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ORIGINAL RESEARCH

Surface electromyography changes of male athletes during 2000 m rowing ergometer test

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Abstract

This study aimed to investigate the changes in surface electromyography (EMG) in four anatomical segments of three muscles during a 2000 m rowing ergometer test. 19 healthy male rowers were requested to perform the test. Surface electrodes were attached to their vast medialis (VAM), erector spinae (ERS) and latissimus dorsi (LD) muscles. Raw EMG signals were presented at five different distance points: start (D0), 500 m (D1), 1000 m (D2), 1500 m (D3) and 2000 m (D4). The mean velocity and power were greater during 0–500 m and 1500–2000 m phases compared to 500–1000 m and 1000–1500 m phases ($p < 0.01$). Integrated Electromyography (iEMG) of VAM was significantly higher at the start and 2000 m compared to consecutive points ($p < 0.05$). The peak root mean square (pRMS) of ERS muscles was significantly higher at the start and 2000 m ($p < 0.05$). The frequency domain indexes mean frequency (MNF) and median frequency (MDF) of all muscles were significantly reduced at 1500 m compared to 1000 m ($p < 0.05$). However, no significant changes were observed in time domain indexes of LD muscles at any distance points ($p > 0.05$). A "fast start-speed maintains-final sprint" pacing pattern was observed during the 2000 m all-out rowing ergometer test. The EMG activation rates of VAM and ERS muscles were greater at the start and final phases, contributing to the increase in power. The decline in MNF and MDF of all three muscles at 1500 m could be related to greater muscle fatigue at this point. When using EMG to analyze endurance exercise, the results were dependent on the length of the test. Although not all EMG indexes were sensitive enough to detect these changes, combing them with different indicators for a comprehensive analysis might be considered.

Keywords

2000 m all-out; EMG; Rowing; Ergometer test; Rowing; Athletes

1. Introduction

Rowing ergometer is a commonly used tool for land training and simulating on-water to evaluate the performance of rowers [1]. It was reported that the results of the rowing ergometer test were highly correlated with performance in a 2000 m competition [2]. To analyze pacing strategies and metabolic responses, the 2000 m trial is often divided into four 500 m stages [3, 4]. Previous literature on 2000 m rowing ergometer tests mainly focused on power output, maximal oxygen uptake, heart rate, blood lactate, and body morphology [5–7], while the performance of local muscles during the test has not be thoroughly examined.

Electromyography (EMG) technology has frequently been used to obtain vast information about electrical muscle activities [8]. It is a useful tool to study muscle contraction properties, muscle fatigue, muscle fiber types and muscle-force sequences during cyclic locomotive exercises such as running, cycling and rowing [9]. EMG has the advantages of non-invasiveness and real-time monitoring, which is suitable for simulating actual competition scenarios and analyzing specific muscles [10].

Additionally, EMG technology is useful for analyzing rowing techniques, reducing the risk of injury and designing training programs [11, 12]. Daireaux *et al.* [13] used EMG to investigate rowing performance and discovered that experienced athletes produced greater integrated EMG (iEMG) than novice athletes, while the novice demonstrated higher variability in EMG activity during the recovery phase. Nowicky [14] employed EMG to investigate the differences in the lower limb and trunk muscle strength across various types of rowing ergometers and demonstrated that EMG is an effective tool to further reveal underlying issues.

Although EMG has been commonly used to study muscle activity during rowing, there is no study on the EMG changes at different distance points in a simulated racing state. It was previously shown that the performance of well-trained rowers during a 2000 m rowing ergometer test was reliable [3, 15]. Gee *et al.* [16] assessed the reliability of EMG measurements in seven muscles during three repeated 2000 m rowing ergometer sessions and found that although the EMG values could be generally considered "acceptable", EMG did not appear to be sensitive enough to detect potential changes between sessions. The results calculated by mean rectified EMG from each 500 m segment could eliminate the changes during the 2000 m trial process. Thus, we hypothesized that EMG could change in EMG may still occur between different distance points and that different EMG indexes could be more sensitive to these changes.

In regard to limitations in existing literature, we designed this present study to investigate seven EMG index changes of three muscles divided into four segments during a 2000 m all-out rowing ergometer test. We hypothesized that the EMG indexes would change according to different phases of the 2000 m test and different muscles, while not all EMG indexes would be sensitive to these changes.

2. Materials and methods

2.1 Participants

Nineteen male-trained rowers (age, 22.53 ± 1.68 years; height, 192.07 ± 5.3 cm; body mass, 88.15 ± 8.52 kg; rowing experience, 6.7 ± 4.5 years) from the Liaoning province rowing team of China volunteered to participate in this present study. All participants had at least four years of experience competing in national rowing competitions and extensive experience with the 2000 m rowing ergometer test. None of the participants had injuries or discomfort during the experiments.

2.2 Design and procedures

Each rower completed a 2000 m rowing ergometer test in the morning 2 hours after a meal. Prior to the test, the participants were instructed to refrain from strength training and intensive exercise for at least 48 hours.

The 2000 m rowing ergometer test was conducted using the ConceptII (Concept, Morrisville, VT, USA) ergometer. The mean velocity and power of each 500 m were recorded from the ergometer's built-in LCD (Liquid Crystal Display). Surface EMG was continuously recorded (Delsys Inc., Boston, USA) with an inter-electrode distance of 10 mm sampled frequency of 4000 Hz. The raw EMG signals were band-pass filtered between 5~500 Hz and transmitted to a computer-based data acquisition and analysis system (EMGworks, Delsys Inc., Boston, USA). The EMG data were divided into five subsets at different distance points: 0 m (D0), 500 m (D1), 1000 m (D2), 1500 m (D3) and 2000 m (D4). A set of 3 consecutive stroke cycles was extracted and averaged to obtain a representative pattern for each 500 m of 2000 m rowing test. The EMG data were analyzed in both time and frequency domains, with Root Mean Square (RMS), Peak Root Mean Square (pRMS), Integrated Electromyography (iEMG), and Maximal Voluntary Contraction Amplitude (MVC) as the time domain analysis indicators, and Mean Frequency (MNF) and Median Frequency (MDF) as frequency domain indicators. EMG indicators of the three muscles were analyzed only during the active phases of each stroke. The active phases were defined as the time interval containing the local maximum of the power envelope, in which the signal power was >1% of the peak power of the stroke [17].

The EMG electrodes were attached to three muscle sites from the right side of the body muscles vastus medialis (VAM), erector spinae (ERS) and latissimus dorsi (LD). These muscle sites have been previously shown to play an important role in rowing techniques [11, 16]. Before fixing the electrodes, the skin was shaved and cleaned with alcohol to minimize the impedance. An elastic band was fixed to the device to ensure that the electrodes did not move during the test. Electrode placement and preparation were performed in accordance with the SENIAM (surface EMG for a non-invasive assessment of muscles) recommendations [18].

Next, the participants were instructed to warm up for ten minutes at their preferred pace on a rowing ergometer, followed by a two minutes' rest, before performing maximum voluntary contraction (MVC) measurement. MVC was recorded in three muscles, and each participant was requested to perform three times five seconds of MVC isometric contraction with one minute of rest between each contraction [19]. The EMG equipment was turned on before the test to ensure it was working properly. After a 5-minute rest, the participants were instructed to perform the 2000 m race simulation with maximal effort and to continue until exhaustion.

2.3 Statistical analysis

Statistical analysis was conducted using the SPSS v23.0 (SPSS Inc., Chicago, IL, USA) software. All data are presented as group mean ± standard deviation. One-way ANOVA (Analysis of Variance) was used to investigate between-phases differences in 500 m mean ergometer output during the 2000 m all-out test. Subsequently, a one-way ANOVA was used to investigate the differences in each respective EMG index of 5 distance points during the 2000 m test for each of the 3 muscle sites. Moreover, a p-value < 0.05 was considered statistically significant.

3. Results

The results showed that the mean velocity and power were greater during the first and last phases (0–500 m and 1500–2000 m) than the middle two phases (500–1000 m and 1000–1500 m) ($p < 0.01$). The iEMG of the VAM muscles was significantly higher at the start and at the 2000 m compared to the other distance points ($p < 0.05$). The pRMS of the ERS muscles was significantly higher at the start and 2000 m compared to consecutive points ($p < 0.05$). The frequency domain indexes MNF and MDF of the three muscles were significantly reduced at 1500 m compared to 1000 m ($p < 0.05$). However, no significant changes were observed in EMG time domain indexes of LD muscles for any distance points ($p > 0.05$).

3.1 Ergometer performance

Table 1 showed that the speed and power were the highest in the first 500 m start phase, significantly higher than in the 500~1000 m phase ($p < 0.01$). In the 1000~1500 m phase, the speed and power did not drop significantly, indicating that

TABLE 1. Velocity and power change during the 2000 m all-out rowing ergometer test.

Ergometer results	0~500 m	500~1000 m	1000~1500 m	1500~2000 m
V (m/s)	5.18 ± 0.09**	5.11 ± 0.10	5.09 ± 0.15	5.15 ± 0.12**
Power (w)	389.37 ± 20.53**	374.63 ± 22.66	369.68 ± 31.32	382.89 ± 27.64**

***Significantly different from previous phase $p < 0.01$, the following are the same.*

they remained stable during the cruise phase. Additionally, the speed and power significantly increased in the 1500~2000 m sprint phase compared to the previous phase ($p < 0.01$).

3.2 EMG changes of VAM

Table 2 shows that at the start, the VAM muscles had the highest EMG activity, and iEMG ($p < 0.05$), MNF ($p < 0.01$) and MDF ($p < 0.01$) were significantly higher than 500 m. At 500 m and 1000 m the EMG of the VAM muscles tended to stabilize without significant changes. At 1500 m, the frequency domain index of EMG decreased significantly, MNF ($p < 0.05$) was significantly lower than 1000 m, and the time domain index remained stable. At the sprint phase of 2000 m, the EMG activity of VAM muscles was the lowest, and iEMG, MNF and MDF decreased significantly compared with the previous phase ($p < 0.01$).

3.3 EMG changes of ERS

Table 3 shows that the pRMS of ERS muscles at the start was significantly higher than that of 500 m ($p < 0.05$). At 500 m and 1000 m, the EMG of the ERS muscles did not change significantly. At 1500 m, the EMG time domain indexes of ERS muscles had no significant changes, but the frequency domain indexes MNF and MDF decreased significantly compared with the previous phase ($p < 0.05$). At 2000 m, the frequency-domain index of ERS muscles did not change significantly, while the time-domain index improved, of which pRMS was significantly higher than that at 1500 m ($p < 0.05$).

3.4 EMG changes of LD

Table 4 shows no significant change in the time domain indicators of LD muscles during the test. In terms of frequency domain indicators, there was no significant change from 0 m to 1000 m, and both MNF and MDF decreased significantly at 1500 m ($p < 0.01$), and the frequency domain indicators did not change significantly at 2000 m compared with the previous phase.

4. Discussion

In this study, we examined the performance of professional rowers in a 2000 m all-out ergometer test. The main finding of this study was that the mean velocity and power were greater during the 0–500 m and 1500–2000 m phases than the 500–1000 m and 1000–1500 m phases ($p < 0.01$). Analysis of the 2000 m ergometer test of different phases revealed that subjects completed the test using a fast start strategy, whereby the speed was stable during the cruise phase and increased during the sprint phase. The results were in line with a previous research on rowing strategy reporting that most athletes used a sprint start strategy during the first 500 m in a competition [20] and that the maximum speed in the start and sprint phases played a key role in the final result. According to a previous study, observing the position of opponents behind was beneficial in controlling the speed of the boat and avoiding waves from other boats [4].

The iEMG of VAM muscles was significantly higher at the start and 2000 m compared to consecutive points ($p < 0.05$) and the pRMS of ERS muscles was significantly higher at the start and 2000 m compared to consecutive points ($p < 0.05$), while there were no significant changes in EMG time domain indexes of LD muscles at any distance points ($p > 0.05$). The MNF and MDF of the three muscles' EMG frequency domain indexes were significantly reduced at the 1500 m phase compared to the 1000 m phase ($p < 0.05$). Our study is the first to analyze the changes in EMG activity using multiple indicators from different distance points during a 2000 m rowing ergometer test. Gee *et al.* [16] investigated the reliability of EMS assessed in seven muscles during three repeated 2000 m rowing ergometer tests and reported that the reliability of EMG values over repeated 2000 m was generally "acceptable" although EMG seemed not sensitive enough to detect potential changes concerning changes in pacing strategy. We hypothesized that the lack of sensitivity of EMG could be related to the results calculated by mean 500 m raw EMG signals. In this present study, we selected EMG data from three strokes at each distance point, whereby significant changes were observed. However, not all the indicators were consistent. In previous studies, the normalization of EMG signals has been highlighted [21–23], and there is no consensus on the optimal normalization process. It was previously described that when EMG is used in rowing training, it might be unreliable to use MVC as the EMG normalization results because most rowers' EMG peaks appear during rowing [14]. MNF and MDF are considered the "gold standard" for evaluating muscle fatigue [24, 25], especially during maximal-intensity exercise [26]. In this experiment, it was speculated that 1500 m might be a critical distance point for fatigue during 2000 m rowing. Our results showed that the frequency domain indicators of the three muscles changed significantly simultaneously, which was not only related to a decline in endurance but might also be related to central fatigue. Airaksinen *et al.* [27] found that changes in EMG activities were not related to peripheral fatigue and were mainly affected by changes in motor center activity. Lepers *et al.* [28] found that during prolonged exercise, the decrease in muscle output power was related to the decrease in nerve impulse firing. Based on these data, we suggest that focus should not only be placed on peripheral fatigue caused by energy metabolism but also on central fatigue due to decreased neuromuscular control during the monitoring of endurance training programs to improve the

TABLE 2. Changes in vastus medialis EMG during the 2000 m rowing ergometer test.

EMG indexes	D0	D1	D2	D3	D4
RMS	124.85 ± 68.56	111.35 ± 42.39	106.88 ± 43.04	110.02 ± 49.28	94.73 ± 53.94
pRMS	262.68 ± 160.23	238.21 ± 97.75	225.72 ± 94.90	224.87 ± 99.27	203.99 ± 130.42
iEMG	120.08 ± 63.51*	92.50 ± 34.28	89.23 ± 33.40	89.70 ± 32.92	78.04 ± 49.54**
MVC	40.34 ±12.84	37.94 ± 10.15	35.88 ± 8.97	36.82 ± 10.30	36.29 ± 14.82
MNF	120.95 ± 18.51**	108.75 ± 17.33	106.48 ± 17.09	103.51 ± 15.66*	77.85 ± 31.07**
MDF	105.84 ± 20.60**	93.67 ± 18.95	92.65 ± 18.67	89.39 ± 17.43	62.76 ± 31.60**

*EMG: electromyography; RMS: Root Mean Square; pRMS: peak root mean square; iEMG: Integrated Electromyography; MVC: maximum voluntary contraction; MNF: Mean Frequency; MDF: median frequency; D0: 0 m; D1: 500 m; D2: 1000 m; D3: 1500 m; D4: 2000 m. *Represents compared with the previous phase* $p < 0.05$*; **Significantly different from previous phase* $p < 0.01$*, the following are the same.*

TABLE 3. Changes in erector spinae EMG during the 2000 m rowing ergometer test.

EMG indexes	D0	D1	D2	D3	D4
RMS	56.67 ± 37.13	49.34 ± 26.81	43.12 ± 17.76	41.41 ± 21.58	65.25 ± 46.27
pRMS	128.29 ± 106.88*	93.53 ± 57.21	86.29 ± 44.83	78.12 ± 48.84	127.82 ± 91.18*
iEMG	49.97 ± 34.14	41.80 ± 31.86	34.95 ± 19.89	31.67 ± 20.12	50.19 ± 39.66
MVC	33.60 ± 16.84	31.56 ± 20.67	27.52 ± 12.32	29.14 ± 17.20	41.01 ± 32.90
MNF	67.67 ± 23.52	65.02 ± 22.22	60.03 ± 21.47	52.00 ± 22.92*	60.00 ± 24.21
MDF	49.52 ± 23.97	47.20 ± 21.94	42.59 ± 22.49	37.32 ± 20.03*	46.58 ± 25.71

*EMG: electromyography; RMS: Root Mean Square; pRMS: peak root mean square; iEMG: Integrated Electromyography; MVC: maximum voluntary contraction; MNF: Mean Frequency; MDF: median frequency; D0: 0 m; D1: 500 m; D2: 1000 m; D3: 1500 m; D4: 2000 m. *Represents compared with the previous phase* $p < 0.05$*.*

TABLE 4. Changes in latissimus dorsi EMG during the 2000 m rowing ergometer test.

EMG indexes	D0	D1	D2	D3	D4
RMS	118.76 ± 62.64	124.11 ± 69.94	97.91 ± 47.56	90.68 ± 45.45	119.39 ± 57.44
pRMS	254.95 ± 128.89	265.24 ± 238.64	195.29 ± 116.78	163.18 ± 77.04	220.95 ± 121.12
iEMG	105.62 ± 50.25	104.69 ± 76.65	84.95 ± 46.56	71.53 ± 32.19	94.25 ± 50.73
MVC	46.00 ± 23.61	49.30 ± 32.87	40.91 ± 22.58	41.67 ± 21.11	45.16 ± 14.28
MVCpeak	104.24 ± 65.11	103.98 ± 115.85	77.92 ± 41.89	72.96 ± 31.70	84.69 ± 41.39
MNF	92.31 ± 28.30	86.76 ± 31.38	83.61 ± 31.07	81.00 ± 30.17**	81.29 ± 23.45
MDF	79.61 ± 30.54	77.05 ± 32.55	73.76 ± 32.69	70.84 ± 31.71**	68.76 ± 22.11

*EMG: electromyography; RMS: Root Mean Square; pRMS: peak root mean square; iEMG: Integrated Electromyography; MVC: maximum voluntary contraction; MNF: Mean Frequency; MDF: median frequency; D0: 0 m; D1: 500 m; D2: 1000 m; D3: 1500 m; D4: 2000 m. **Significantly different from previous phase* $p < 0.01$*, the following are the same.*

sports performance of athletes from the perspective of central fatigue.

VAM muscles play a major role in the initial phase of knee extension [29]. Previously, Secher *et al.* [30] found knee and hip extension important for rowing power generation. Yoshiga *et al.* [31] and Shimoda *et al.* [32] reported that knee extension strength was related to ergometer rowing results and that VAM muscles are critical for rowing acceleration. According to the results presented in Table 2, iEMG, MNF and MDF of VAM muscles were significantly higher during the start phase than during the 500 m phase, it means VAM recruited more motor units to power the ergometer's accelerate from rest to motion. Guével [33] proved that VAM muscles played a major role in improving the power of the ergometer through changes in the MVC level of VAM muscles during rowing, which was concordant with our present study as similar conclusions were obtained through different EMG indicators.

According to the results presented in Table 3, the pRMS of ERS muscles was significantly higher in the start phase and sprint phase than in the cruise phase. pRMS represents the peak value of EMG amplitude, which can reflect the maximum electrical activity of the exercising muscles. During the start phase and the sprint phase, the ergometer speed increased, and the maximum electrical activity of ERS muscles increased significantly. During rowing, ERS muscles stabilize and support the spine in the early stage of leg press and to contract and exert force in the later stage of body swing. The spine is known to be the most injured part of rowers [34]. Koopmann *et al.* [35] found that low back pain might be related to spinal stability and recommended that the degree of spinal curvature should be controlled during training by improving muscle strength around the spine. Therefore, paying attention to the exercise state and fatigue levels of ERS muscles can reflect on the core strength level of athletes, prevent the occurrence of sports injuries, and identify the presence of wrongly implemented techniques by athletes.

The correct rowing technique is defined by a long drive phase and relaxed and controlled recovery. The drive phase is initiated with a push from the legs. The energy generated by leg presses during rowing is transferred through the arm to the handle, during which LD muscles play the role of connection and suspension [36]. Rodriguez *et al.* [37] found that sustained production of propulsion was associated with trunk extension and upper extremity activity during rowing. According to the results presented in Table 4, there was no significant change in the EMG time domain index of LD muscles throughout the whole rowing task. It can be surmised that LD muscles generated a consistent and stable force during the varying ergometer velocities, serving as a strong connection between them.

5. Conclusions

In conclusion, this study sheds light on the pacing pattern of the 2000 m all-out rowing ergometer test, which includes a “fast start-speed maintain-final sprint”. The higher EMG activation rates of VAM and ERS at the start and final phases indicate a higher contribution to the increase in power output. The decline in MNF and MDF of all three muscles at the 1500 m point reflects increased muscle fatigue. The study also highlights the importance of using multiple EMG indexes for comprehensive analysis, as the sensitivity varies with the length of the test. This study’s contribution lies in its analysis of multiple EMG indexes of the three main force-generating muscles of professional rowers during rowing-specific technology, providing insights into the dynamic changes of EMG indexes in different stages of the commonly used 2000 m rowing ergometer test.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

XHZ and JLL—designed the research study. JLL and FR—performed the research; wrote the manuscript. XHZ—provided help and advice on the rowing ergometer test design. JLL—analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was performed with the approval of the Institutional Review Board of Capital University of Physical Education and Sports (2020A63). All the study participants signed an informed consent form.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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