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NORMALIZATION OF ERECTOR SPINAE EMG FOR ISOKINETIC CYCLING TRIALS

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INTRODUCTION

There has been considerable research into increasing cycling performance [3] and into assessing the benefits of cycling in rehabilitation [7,10]. Generally, research on cycling is focused on lower limb function which, considering that the locomotive force is generated by the legs, is a good place to start. But it is now understood that the core muscles are essential for generation of cycling power [1] and stability provided by the core allows the legs to efficiently transfer force to the pedals.

A common way to study muscle function is to observe muscle activation via recording the electromyogram (EMG). Both the amplitude and timing of activation can provide insight into how certain muscles act to complete specific tasks.

Interpretation of EMG amplitude requires special attention. Several confounding factors combine to vary the amplitude of the EMG signal between trials, subjects and muscles [4]. Most researchers use normalization to reduce the impact of these factors. However, the normalization process varies from study to study. Maximal voluntary isometric contractions (MVICs) are typically used for normalization of isometric EMG signals. Under dynamic conditions, limb position and joint angle vary and the recorded EMG signal is not stationary. MVICs are not ideal for normalizing this type of signal. [2]

There has been research into different methods to normalize EMG data recorded from lower limb muscles during cycling [2,5,9]. The purpose of this study is to determine a suitable normalization procedure for EMG data recorded from the core muscles, specifically the erector spinae, during performance of a cycling task.

METHODOLOGY

Participants

Participants were active, healthy cyclists who cycle a minimum continuous distance of 20 km at least twice per week. Due to equipment constraints, all participants were required to be 172cm or taller in height. They were recruited from the local Kingston, Ontario area. No other restrictions to participation were enforced. Before participating, each individual read a letter of information detailing the purpose, methods and risks of the study, and signed a consent form.

Equipment

A twelve-speed bicycle was mounted onto a Kurt Kinetic fluid-filled bicycle trainer. The Road Machine trainer emulates the resistance experienced by a 165 lb. (78.4 kg) cyclist, riding a 23 lb. (10.4 kg) bicycle with 170 mm crank arms, up a 1% grade. Kurt Kinetic provides a curve that approximates, with an accuracy of ±3%, the resistance provided by the trainer as a function of the bicycle speed where P is in watts and s is the speed of the bicycle in mph. [11]

$$P = 5.244820s + 0.019168s^3 \quad (1)$$

To detect full revolutions of the left pedal crank and the rear wheel, Hall sensors were mounted on the bottom bracket and the rear stays as proximity sensors. Magnets were mounted on the left crank arm and one spoke of the rear wheel.

Procedure

EMG electrodes were placed in accordance with SENIAM guidelines at eight sites on each participant: the right and left vastus lateralis (RVL, LVL), biceps femoris, gluteus medius and erector spinae (RES, LES). A ground electrode was attached over the anterior superior iliac

spine. Before the electrodes were attached, recording sites were shaved and cleaned with alcohol.

Once the electrodes were attached, the participant mounted the bicycle. An initial sprint trial was performed to acquire normalization data. This was followed by sixteen one-minute trials in which resistance (180 watts or 280 watts), cadence (65, 75, 85, or 95 rpm) and handlebar hand position (hoods or drops) were varied. A final sprint trial was performed to again collect normalization data and assess any changes to maximal activation level.

The participant started the sprint trials from a stationary position in the highest possible gear and was verbally encouraged to generate as much power as possible. A display of the power output, in Watts, was provided. The sprint trial was concluded when the participant could no longer increase his/her power output for at least 5 seconds. No sprint trial lasted more than 30 seconds.

The participant also began the 16 one-minute trials from a stationary position, and ramped up to speed as quickly as possible. Once the desired cadence was achieved, the participant was instructed to maintain a constant cadence, which provided a more stable resistance.

Data Collection

The EMG and Hall sensor data were collected at 1024 samples/second using a Texas Instruments analog-to-digital conversion (ADC) board. Wheel speed and cadence were calculated based on the number of samples between the rising edges of the Hall sensor records. The EMG data were zero-meaned and rectified. An example of a rectified emg signal averaged over several pedal cycles can be seen in Figure 1.

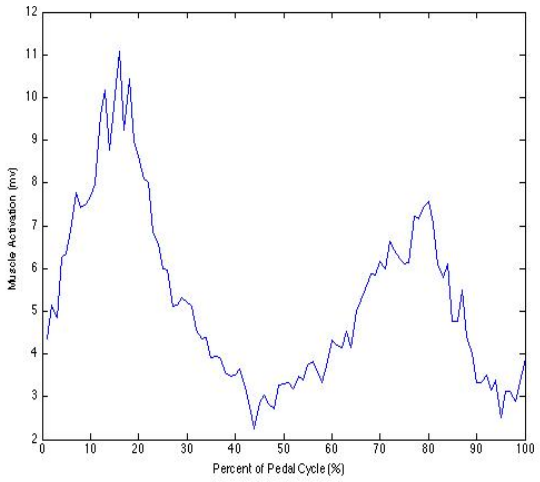
DATA ANALYSIS & RESULTS

Six methods to determine a normalization factor from each sprint trial were considered:

1. Overall peak value
2. Peak value after initial acceleration phase
3. Peak value of averaged time-normalized pedal cycles
4. Average peak value of pedal cycles
5. Peak value of mean of time-normalized pedal cycles
6. Mean of all time-normalized pedal cycles.

To compare the effectiveness of these methods, the intra-subject coefficient of variation (CV) and intra-class correlation coefficient (ICC) were computed for both sprint trials. Values are given in Table 1 and Table 2.

Figure 1: Example of LES activation averaged over several pedal cycles; left crank is at TDC at 0%



The level of muscle activation was estimated in three ways, from the rectified EMG data:

1. Peak of averaged time-normalized pedal cycles
2. Average peak of pedal cycles
3. Mean of all time-normalized pedal cycles

The muscle activation estimates, obtained using the three procedures, were assessed to determine the relative signal levels for the low power (180 W) versus high power (280 W) trials, where the activation levels should be well separated for the two power levels. Average low power to high power ratios for the ES and VL ranged from 0.60 to 0.81 depending on resistance and cadence. In general, the ratio increased for increasing cadence.

The intra-subject CV was calculated a second time, for the normalized muscle activations obtained using the different normalization methods, in order to assess the error and consistency of the various methods. The results are presented in Tables 3 and 4.

The normalized signal level estimates for the right side and left side muscles (RVL, LVL, RES, LES) under each cadence-resistance condition were also assessed. The mean differences between the right and left side muscle activations are given in Tables 5 and 6.

Table 1: Within Subject CVs of Normalization Factor as a percentage

Muscle Group	Normalization Factor Method					
	1	**2**	**3**	**4**	**5**	**6**
LES	**19.7**	23.6	36.0	47.4	29.1	41.6
RES	**19.1**	22.0	38.4	41.6	43.7	47.0
LVL	19.1	**17.2**	13.7	61.0	57.0	09.8
RVL	16.0	**15.8**	12.8	46.4	53.1	11.8

Table 2: ICCs of Normalization Factors

Muscle Group	Normalization Factor Method					
	1	***2***	***3***	***4***	***5***	***6***
LES	0.84	0.78	0.48	0.74	0.91	0.53
RES	0.87	0.84	0.60	0.79	0.79	0.29
LVL	0.89	0.92	0.95	0.61	0.75	0.97
RVL	0.91	0.91	0.94	0.73	0.75	0.95

DISCUSSION

Intra-subject coefficient of variation (CV) and intra-class correlation (ICC) are used to determine the repeatability and reliability of a normalization method [5,8,9]. A lower CV generally indicates less error and greater consistency between repeated measures whereas a higher ICC indicates a greater reliability and therefore repeatability [8]. The CV was calculated as described by Glüer et al. [6], and the ICC was calculated as described by Knutson et al. [8]. The CV values indicate that method 1 gives the most consistent normalization factors for the ES muscles, and method 2 gives the most consistent factors for the VL muscles. The calculated ICCs for these methods are generally close to 1 indicating good repeatability.

The activation ratios calculated for all of the muscles at the two different powers indicated that all 3 methods used to estimate activation level maintained a difference in signal level in relation with cycling power. By this criterion, all methods produce a viable activation level estimate.

Table 3: Within Subject CV of Normalized LES Activation across Subjects and Trials

Activation Level Method	Normalization Factor Method					
	1	***2***	***3***	***4***	***5***	***6***
1	70	75	84	120	139	70
2	22	23	26	38	44	22
3	13	14	16	22	26	13

Table 4: Within Subject CV of Normalized LVL Activation across Subjects and Trials

Activation Level Method	Normalization Factor Method					
	1	***2***	***3***	***4***	***5***	***6***
1	67	69	91	126	125	92
2	26	27	37	57	55	38
3	10	10	13	18	18	17

After normalizing the signals from each muscle, it is reasonable to assume that the activation for symmetric muscles in the same group, i.e., RVL and LVL; RES and LES, have the same activation level under constant conditions. Any asymmetry in the muscle activation should be nullified by normalization of the signals, since separate normalization factors were obtained for the right and left side muscles. Thus, it is hypothesized that a small difference in the mean normalized right and left side activation estimates is indicative of a good method for determining the normalization factor.

After normalization, smaller differences in activation levels between the symmetric muscles were observed for the first and second normalization methods. This provides further evidence that these are the preferred methods for obtaining normalized signal activation levels.

The intra-subject CV calculated for the normalized muscle activations obtained using the different normalization methods (Table 3 and 4), indicate the best consistency for the first and second methods for determining the normalization factor combined with the third method for determining the muscle activation

Table 5: Mean Difference and Standard Deviation between Left and Right Vastus Lateralis Across Trials and Subjects

Activation Level Method	Normalization Factor Method											
	1		*2*		*3*		*4*		*5*		*6*	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1	0.022	0.087	0.022	0.089	0.104	0.350	3.524	6.138	1.168	2.065	0.317	1.247
2	0.075	0.157	0.077	0.161	0.358	0.634	11.331	11.568	3.733	3.822	1.128	2.262
3	0.007	0.014	0.007	0.015	0.032	0.059	1.004	0.933	0.331	0.316	0.095	0.206

Table 6: Mean Difference and Standard Deviation between Left and Right Erector Spinae Across Trials and Subjects

Activation Level Method	Normalization Factor Method											
	1		*2*		*3*		*4*		*5*		*6*	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1	0.019	0.074	0.020	0.076	0.072	0.346	0.730	2.411	0.287	0.991	0.211	1.024
2	0.042	0.142	0.045	0.146	0.192	0.695	1.689	4.153	0.667	1.680	0.489	1.995
3	0.008	0.017	0.008	0.017	0.025	0.080	0.225	0.313	0.084	0.109	0.066	0.221

level. Thus, these combinations for obtaining normalization coefficients and estimated muscle activations are appropriate for use with data recorded during cycling.

It is interesting to note that activation ratios obtained for the ES follow very closely those of the VL. This was not necessarily expected considering that the VL are the main force producing muscles involved in propelling the bicycle. The core muscles are stabilizers that may or may not exhibit an increase in EMG activity during power production. In this case, however, it is clear that activation of the stabilizers increases with respect to the power generated during cycling.

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