REPEATABILITY OF INTRAMUSCULAR ELECTROMYOGRAPHIC RECORDINGS DURING CYCLING

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Fine-wire electromyographic (fEMG) techniques are indicated for the study of distal lower limb muscle recruitment during cycling, but evidence to support the repeatability of fEMG recordings is contradictory. This study investigated the repeatability of fEMG recordings from tibialis anterior (TA), tibialis posterior (TP), peroneus longus (PL), gastrocnemius lateralis (GL) and soleus (SOL) during cycling. The repeatability of fEMG recordings normalised to maximum measured EMG amplitude was high, with mean coefficients of multiple correlation (CMC) ranging from .82 .15 (GL) to .89 .09 (TA). The repeatability of fEMG recordings increased with greater test-retest intervals ($p < .008$). Data normalised to maximal or submaximal contractions were less repeatable ($p < .001$). These findings support the use of fEMG techniques to investigate distal lower limb muscle recruitment during cycling.

KEY WORDS: intramuscular electromyography, repeatability, cycling.

INTRODUCTION: Knowledge of distal lower limb muscle recruitment during cycling is limited, and the findings of previous studies are highly inconsistent. These studies have utilised surface electromyography (sEMG), which provides a non-invasive technique for the measurement of muscle activation. However, sEMG recordings from smaller and less superficial muscles may be inaccurate due to cross-talk from adjacent muscles. Furthermore, recordings from surface sensors during dynamic tasks involving large ranges of motion, such as cycling, may include artifactual changes due to movement of the muscle relative to the recording electrode (Rainoldi et al., 2000). These factors may contribute to the inconsistency of existing data.
As an alternative, techniques for intramuscular fine-wire EMG (fEMG) recordings have been described in the literature. Insertion of fine-wire electrodes is essentially pain free and their continuing presence is rarely noted by participants. It is argued that signal contamination from adjacent muscles is significantly reduced with intramuscular recordings (Solomonow et al., 1994), and the problem of electrode movement relative to the muscle is avoided because fine-wire electrodes are flexible and can move with the muscle.
While intramuscular electrodes provide selective measures of muscle activity, evidence to support the repeatability of fEMG recordings is contradictory. Numerous studies suggest that repeatability is low (e.g. Kabada, Wootten, Gainey, & Cochran, 1985), and relate this finding to intramuscular haematoma, displacement or deformation of the electrode wires, variation in electrode placement, and amplitude normalization methods. More recent studies report greater repeatability (e.g. Bogey, Carny, & Mohammed, 2003), which may relate to advances in fEMG techniques and other methodological factors such as longer test-retest intervals.
The aims of the present study were 1. to evaluate the repeatability of fEMG recordings from five muscles of the distal lower limb during cycling, 2. to determine if repeatability is influenced by normalization methods, and 3. to determine if repeatability increases with the duration of the test-retest interval. Accurate and repeatable measures of muscle activation from the distal lower limb will enable more detailed study of these muscles in cyclists.

METHODS:
Participants: Participants were seven road cyclists (six male, one female) with at least two years of cycling experience, aged 31.3 ± 5.7 years.
Electromyography: Electromyographic (EMG) recordings were made with intramuscular electrodes from five distal lower limb muscles: tibialis anterior (TA), tibialis posterior (TP), peroneus longus (PL), gastrocnemius lateralis (GL) and soleus (SOL). Bipolar fine-wire electrodes were fabricated from 75 µm Teflon®-coated stainless steel wire. Two millimeters of insulation was stripped from the end of each wire. After insertion into a hypodermic needle

(0.65 x 32 mm) the exposed tips were bent back at 1.5 mm and 4 mm.

Intramuscular electrodes were inserted under guidance of real-time ultrasound (5 MHz curved array transducer). On each occasion, electrodes were positioned relative to adjacent anatomical landmarks as previously described (Chapman, Vicenzino, Blanch, Hodges, & Knox, 2004). Insertion sites were not explicitly marked for the purpose of relocation, and if the preceding site of insertion was visible, the electrode was inserted ~3 mm from this site. EMG data were amplified (x 2000), band-pass filtered between 10-1000 Hz, sampled at 2 kHz, and digitized with a 16 bit A-D converter. Recordings were unilateral, determined by random selection.

Standardized maximal (MVC) and submaximal voluntary isometric contractions (sMVC) were recorded for EMG normalization. For sMVC contractions, participants held the mass of the body segment against gravity. During all MVC and sMVC trials, participants were instructed to gradually increase muscle tension over 3 s, maintain tension for 5 s, and release tension over 3 s. Three contractions were recorded for both sMVC and MVC, and the mean maximum values used for normalisation.

Crank Orientation: The angular orientation of the cranks was measured with four light reflective sensors. Sensor pairs were positioned either side of the bike's cranks such that a marker aligned with each crank's central axis triggered the sensors at top centre (TC) and bottom centre (BC).

Procedure: Participants attended two testing sessions 5-20 days apart (mean 12.3 6.3). Each session consisted of 17 min of cycling. EMG data were captured for 1 min at a randomised time during the final 12 min. Cycling trials were conducted on each participant's bike secured on a magnetic trainer. Cadence and exercise intensity were controlled (Chapman et al., 2004).

Data Management and Analysis: EMG data were adjusted for DC offset and high-pass filtered at 50 Hz to remove low frequency movement artefact. Individual pedal strokes were identified using data from the reflective sensors. The 10 pedal strokes of cadence closest to 77.5 rpm were selected for analysis, i.e. pedal strokes were non-contiguous selections from the 1 min of data capture. Data for each pedal stroke were full-wave rectified and time normalized to 100 points. EMG amplitude was normalized to MVC, sMVC and the maximum EMG amplitude from the 10 selected pedal strokes (MAX).

Coefficients of multiple correlation (CMC) (Growney, Meglan, Johnson, Cahalan, & An, 1997) were used to evaluate the repeatability of EMG waveforms. Root mean square error (RMSE) was also calculated as it provides an indication of absolute error between trials. CMC was compared for 10% windows to determine variation in repeatability between stages of the pedal stroke. Repeatability was compared between muscles using a one-way analysis of variance (ANOVA). The relationship between repeatability of fEMG data and the duration of the test-retest interval, and between fEMG repeatability and normalisation method were assessed using multiple regression analyses.

RESULTS: EMG recordings from the distal lower limb during cycling are presented in Fig. 1. Recordings from TA, PL, GL and SOL were successful in 71%, 77%, 100%, and 93% of cases, respectively. TP insertions were successful in 58% of cases, but insertion was not attempted for one participant due to the proximity of neurovascular structures.

CMC and RMSE values describing the repeatability of EMG data are presented in table 1. Normalization to maximum EMG amplitude (MAX) provided more repeatable data than normalization to maximal (MVC) or submaximal (sMVC) reference values ($p < .001$). CMC of data normalized to maximum EMG amplitude averaged .85 .10, and exceeded 0.80 in 76% of cases. Average absolute error (RMSE) was 8.1 5.6% but was = 10% in 71% of cases. Repeatability did not vary between muscles ($p = .523$) but did increase with longer test-retest intervals ($p < .008$). Repeatability was consistent throughout the pedal stroke for TA, TP, PL and SOL, but was less between 60 and 80% of the pedal stroke for GL.

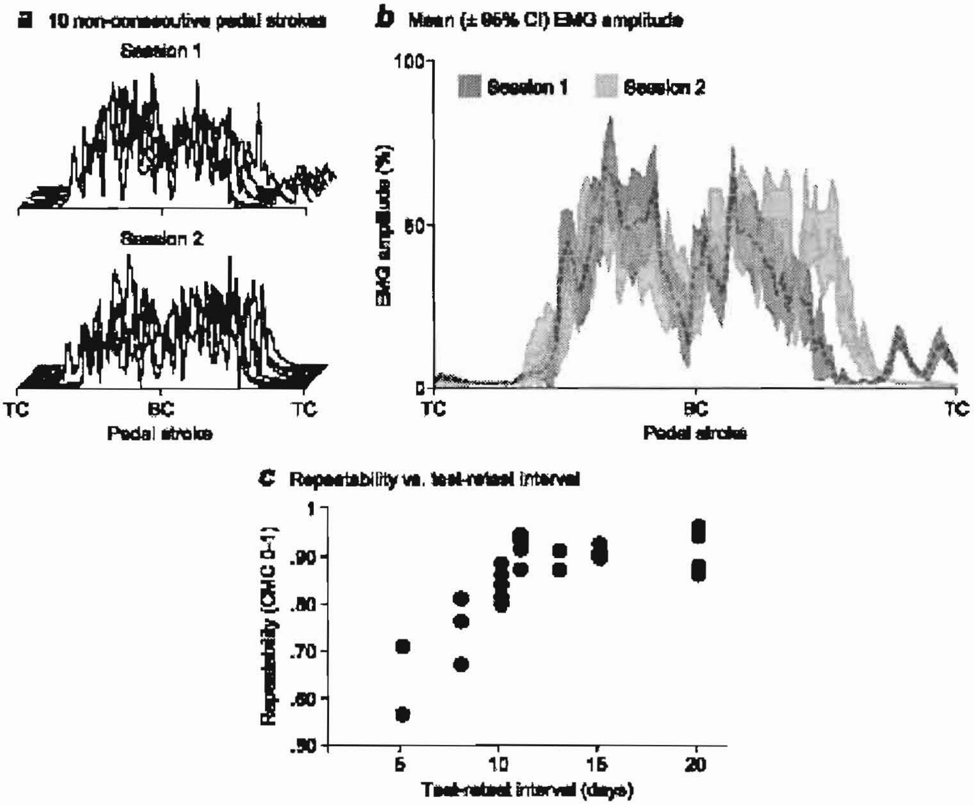

Figure 1: Repeatability of fEMG recordings. (a) Rectified GL EMG for 10 non-consecutive pedal strokes from a representative cyclist are plotted as an example (CMC = .82, RMSE 13.0%). (b) Mean 95% confidence interval EMG amplitudes for GL from the same cyclist. Note that these data were less repeatable than average and illustrate that variation between measures was greater during the upstroke for GL, which suggests some functional variation in the motor units sampled for this muscle. (c) Repeatability (CMC) data are plotted against test-retest interval, showing that repeatability increased with increasing test-retest interval.

Table 1: Repeatability of fEMG measures. CMC (0-1) and RMSE (%) are presented for data normalized to maximum EMG amplitude (MAX), and RMSE for data normalized to submaximal voluntary contraction (sMVC) and maximal voluntary contraction (MVC) reference values.

Muscle		Repeatability of fEMG data (mean ± SD)			
		CMC MAX	RMSE MAX	RMSE sMVC	RMSE MVC
TA	tibialis anterior	.89 ± .09	5.8 ± 4.1	211.3 ± 50.9	214.7 ± 237.1
TP	tibialis poster	.85 ± .04	5.0 ± 6.8	183.3 ± 163.3	94.9 ± 17.6
PL	peroneus longus	.88 ± .04	6.2 ± 1.6	433.8 ± 198.1	246.7 ± 90.9
GL	gastrocnemius lateralis	.82 ± .15	10.3 ± 7.5	161.2 ± 189.2	120.7 ± 108.4
SOL	soleus	.85 ± .08	8.9 ± 5.2	200.0 ± 231.7	166.0 ± 121.9

DISCUSSION: Knowledge of distal lower limb muscle recruitment during cycling is limited. fEMG techniques may facilitate more detailed study of distal lower limb muscles, but their repeatability has been questioned. These data argue that repeatable EMG can be recorded with intramuscular fine-wire electrodes from muscles of the distal lower limb during cycling.

In some instances recordings may be unsuccessful due to movement or dislodgment of the electrode wires during extraction of the guide needle or when cycling. These recordings will

include artifactual changes that can be identified visually, and replacement of electrodes is possible. Electrode placement may be difficult for smaller and less superficial muscles such as TP, and the likelihood of successful recordings lower, but repeatability is unaffected.
Electrode placement for TP from the posteromedial aspect of the leg is made difficult by overlying muscles and the proximity of the tibia and neurovascular structures. Insertion into TP from he anterior aspect of the leg is possible, and may reduce the risk of damage to neurovascular structures, but anterior insertions are prone to displacement during dynamic tasks due to the opposing movement of TA in sagital plane ankle motion.
EMG data normalized to maximum EMG amplitude provided a more repeatable measure of muscle recruitment, which is consistent with the literature (Yang & Winter, 1984). Variation in recruitment patterns for normalization contractions could result from only small changes in manual handling or body position, and may influence repeatability of amplitude estimates.
Recent studies that report high repeatability are characterized by longer test-retest intervals (e.g. Bogey et al. 17.1 2.6 days) than preceding studies (e.g. Kadaba et al. 7 days), and repeatability of the current data increased with increasing test-retest interval duration. These findings suggest that intramuscular haematoma or disruption of muscle tissue, which are likely to be more significant when the test-retest interval is shorter, may influence the repeatability of fEMG data. Also, preceding studies performed reinsertion at the exact location of the initial insertion, further increasing the likelihood of insertion into any remaining haematoma or tissue disruption. This problem was avoided in the current study, and in recent studies (Bogey et al., 2003), because insertion sites were not explicitly marked.
Greater error during the upstroke in recordings from GL suggests that there can be functional variation in the motor units sampled from this muscle by fEMG recordings. One disadvantage of fEMG techniques is that they can sample from only a small number of motor units. Variation in the recorded EMG pattern due to deviation in electrode placement relative to muscle structure may be more likely for GL as the muscle is of fusiform structure.

CONCLUSIONS: fEMG methods avoid the problems of signal contamination and electrode movement, but evidence to support their repeatability is contradictory. These data argue that fEMG provides a repeatable technique for the assessment of distal lower limb muscle recruitment during cycling. If repeat recordings are required, the duration of the test-retest interval requires consideration, as does the method of amplitude normalization. fEMG techniques are indicated for further study of distal lower limb muscle recruitment during cycling.

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