MVC exertions prior to the experimental trials. In the current study the two levels of absolute threshold were 3% and 5% MVC (i.e., 3% and 5% of the integrated EMG from the MVC exertions). These are called absolute because the threshold was defined once and then used throughout the experiment (Table 1). While it is recognized that these 3% and 5% MVC IEMGs, captured in a 20 degree trunk flexion posture, are not an exact match with those that would have been collected in the near full flexion posture, this technique is consistent with those studies employing this % MVC approach (Dickey et al., 2003; McGill and Kippers, 1994; Shin et al., 2009). By contrast, the self-reference threshold values are calculated on a trial-by-trial basis. In this approach the steady-state value of the pEMG in the full flexion posture is found. This is a small signal and describes the steady state of the EMG signal while the participant assumes a full flexion posture. The self-reference threshold technique then uses this value and a multiplier (in this case 2× and 3×) to establish the threshold for EMG-off including 2 frp (note: "frp" denotes EMG signal while full flexion) and 3 frp (Figure 2). It is important to note that FRP must be achieved in the full flexion posture for these self-referencing algorithms to function properly. If the pEMG value is artificially high because FRP was not achieved in these full flexion postures (possibly due to muscle guarding due to the task being performed or the characteristics of the individual performing the task), the timing of the beginning of this period (i.e., FRP) as predicted by this algorithm will be incorrect. In the current study FRP was always achieved because of the simplicity of the tasks performed (no hand-held weight, sagittally symmetric full-flexion postures, healthy participants, etc.). In cases where there is a question as to whether FRP was achieved, a quantitative method of demonstrating that FRP was achieved is needed (e.g. Ning et al., 2011) prior to applying any of the algorithms considered in this study. In all four cases when the pEMG signal is less than the threshold value, the first EMG-off point is identified. If the value of the level of independent variable duration (described in more detail in the next paragraph) is "none" then the EMG-off point is that point. If the level of this duration variable is set as 50 data points, the algorithm will continue to follow the data until a sequence of 50 consecutive pEMG data points are less than the threshold. When this occurs the first of these fifty consecutive points is the point at which EMG-off occurred. Similar methods were used to find the EMG-on point. However, the computer algorithm in EMG-on searching started from the peak of the pEMG profile during the extension phase to the full flexion (backward search). The benefit of backward search was to avoid unexpected peaks in full flexion posture shown in previous studies (Solomonow et al., 2003b; Shin et al., 2009). Thus, for our analysis the four levels of the independent variable 'threshold' are: "3%MVC", "5%MVC", "2 frp" and "3 frp".

Third, the effectiveness of having a required 'duration' of meeting the threshold was investigated. This measure of required data points or "RDPs" was included to avoid situations where a single (or a few) data point(s) met the threshold, but were not a true signal in that the EMG signal is variable and noisy, especially under the low-level smoothing. No RDPs (e.g., find first point meeting threshold) and 50 RDPs (e.g., find first point followed by fifty data points continuously meeting threshold) (~50 ms) were compared. In other words, data must maintain threshold requirement for 50 data points in the "50 RDP" condition, but there was no such requirement in "no RDP" condition. Thus, for our analysis the two levels of the independent variable 'duration' are: "No RDPs" and "50 RDPs". In total there are 48 combinations (6 level of smoothing x 4 levels of threshold x 2 levels of duration).

Table 2. Independent variables and their definitions. Note: IVs (independent variables); MVC (maximum voluntary contraction); pEMG (processed EMG using six types of smoothing techniques); IEMG (integrated EMG); MAV (moving average); MSD (moving standard deviation); * (using unrectified EMG signal)

IVs	Level	Definition
Threshold	3% MVC	pEMG less than 3% IEMG of MVC
	5% MVC	pEMG less than 5% IEMG of MVC
	2 frp	pEMG less than 2 times the average of 1024 data points in FRP pEMG
	3 frp	pEMG less than 3 times the average of 1024 data points in FRP pEMG
Smoothing	None	No additional smoothing over rectified EMG
	MAV	One-fourth second moving window establishing average EMG profile
	MSD	One-fourth second moving window establishing SD profile *
	Butterworth at 0.5 Hz	Butterworth low pass filter at 0.5 Hz using rectified EMG
	Butterworth at 5 Hz	Butterworth low pass filter at 5 Hz using rectified EMG
	Butterworth at 50 Hz	Butterworth low pass filter at 50 Hz using rectified EMG
Duration	None	No data requirement
	50 data points	Data maintains threshold requirement for 50 data points


No smoothing

Butterworth - 50 Hz

Avg moving window

Butterworth - 5 Hz

SD moving window

Butterworth - 0.5 Hz

Figure 1. Six types of data smoothing techniques.

2.4 Implementation of the computer algorithm

First, the general EMG signal processing procedure generated the rectified EMG profiles. Six types of smoothing techniques were then applied on the rectified EMGs (except MSD – using unrectified EMG) to generate the six types of pEMG profiles (Figure 1). Second, the threshold values were determined. The absolute-reference threshold (3 and 5% MVC) was calculated by using premeasured IEMGs during MVCs (e.g., MVC (2.051 mV) × 0.03 = 0.065 mV). The self-reference threshold (2 frp and 3 frp) made use of the pEMG at full flexion in each trial to calculate the threshold. For example, if the pEMG in full flexion, captured from 50 Hz Butterworth filtered EMG profiles, was 0.023mV, 2 frp (0.023 mV × 2 = 0.046 mV) and 3 frp (0.023 mV × 3 = 0.069 mV) can be calculated and used to find the first point meeting the thresholds (EMG-off points with no RDPs) (point A and B in Figure 2). Third, the 50 RDPs were applied to the results of no RDPs such as point A and B in Figure 2. For satisfying the 50 RDP condition the pEMG must stay beneath the threshold (two reference lines in Figure 2). The first points satisfying the 50 RDP requirement were C and D. Note that no RDPs unexpectedly selected a point at the deep valley of the EMG signal as EMG-off point (A and B in Figure 2) and resulted in earlier EMG-off point than expected.

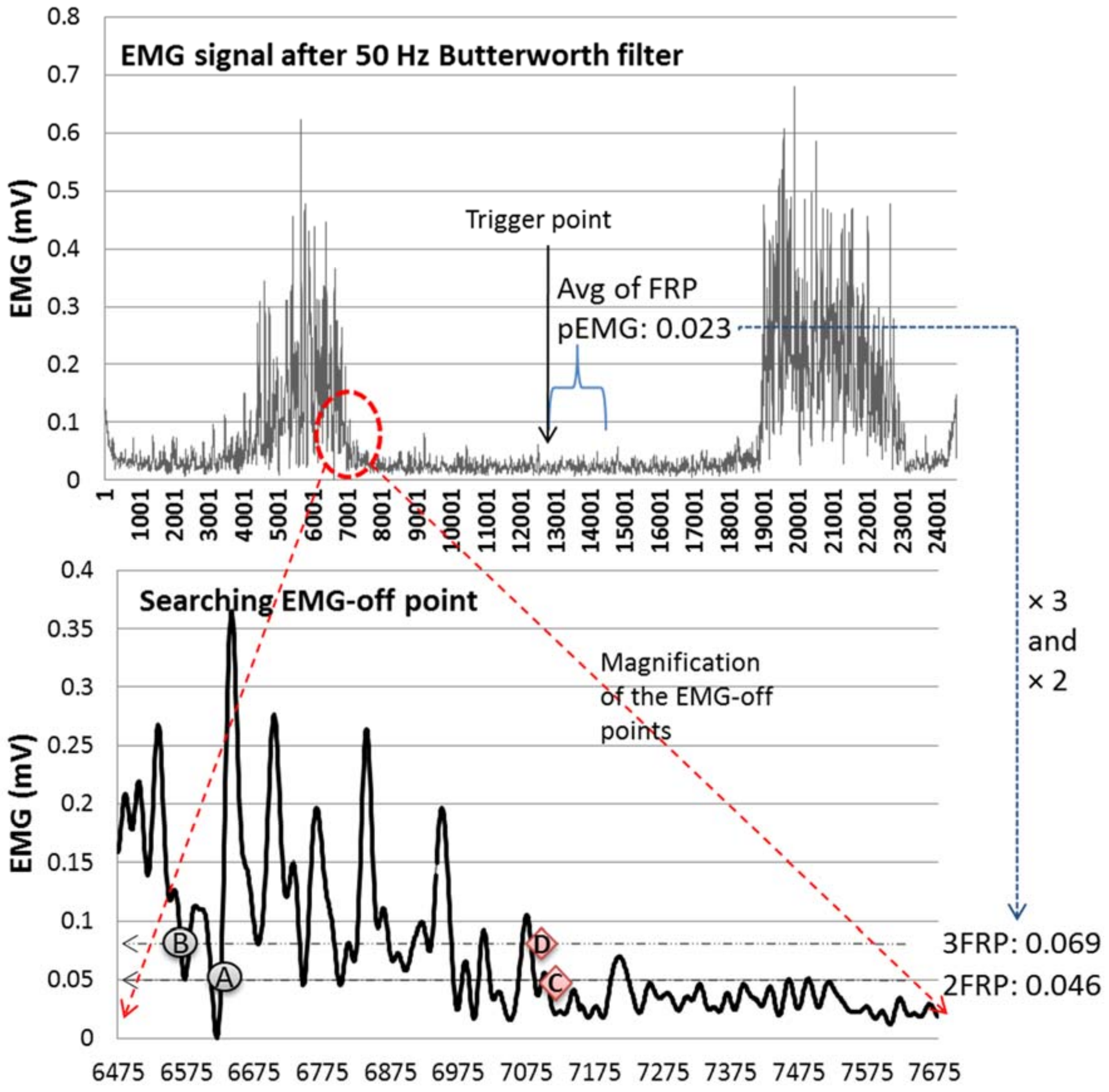


Figure 2. Visual illustration of the EMG-off point calculation of a trial. Note: 2 frp (0.023 mV × 2 = 0.046 mV); 3 frp (0.023 mV × 3 = 0.069 mV)

2.5 Standard EMG-off and -on point determination

Two experienced examiners visually determined the standard EMG-off and EMG-on points for evaluation of the computer-based algorithms following the method of Hodges and Bui (1996). The examiners inspected all 160 samples and identified the EMG-off and -on point for each. They repeated the same task after a week for calculating intra-examiner reliability. Finally, the mean of four data (2 examiners × 2 repetitions) was calculated, and then used as the "gold standard" for comparison with each of the predictions of computer-based algorithms. The root mean square error (RMSE) between the gold standard and predictions of the 48 algorithms were calculated and used as the dependent variable.

2.6 Statistical analyses

First, the assumptions of the statistical model (homogeneity of variances, normal distribution, and independence of observations) were evaluated using the visual inspection of residual plots technique advocated by Montgomery (2005). Second, single measure intraclass correlation coefficient (ICC (1,1)) was used to test intra-rater reliability, and average measure ICC (3,1) was used to reveal the inter-rater reliability of the estimates of the EMG-off and EMG-on angles (MacLennan, 1993; Shrout and Fleiss, 1979). In addition, paired t-test was employed to test for the presence of the inter-rater bias on these angles. ANOVAs were conducted to test the effect of three independent variables (threshold, smoothing and duration and their interactions) on RMSE, and Bonferroni post-hoc tests were performed to further explore the significant effects. Simple effects analyses were conducted to explore the main effects within significant two-factor interactions. Finally a paired t-test was employed to reveal any differences between the EMG-off and EMG-on values. The criteria *p*-value of $p<0.05$ was used for all statistical tests.

3. Results

The inter- and intra-observer reliabilities were calculated by ICC: (1) inter-observer reliability (average measure ICC = 0.993); (2) intra-observer reliability of examiner A (single measure ICC = 0.995); and (3) intra-observer reliability of examiner B (single measure ICC = 0.996). In addition, paired t-test confirmed no difference between two observers (*t*-value = 1.41; *p*-value =

0.16). The results revealed very strong repeatability of the visual inspection technique providing confidence in our gold standard for comparison.

The results of the ANOVA of the RMSE for the EMG-off variable revealed significant two-way interactions between threshold and duration (Figure 3), smoothing and duration (Figure 4), and smoothing and threshold (Figure 5) in both L3 and L4 paraspinals. As there were no differences in the trends between the L3 paraspinals and the L4 paraspinals, only the results of L4 paraspinals are presented in Figures 3, 4 and 5. Exploration of the threshold × duration (Figure 3) interaction showed that the RMSEs were significantly higher when under the No RDPs condition. However, the interaction between smoothing and duration (Figure 4) shows that the role of the duration variable is significant when employing the "50Hz" or "None" smoothing techniques, but was not relevant when using the other smoothing techniques (5 Hz, 0.5 Hz, MAV, and MSD). Likewise the smoothing x threshold interaction in Figure 5 shows that the "None" and "50Hz" smoothing techniques had much higher RMSE error values than the other smoothing techniques. Simple effects analysis of this smoothing x threshold two-way interaction (excluding the "None" and "50 Hz" conditions) revealed that the "3% MVC" threshold had a statistically significantly higher RMSE than the other three thresholds, while the "3 frp" threshold produced a statistically significantly lower RMSE under the "0.5 Hz", "MAV" and "MSD" smoothing techniques. Finally, this simple effects analysis showed that RMSE of the "2 frp" and "5% MVC" were not statistically significantly different from one another for any of the smoothing techniques.

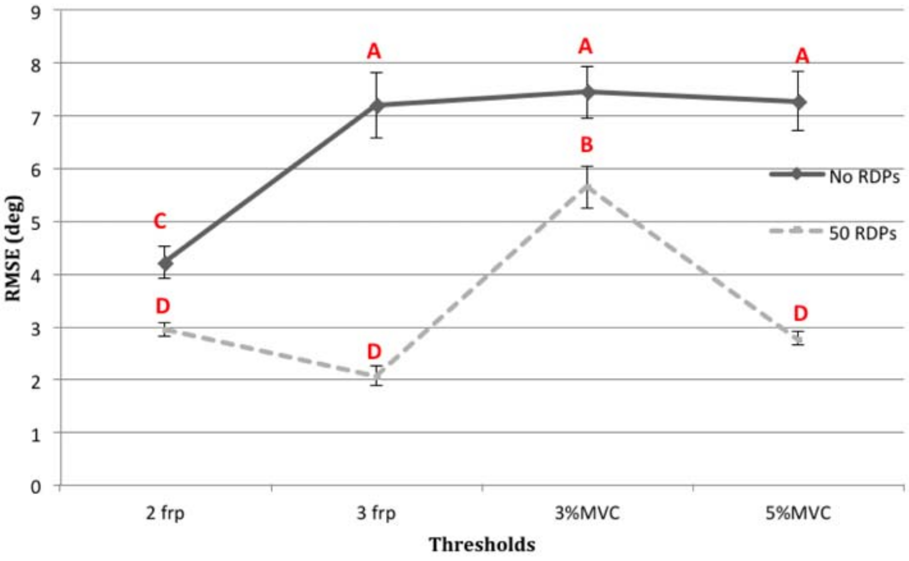


Figure 3. Interaction plot between thresholds and required data points (RDPs) of EMG-off point of L4 paraspinals. Note: The values “A”, “B”, “C”, and “D” represent the results of the post-hoc tests. Values of the RMSE with the same letter indicate that they are not statistically significantly different. Error bars show standard error.

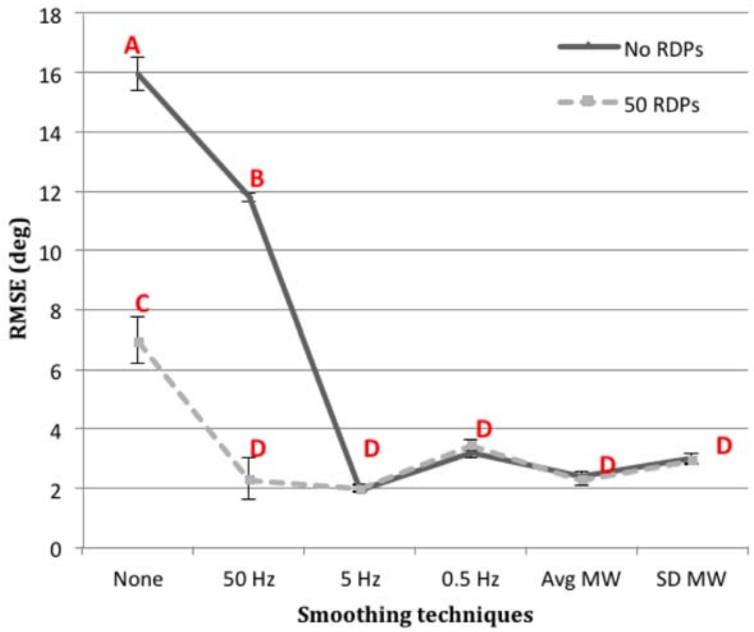


Figure 4. Interaction plot between smoothing techniques and required data points (RDPs) of EMG-off point of L4 paraspinals. Note 1: MAV (moving average); MSD (moving standard deviation); Note 2: The values “A”, “B”, “C”, and “D” represent the results of

the post-hoc tests. Values of the RMSE with the same letter indicate that they are not statistically significantly different. Error bars show standard error.

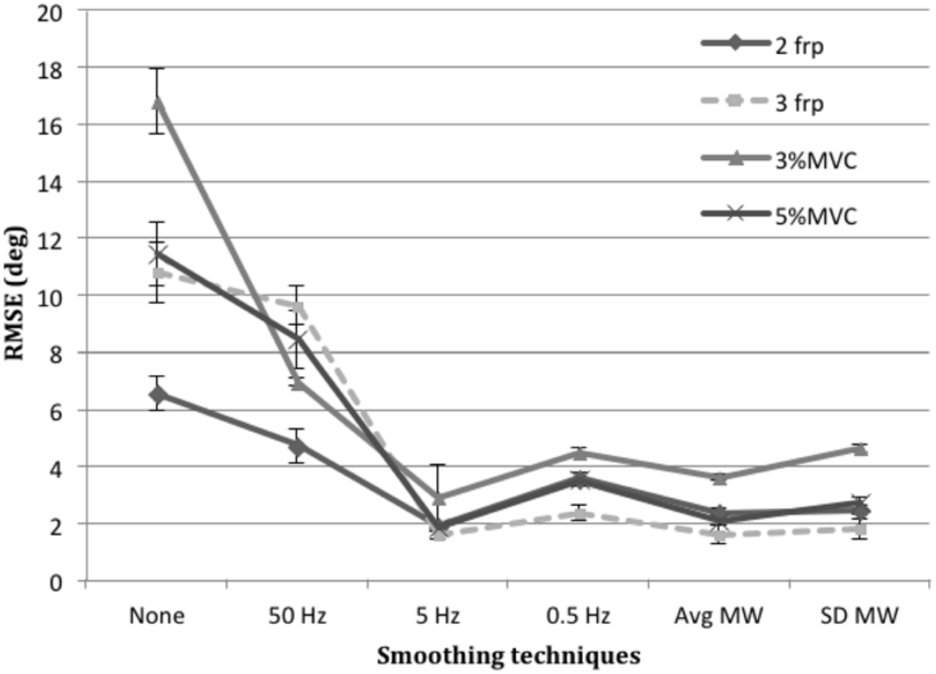


Figure 5. Interaction plot between smoothing technique and threshold for the EMG-off point of the L4 paraspinals. Note 1: MAV (moving average); MSD (moving standard deviation); Error bars show standard error.

Interestingly, the results of the analysis of the EMG-on data showed significantly lower levels of RMSE for both L3 and L4 paraspinals (p-value < 0.001 for both muscles) as compared to EMG-off RMSE values. In fact, if the value of smoothing was “MAV”, “MSD”, “5 Hz” or “0.5 Hz” (the acceptable smoothing values) the average RMSE for the EMG-on value was only 0.2 degrees while the comparable value for EMG-off was 3.1 degrees.

4. Discussion

This study aimed to establish characteristics of a reliable algorithm for defining the lumbar angle at which the lumbar extensor muscles “turn off” and “turn on” during the trunk flexion and extension movement, representing the natural transition of the extension moment generation from the active to the passive tissues. First, when comparing the predictability of the EMG-off vs. the EMG-on angles, the results of this study showed significantly lower values of the RMSE for the EMG-on angles (in concentric phase of the motion) as compared to the EMG-off angles (in the eccentric phase of the motion). The result is likely attributable to the greater muscular activation level in the concentric contraction motion than the eccentric contraction motion under the same level of force generation (Huang and Thorstensson, 2000; Tesch et al., 1990). EMG signals with more abrupt changes in activation level (as those seen during the transition from silence to concentric trunk extension) provide a much more definable EMG-on value as compared to the more gradual "transitioning" that occurs as the trunk extension moment is gradually shifted from active to passive tissues during the eccentric motion. This was seen both in terms of the ease at visually defining the EMG-on angles as well as the accuracy provided by the computer algorithm technique (when a Butterworth filter with a low pass cutoff value of 5 Hz or less was employed.) The remainder of this Discussion therefore will focus on the characteristics of an algorithm for establishing the EMG-off angle during the eccentric trunk flexion motion.

The results of the effects of 'duration' and 'smoothing' are closely related and are therefore discussed together. The results of this study show that the role of a duration requirement (RDPs) is irrelevant when appropriate smoothing techniques are employed. More specifically a Butterworth filter with a cutoff frequency of less than 5 Hz negated the value of a duration factor in the algorithm in this study. This provides support for the argument that the 50 RDP functioned as a simple filter on the EMG signal. A comparison of the six smoothing techniques considered in this study, showed that the "50 Hz" and "None" conditions provided comparatively high RMSE values and should not be utilized. Of the remaining four smoothing techniques considered in this study, the 5 Hz cutoff frequency generated the lowest average RMSE values of all considered. The increase in average RMSE value between 5 Hz and 0.5 Hz indicates an over-smoothing effect that can have a deleterious effect on these EMG-off point predictions. Of the levels of smoothing considered in this study, a fourth order, zero lag Butterworth low pass filter with a 5 Hz cutoff is recommended.

Regarding the difference between two types of thresholds, some limitations of the absolute thresholds (3% and 5% MVC) as compared to the self-reference thresholds (2 frp and 3 frp) may be indicated by the results of this study. Our results indicated that when the appropriate smoothing filter is applied ("5 Hz", "0.5 Hz", MAV, or MSD in this study) the threshold value of 3 frp generated consistently lower values of RMSE of the predicted EMG-off values (Figure 5). One of the benefits of the self-reference threshold approach is that it overcomes some limitations of the absolute threshold approach. Specifically, the absolute threshold approach is not able to account for the small variations in the magnitude of the EMG signal in the full flexion posture that can exist between trials. Once the absolute threshold is set (3% MVC or 5% MVC) these do not change regardless of what is happening with the subject. For example, it is possible that the subject can have different muscle activation patterns after an FRP protocol designed to generate viscoelastic strain (Solomonow et al., 2003). In addition, an increase of the FRP EMG on imposition of external loads in flexed position were observed by Schults et al. (1995) as compared to the normal flexed condition, suggesting the need to redefine the FRP EMG between trials. In addition, the self-reference threshold may be useful for the study of chronic low back patients because it does not require the use of maximum voluntary contraction exertions. Prior studies have revealed clinical significance of FRP in diagnosis and treatment of patients with low back pain (Colloca and Hinrichs, 2005; Neblett et al., 2003; Shirado et al., 1995; Watson et al., 1997). If the 2 frp or 3 frp approaches are to be used in this population the achievement of true FRP must be established quantitatively (e.g. Ning et al., 2011) prior to employing these algorithms to determine onset/cessation values. If it is not achieved, then unexpected and unreasonable results will be found because of the over-inflation of the baseline FRP value. For example, if a hand-held load is introduced into the full flexion posture there may be a significant increase in the value of the EMG signal generated (e.g. guarding response). If this increase in the FRP EMG is not allowed to abate, then the self-reference techniques will generate inaccurate results. The system must be allowed to come to a new FRP silence period before applying the algorithm to establish onset. Likewise if the subject population is a group of low-back patients, the risk of FRP not being achieved is high (muscular guarding or other protective mechanisms) and the achievement of FRP must be demonstrated. In both of these cases, if FRP is never achieved, then the algorithm should not be applied. With these important caveats, the self-reference threshold "3 frp" tested in this study does appear to have some advantages over the absolute reference techniques evaluated.

The results of the current study have helped to define appropriate components of an algorithm to identify the EMG-off and EMG-on points during studies focused on exploring the flexion-relaxation phenomenon of the trunk musculature. Benefits of a computer-based algorithm for this purpose are twofold. First, the method is objective. The human visual inspection method introduces the potential for bias. Second, the computer-based algorithm can dramatically save time for data analysis. An important limitation to the generalizability of the results of this study is that our participants were healthy young adults and the task they performed was relatively simple and consistent. Future studies are required to expand this work to demonstrate the effectiveness of this approach in tasks requiring different levels of effort while in the full flexion posture as well as exploring the value of this technique for use in patients with low back conditions.

Conflict of interest statement

The authors do not have any financial or personal relationships with other people or organizations that could inappropriately influence their work.

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