Electromyography (EMG) normalization method for cycle fatigue protocols

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ABSTRACT

HUNTER, A. M., A. ST CLAIR GIBSON, M. LAMBERT, and T. D. NOAKES. Electromyographic (EMG) normalization method for cycle fatigue protocols. Med. Sci. Sports Exerc., Vol. 34, No. 5, pp. 857—861, 2002. Purpose: To determine the most effective electromyographic (EMG) normalization method for cycling fatigue protocols. Methods: Ten healthy subjects performed two 5-s isometric knee extension maximal voluntary contractions (MVC) at a knee joint angle of 60°, two fixed cycle pedal contraction at knee joint angles of 60° (60°A) and 108° (108°A), and a dynamic single maximal revolution of a cycle pedal (1REV). Integrated EMG (IEMG) data were recorded for all contractions and power output recorded during MVC and 1REV. Results: Mean IEMG for MVC was significantly (P < 0.01) greater than 60°C, 108°C, and 1REV. There were no significant differences between MVC and 1REV power output/EMG relationship. Conclusions: MVC will record a higher IEMG than 60°A, 108°A, and 1REV. As IEMG was greatest during MVC, and the relationship between IEMG and power output was not different between MVC and 1REV, normalization against maximal possible recruitment potential is most likely during MVC. Key Words: INTEGRATED ELECTROMYOGRAPHY (IEMG), VOLUNTARY CONTRACTIONS

Electromyography (EMG) is used to display muscle activation patterns and has been extensively employed to interpret both dysfunctional and functional muscle recruitment patterns related to cycling activity (8).

Absolute EMG signals only provides the investigator with a subjective measurement of muscle activation. This subjectivity is caused by, first, high levels of neural recruitment intersubject variability and, second, the inaccuracy associated with using different surface electrode placement sites when conducting repeated trials. To overcome these problems of quantifying an EMG signal so that the muscle’s relative activity can be assessed, it is necessary to use a normalization technique. Comparing a specific EMG muscle activity with a reference EMG value and expressing the activity of the muscle as a percentage of this reference value can establish relative muscle activity. This enables the conversion of subjective EMG values into data points that have a significant interpretative meaning (12).

EMG normalization allows for comparisons obtained over a variety of conditions. Between-subject comparisons can be made after normalizing the EMG activity, because the reference activity for a given subject is compared with the relative amount of activity for that subject and is therefore dependent on each individuals’ own proportion of maximal activity. The investigator then has the ability to compare the relative EMG for a given workload across subjects. Furthermore, EMG normalization also allows for slight changes in variables such as electrode placement and skin impedance (12).

For EMG normalization to be effective, the reference activity has to be reliable and repeatable. Knuston et al. (9) compared dynamic with isometric leg extension. Their results showed that the isometric leg extension tests had a higher intraclass correlation coefficient between trials compared with dynamic leg extension, therefore improving the reproducibility of the data.

As well as being a reliable reference point, the EMG normalization method should also have relevance to the given task. Yang and Winter (17) concluded that the isometric leg extension maximal voluntary contraction (MVC) is the only method that aims to reveal the percentage of the maximum activity of the muscle performance requirement to a specific task. However, when normalizing EMG data to a dynamic task such as cycling, there are a number of differences in the actions of the muscles involved that make the relevance of isometric MVC questionable.

Previous researchers have documented that a maximum contraction implies that all motor units are firing at their maximum rate (11). To obtain a maximum contraction during static activity, it is essential to determine the optimal knee angle. St Clair Gibson (14) showed that during isokinetic activity, the optimal knee angle (reference 0° with the leg in full extension) for peak force during concentric activity was between 60° and 65°. In support of this, it has been widely recognized that the EMG recorded during isokinetic MVCs of knee extensor muscles is largest in mid range of motion (5,7) and is greater for concentric in comparison with eccentric activity (2,7,15). However, Bolourchi and Hull (6) reported that during cycling, the peak pedal load was recorded between 90 and 100° of the 360° cycle.
(0° being with the pedal at 12 o’clock), which means that the knee angle is greater than 60° at this pedal position. We therefore estimated a knee angle of 108° for peak force by seating a subject on the bike, setting the pedal at 95° and measuring the angle of that knee.

To the authors’ knowledge, there are no data on the most effective EMG normalization protocol for cycle fatigue protocols. Accordingly, four normalization protocols were designed for EMG measurement: isometric MVC, isometric cycle pedal contractions at knee angles of 60° (60°A) and 108° (108°A), and a one dynamic maximal cycle pedal revolution (1REV) with the aim of determining the most effective normalization procedure for cycling protocols.

**MATERIALS AND METHODS**

Ten healthy men volunteered for this study. The mean age and body mass of the subjects were 21.4 ± 2.6 yr and 72.3 ± 8 kg, respectively. All subjects were physically active, and each signed an informed consent before the study. The Research and Ethics Committee of the University of Cape Town Medical School approved the study.

**Isometric maximal voluntary contraction (MVC).** The MVC of the subject’s right knee extensor muscles were measured on an isokinetic dynamometer (Kin-Com, Chattanooga Group Inc., Chattanooga, TN). Subjects sat on the dynamometer and their hips, thighs, and upper bodies were firmly strapped to the seat. In this position their hip angle was at a 100° flexion. The right lower leg was then attached to the arm of the dynamometer at a level slightly above the lateral malleolus and the axis of rotation of the arm was aligned with the lateral femoral condyle. The arm of the dynamometer was set so that the knee was at start and stop angles of 60° and 65°, respectively, from full leg extension (Fig. 1a). Each subject performed four submaximal familiarization contractions before performing two maximal MVCs, the maximal of which was used for subsequent analyses. All subjects were encouraged verbally to exert maximal effort during both MVCs.

**Fixed pedal isometric maximal voluntary contraction.** The subject was positioned on an electronically braked cycle ergometer (Wat sof, Watsystem, ITC Corp., Bloomington, MN). The saddle height was adjusted to a position chosen by each subject to be the most economical for his own cycling performance. With the use of a goniometer, a knee joint angle of either 60° (60°A) (Fig. 1b) or 108° (108°A) (Fig. 1c) (from full leg extension) was determined by placing the axis of rotation on the lateral femoral condyle and lining up each of the two arms on the center plane of the femur and fibula. A wooden block was built to a dimension of 16 × 8 × 8 cm with a deep groove inserted across the 8 × 8 cm section to accommodate the bottom of the paddle. The block was then positioned underneath the pedal and its height was adjusted to fit the required knee joint angle by placing the appropriate number of wooden tiles between the floor and block. Each subject performed four submaximal familiarization contractions before performing two maximal isometric contractions, the latter of which were used for subsequent analyses. All subjects were encouraged verbally to exert maximal effort during both contractions.

**One revolution maximum (1REV).** The feet of the subjects were firmly strapped into the pedals of the cycle ergometer and the right knee joint set at a starting angle of 108° by using a goniometer as described above. The subjects were instructed to remain seated in the saddle throughout the test. With a starting load of 0.7 kg/body weight the subject was instructed to pedal as many revolutions as possible; if two or more revolutions were completed, the subject was instructed to stop. The protocol was continually repeated by adding 0.05 kg/body weight on the starting load each time until the subject could no longer complete a full revolution of the pedal. The data from the last single full revolution was subsequently used for analyses.

**Electromyographic (EMG) testing.** Before maximal isometric strength testing on the Kin-Com isokinetic dynamometer, EMG electrodes were attached to the subject’s lower limb midway between the superior surface of the patella and the anterior superior iliac crest on the “belly” of the rectus femoris. Before placement of the electrode, the site was shaved, abraded with sandpaper, and cleaned with ethanol. A triode electrode (Thought Technology, Montreal, Quebec, Canada) was placed on the skin with an electrode gel applied between the skin and the electrode. The surface area of the electrode was 3 cm in diameter and the needle tip was centered in the electrode. The electrode was covered with a semi-permeable film to protect the surface of the electrode from sweat and cleaning solutions.

**FIGURE 1—Isometric maximal voluntary contractions for (a) leg extension (MVC) at a knee joint angle of 60°, fixed pedal contractions at knee joint angles of (b) 60° (60°A), and (c) 108° (108°A). The arrow indicates direction of force.**
Canada) was then taped on the leg, covered with cotton swabs to minimize interference from sweat and connected to a preamplifier. Outputs from the preamplifier were relayed to a Flexcomp/DSP EMG apparatus (Thought Technology, Montreal, Canada) via a fiber optic cable and stored by an on-line computer. EMG was recorded for 5 s during MVC, 60°A, 108°A, and for the time taken to complete 1REV. The EMG signal was captured at 1984 Hz and notch filtered at 50 Hz to limit electrical interference.

The raw EMG signals were full-wave rectified, movement artifact removed by using a high-pass second-order Butterworth filter with a cut-off frequency of 5 Hz, then smoothed with a low-pass second-order Butterworth filter with a cut-off frequency of 5 Hz. This was performed using MATLAB® gait analysis software. This integrated EMG signal was proportional to the amount of force generated by the muscle (10).

Statistics. A one-way ANOVA (with repeated measures) was used to evaluate statistical significance of the variables measured. A Scheffe’s post hoc test was used to detect differences of the activities measured. Single comparisons between activities for work/EMG were analyzed with a paired Students t-test using two-tailed values of P. Significance was accepted as P ≤ 0.05 and all data expressed as mean ± SD.

RESULTS

Integrated EMG (IEMG) for MVC was significantly (P < 0.01) greater than 60°A, 108°A, and 1REV (Table 1). Table 1 shows that 60°A, 108°A, and 1REV produced 93, 86, and 75%, respectively, less IEMG than MVC; 108°A produced 50% more IEMG than 60°A. Intersubject coefficient of variation for IEMG during MVC, 60°A, 108°A, and 1REV was 57, 71, 82, and 45%, respectively.

Although there were no significant differences between MVC and 1REV work/EMG relationship, MVC produced 37% more work/EMG than 1REV (Table 2).

DISCUSSION

The findings of this study were that MVC produced greater IEMG activity than 60°A and 108°A, which would suggest a higher rate of motor units firing or recruitment of a greater number of motor units. This could be caused by, first, a greater force output in the MVC group. Although force was not measured in 60°A and 108°A, previous studies have shown that during isometric contractions the EMG signal is proportional to the amount of force generated by the muscle (10).

Second, MVC involves just the knee joint, whereas 60°A and 108°A involve the hip, knee, and ankle joint. During MVC, the subject is tightly strapped into the chair to minimize movement and isolate contraction of the quadriceps femoris muscle group. Throughout 60°A and 108°A, 12 superficial muscles that represent the prime movers involved in imparting energy to a bicycle are likely to be used (8). Subsequently, it is possible that because of the number of synergists involved, they will not all be contracting maximally and simultaneously, which results in a lesser IEMG recording from the rectus femoris. Moreover, if this is the reason for the differences found in this study, reduced IEMG may not only be a consequence of reduced force output during 108°A and 60°A but also a reduced force/EMG relationship. Thus, 60°A and 108°A actions could result in trade-off synergism, which is an attempt to delay fatigue by adapting muscle activities so that the load can be sustained (13).

Third, it has been suggested that during leg press activity, the rectus femoris muscle may act as an antagonist by flexing about the hip joint, therefore reducing its activity in comparison to the knee extensors (16). A similar situation could occur with 60°A and 108°A in comparison with MVC. The EMG activity was assessed in the rectus femoris, which could result in reduced IEMG activity. However, it has been suggested that there is antagonistic activity of the bicep femoris, which will progressively increase to stabilize the knee and reduce the force output during leg extension (4). This being the case, a reduced IEMG activity would also be observed during MVC. Interestingly, Alkner et al. (1)
showed no variance in IEMG results between both leg extension and leg press and concluded that isometric actions performed at a high degree of flexion about the knee joint is very similar in the multi-joint leg press and single joint leg extension. This does then suggest that the isometric leg press may be a more relevant activity to use for normalizing against cycling activity, as the action is more similar to cycling than MVC. However, in comparison with the leg press, 60°A and 108°A actions are likely to involve a far greater number of synergist muscles and because the subject is sitting on a cycle saddle will allow the body weight to transfer over to assist the contracting leg, which would also account for the larger variations for these contractions between subjects. This will also mean that to use an isometric leg press as a means of normalization would not be specific to the action of cycling. Although the contraction is more similar than MVC, the back is supported, and subjects are unable to assist the contraction by shifting their body weight. However, further studies are needed to determine the effectiveness of the isometric leg press as a normalization tool.

There was a higher IEMG for MVC than 1REV and a higher, though not significant greater, work/EMG relationship for MVC. The increase in IEMG is probably caused by a smaller force output for 1REV. However, it is surprising that 1REV did not produce more IEMG, when the action had increasing angular velocity. IEMG increases with increasing angular velocity during concentric contractions (2,7,15). Hunter et al. (unpublished data) recorded higher peak IEMG throughout a 30-s Wingate cycle protocol than for a 5-s MVC, which was due to a very high angular velocity from pedalling speeds in excess of 120 rpm. Nevertheless, because there was insignificantly more work/EMG during MVC, it can be assumed that the angular velocity achieved during 1REV was insignificant. Furthermore, as with 60°A and 108°A, 1REV involves more synergist muscles, which will inevitably produce a lower work/EMG relationship than MVC. It could therefore be suggested that the first 5 s of a Wingate test be used as a normalization tool for dynamic cycling; however, although the 30-s Wingate has been shown to be highly reproducible (3), the validity of a 5-s Wingate has yet to be determined. Although the Wingate requires a similar action to that of submaximal cycling to exhaustion, the large differences in both intensity and cadence will inevitably involve different contributions of synergist muscles. These differences will mean that the relevance of a 5-s Wingate as a normalization tool for submaximal cycling to exhaustion is indeed questionable.

Finally, there was a tendency for IEMG during 108°A to be higher than IEMG for 60°A. Assuming that this was different, then it can be explained from a more efficient knee angle, which allows for a greater generation of force production when the knee is fixed at 108°. However, as described earlier, because there are so many synergist muscle groups and the ability to transfer the body weight, any efficiency gained from a different knee angle will be far outweighed by other factors and result in minimal IEMG differences.

In summary, IEMG was significantly greater in MVC than 60°A and 108°A due to either greater force output in MVC or more synergist muscle involvement in 60° and 108° causing a decrease in force/EMG relationship and flexing of the hip joint throughout 60° and 108° by the rectus femoris acting as an antagonist resulting in a reduced IEMG. Second, MVC produced more IEMG than 1REV; however, there was no significant difference in the work/EMG relationship, which could have been caused by 1REV producing less force, greater inclusion of synergist muscles, and minimal angular velocity. Finally, there was a tendency for IEMG for 108°A to be higher than IEMG for 60°A, possibly due to more efficiency gained from a different knee angle; however, other factors such as shifting of body weight and inclusion of synergist muscle groups in 60°A to compensate for a comparatively inefficient knee angle will affect the IEMG.

In conclusion, this study has shown that MVC will record a higher IEMG than 60°A, 108°A, and 1REV and that there is no significant difference in the force/EMG relationship between MVC and 1 REV. It would appear that MVC has fewer variables to affect both IEMG and force output. However, further investigations is required for, first, the isometric leg press and 5-s Wingate as possible normalization protocols and, second, the force output/EMG relationship and repeatability for 60°A and 108°A. This work supports previous findings that MVC produces highest levels of EMG and therefore will be more effective in describing maximal muscle recruitment activity and suggests that MVC can be used as a normalization procedure for dynamic cycling activity.

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